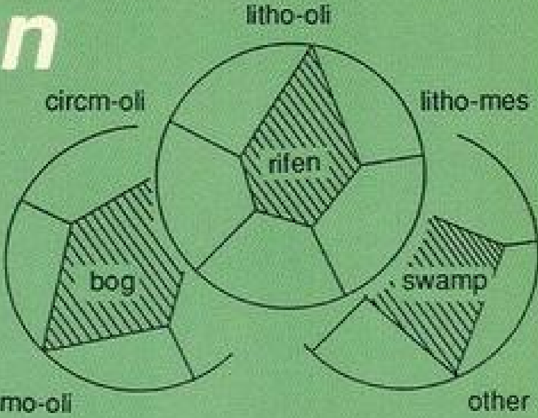
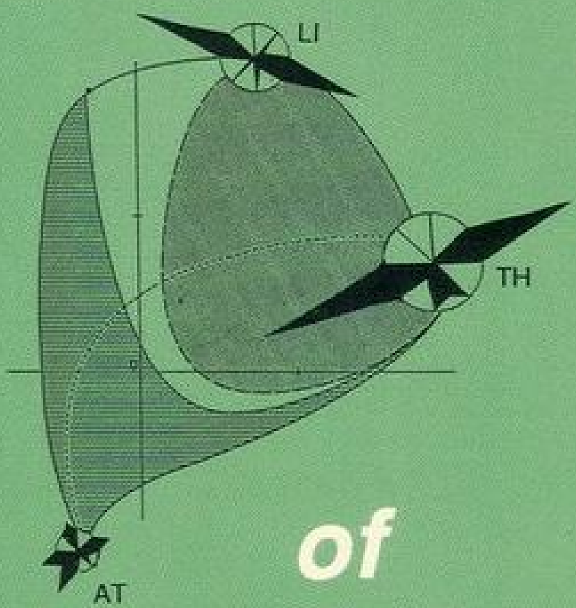
Vegetation and Hydrology of Floating Rich-Fens

Vegetation



and hydrology



# of floating rich-fens

Geert van Wirdum

Vegetation and hydrology of floating rich-fens

Postscript

This is (printed from) a searchable 'reprint' in portable document format. Figures, tables, and the start of paragraphs are found on pages with the same numbers as in the original book, but text flow at the bottom and top of some pages slightly changed due to reformatting. When citing, refer to the original book reference:

Van Wirdum, Geert, 1991. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6).

Comments and questions are welcomed by geert@jolicoeur.nl

The book was peer reviewed and accepted for publication by
Prof. Dr. P.J.M. van der Aart, University of Utrecht,
Prof. Dr. Ir. J.C. van Dam, Technical University of Delft,
Prof. Dr. P.J. Jungerius, University of Amsterdam,
Prof. Dr. P.J.C. Kuiper, University of Groningen and
Prof Dr. Ir. I.S. Zonneveld, International Institute for Aerospace Survey and Earth Observation (ITC), Enschede.
It was successfully defended as a PhD thesis February, 8th, 1991 with promotors
Prof. Dr. T. van der Hammen, University of Amsterdam and
Prof. Dr. W. H. van der Molen, University of Wageningen.

The following corrections and changes were made to avoid confusion:

Chapter 3:
p.37: footnote added;
p.43: last sentence corrected.

Chapter 5:
p.60: reference to Fig.4.4 added to explain shading;
p.75: legend of Fig.5.7 corrected.

Chapter 6:
p.99: note added.

Chapter 7:
p.116, 118: confusion between baulks and ditches in figures 7.3 and 7.4 removed.

Chapter 8:
p.135: formula corrected: $\boldsymbol{\varphi_z = \varphi_0 - bz}$;
p.144: footnote added;
p.146-147: instances of the word 'reliable' replaced by 'credible', the solution for $\boldsymbol{\kappa}$ being within the range concluded in the section on heat capacity and thermal diffusivity, p.136-138;
p.150-152: some instances of variable **I** replaced by $\mathbf{v_l}$ to reduce confusion between volume in the overall budget and the related lateral velocity in the preferential flow channel;
p.154: footnote added.

Chapter 9:
p.164: confusion between baulks and ditches in figure 9.6 removed;
p.168: footnote added;
p.174: symbol error in graph pointed out.

Chapter 11:
p.217: reference corrected;
p.220: order of column headers in table 11.3 corrected.

Appendix C:
P240: Campylopus fragilis (subsp. pyriformis) now named C. pyriformis.

Appendix D:
p.253: Figure D.1 redone with the computer programme MAION to correct misplacement of At-W80;
p.250-251: formulae explaining mol(a) and its relation to mol(c) corrected;
p.260: enumerator in formula near the bottom of the page corrected: $\{1 + (0.33\ \mathbf{a_i I}^{1/2})\}$;
p.264: last text block above section on Ionic Ratio corrected.

Vegetation and hydrology of floating rich-fens

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam,
op gezag van de Rector Magnificus
prof.dr. P.W.M. de Meijer
in het openbaar te verdedigen in de Aula der Universiteit
(Oude Lutherse Kerk, ingang Singel 411, hoek Spui),
op vrijdag 8 februari 1991, te 15.00 uur

door

Geert van Wirdum
geboren te Amsterdam

FACULTEIT DER BIOLOGIE

promotores
Prof. dr. T. van der Hammen
Prof. dr. W.H. van der Molen

CIP-DATA KONINKLIJKE BILIOTHEEK, DEN HAAG

Wirdum, Geert van

Vegetation and hydrology of floating rich-fens / Geert van
Wirdum. - Maastricht : Datawyse. - Ill.
Thesis university of Amsterdam. - With ref., - With
summary in Dutch
ISBN 90-5291-045-6
SISO 586.6 UDC 58:556.56(043.3) NUGI 825
Subject headings: eco-hydrology / fen vegetation / seepage.

Produktie: Datawyse Maastricht, Ruud Leliveld
Technisch tekenwerk: Arjan Griffioen, Ruut Wegman (RIN)
Druk: Datawyse Maastricht / Krips Repro Meppel

Het veldonderzoek in de periode 1973-'75 werd mogelijk gemaakt door een subsidie van de Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek, onderzoeksbijdragen van vele studenten, diverse diensten verleend door het Hugo de Vries-Laboratorium van de Universiteit van Amsterdam, en vergunningen voor veldonderzoek verleend door de Vereniging tot behoud van Natuurmonumenten en het Staatsbosbeheer.
Het Rijksinstituut voor Natuurbeheer stelde mij in de periode 1975-1990 in de gelegenheid een gedeelte van mijn tijd te besteden aan verdiepend onderzoek, uitwerking van gegevens en rapportage.

What is obviously essential to something, but not well understood,
is often denoted as its `structure'
(cf Rolf Lohberg & Theo Lutz (1968), `Keiner weiss, was Kybernetik ist')

Human interest in nature is probably because of its structure

Quagfens have a notable, but weak and unstable structure

Preface

Early in 1969 Dr.S.Segal introduced me to the study of quagfens in North-West Overijssel. Dr.J. van Donselaar and Dr.L. de Lange supported my deeper inquiry from 1973 to 1975. With a sum total of some 35 inventive students around, the main lines of quagfen eco-hydrology were drawn in those years. At my appointment at the Research Institute for Nature Management (RIN) in 1975 I was not prepared to practice the distance necessary to enjoy and report what I learned, rather than aching for more. After twenty years I obviously can no longer continue this without blame, and this period has fortunately been just long enough to get some important clues as to what sort of natural devices quagfens are. In this thesis I essentially report these clues on the basis of detailed observations in one of the investigated complexes. Other quagfens contributed no less to what I learned, but the interests of the family whose accomodation I joined withhold me from a treatment now.

I am much indebted to Professors Meeuse, who replaced Dr.Van Donselaar, and Van der Molen. It was impressive to experience their continued interest and patience at each delayed *rendez-vous* in the coffee-shop "De Plantage" in Amsterdam. Prof. Van der Hammen kindly accepted to replace Meeuse as promotor when this became necessary.

Contents

Detailed contents

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 1

General introduction

This thesis deals with the ecological relation between the vegetation of rich-fen quagmires (quagfens) in abandoned turbaries in North-West Overijssel (The Netherlands), and hydrological factors. The *seepage hypothesis for Dutch quagfens* was a starting point for a broader definition of the problem area to be explored (Chapter 2). That hypothesis aims at an ecological explanation of the rare occurrence of certain (extreme) rich-fen species that have drawn the attention of nature conservation in many North-West European countries. Most of these species are characteristic of the phytosociological Association *Scorpidio-Caricetum diandrae*. In the low-lying part of The Netherlands their occurrence is almost strictly limited to terrestrializing former turbaries to which a mowing regime is applied. Elsewhere they are notable but uncommon plants in some dune slacks and valley fens, often also under a mowing or light grazing regime.

This distributional pattern seems to apply to other countries at the same latitude also: Germany (Ellenberg 1978), England (Wheeler, pers. comm.), and Poland (Tomaszewska 1988). In the absence of a vegetation management (mowing) the stands in terrestrializing turbaries usually develop into a carr vegetation. Mowing alone, however, is not sufficient to evoke the development of the type of vegetation involved. In the terrestrializing turbaries in The Netherlands a striking difference exists between quagfens developing quickly into *Sphagnum* reeds and quagfens with stands of *Scorpidio-Caricetum diandrae* and related vegetation. These differences fit into the general scheme of mire types developed in North-West Europe (compare the treatment by Moore & Bellamy 1973), suggesting a rather broad relevance of the underlying ecological questions, even to the study of bog formation.

In many countries the re-generation of bog vegetation on cut-over bog surfaces is stimulated, but it has appeared that such a re-generation is often much less easy to achieve than the formation of initial bog vegetation on floating rafts, both in fenlands and in turf ponds excavated in a bog surface. It is indeed remarkable to observe the development of dense carpets of *Sphagnum papillosum* and, occasionally, even *S. imbricatum* and *S. fuscum*, upon rafts floating over bodies of even slightly brackish water. At least two sets of factors appear to be decisive for the development of various sorts of mire: the fluctuations of the water level (inclusive of the frequency of flooding), and the water composition, depending on water flow. Quagmires offer an opportunity to investigate the influence of water flow and water composition under almost `controlled' conditions as regards water level fluctuations, still representative for the development of a broad range of types of mire vegetation. The main line of this research leads from the milieu as it is indicated by plant species, via a hydrological description of the environment, into an attempt quantitatively to understand the relationships between the three.

In the first part of this thesis (Chapters 2,3) I analyse the *seepage hypothesis for Dutch quagfens*, resulting in a reformulation of this hypothesis and the derivation of an ecological reference system (the species-wise list of indications, Appendix C), and of certain questions that can be investigated. This is followed by an introduction into the study area and the prevailing hydrological environment (Chapters 4,5). The water management in the study area appears to provide boundary conditions for the development of terrestrializing quagfens, especially as regards the water supply. On the whole-area scale this is indicated by the changing patterns of distribution of various species (Chapter 6). The attention is drawn to the possible importance of processes that were not yet considered before, especially a gradual desalting of parts of the area formerly influenced by slightly brackish water.

In reporting my results I was in the comfortable position that I had to make a choice out of the case studies done and of various analyses of quantitative data. This choice was made in favour of a, hopefully clear, exposé of the rôle of *seepage* in one single quagfen complex, De Stobbenribben, rather than an in-depth treatment of quagfen vegetation in the larger mire area of North-West Overijssel. So much has been written and orally communicated about the *seepage* problem that only a careful treatment of a key case could clear away some of the confusion left. This key case is introduced in Chapter 7. This case is a *de facto* representative one, since De Stobbenribben is one of the very last areas with a well-developed vegetation of *seepage indicators* in The Netherlands. In the Vechtplassen area in the province of Utrecht no such extensive carpets of *Scorpidium scorpioides* have been left, and almost all examples of quagfen vegetation nowadays include species indicating a more eutrophic milieu.

The choice of methods and detail of the hydrological investigations were specifically tuned in to the relevant ecological problems. While such an eco-hydrological approach has, in The Netherlands, arrived at a mature stage in the application to agriculture (agro-hydrology), it is probably only in the years of growing pains as regards natural `ecosystems' and the application to nature protection. As a consequence, along with the results obtained in De Stobbenribben, quite some attention is paid to the development of suitable methods (Chapters 8,9, Appendix D).

In the course of the research, and upon comparison with results of other investigations carried out in the mean time, it occurred to me that the importance of *seepage*, in North-West Overijssel usually as a lateral inflow of slightly calcareous water, related to the quagfen vegetation through the base state of the peat. The hydrological part of this relation is quantitatively studied in Chapter 10 and the results seem to be in line with the apparent nutrient economy of the local stands of vegetation, but the base state itself, and its influence upon the availability of nutrients, had to stay a lacuna in the data collected. In sofar the results of this project indicate the importance of a more direct investigation of the base state, and of the rôle of exchange processes between the peat and the water, in future projects. Such investigations are also demanded to explain the occurrence of *seepage indicators* as a result of other mechanisms than *seepage* that can maintain a high base state in the uppermost horizons of the peat.

A detailed summary with a general discussion of the results obtained is provided in Chapter 11. In order not to exceed some acceptable length for the main text of this thesis, certain background data have been provided as appendices. Among these are an explanation of terms (Appendix A) and a detailed treatment of the method developed for the interpretation of chemical analyses of natural waters (The MAION method, Appendix D), which has found applications far beyond the scope of the present report, but was never published in full before. Although I have tried to include the data necessary to check my results throughout this thesis, no complete listing of all basic data is included. I am willing to provide such data on an `as is' basis upon specified requests. Appendix F more-over lists data reports, many of which resulted from student's projects that formed part of the present investigation. Several of these reports have not been explicitly referenced in this thesis.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 2

Published evidence of seepage in rich-fen quagmires (quagfens)

2.1 Introduction

The word *seepage*, as a translation of (Dutch) *kwel*, has often been used in ecological descriptions of rich-fen quagmires (quagfens) in The Netherlands. This was stimulated by the description of similar stands of vegetation in Central Europe by authors referring, in German, to *Quell* as an important site factor. *Quell*, *kwel*, and *seepage* can be used in a variety of technical and colloquial meanings. The meaning intended by Segal (1966), *i.e.*, the oozing out of groundwater as a result of artesian pressure, is taken as a starting point here in the presentation of the *seepage hypothesis for quagfens* that was widely accepted by Dutch ecologists associating the occurrence of the plant species and types of vegetation involved with a regional discharge of groundwater. It will be shown that this supposition is only weakly supported by the pertaining literature. Nonetheless there are several indications of seepage in a more general sense, *i.e.*, of the percolation of allochthonous water, in whatever direction, through the quagfen root zone. The supply of calcium seems to play a vital rôle here.

2.2 Definitions of seepage

According to Hooghart (1986) the Dutch word *kwel* is equivalent to the English *seepage* and *exfiltration*. Two definitions are listed: (1), the outflow of groundwater, and, (2), more specifically, the outflow of groundwater under the influence of a larger hydraulic head outside the seepage area, *i.e.*, a regional groundwater discharge. Hence, the intensity of seepage is defined as the volume of water seeping out per unit of time and per unit of horizontal surface area of the region considered.

In The Netherlands, a regional groundwater discharge is associated with streamlines often reaching depths of over one hundred metres, and travel times of hundreds or even thousands of years. Accordingly, the discharging groundwater is usually saturated with calcium and (bi)carbonate ions, at a carbon dioxide tension above the atmospheric one, and it is unpolluted, although it may have been enriched with chloride and other ions from deeper strata.

At variance with these definitions, Thomson & Ingram (in Ivanov 1981, p.252) note, (3):

> 'By the seepage or intensity of water exchange in a mire we understand the total quantity of water flowing per unit of time through a volume of peat 1 m^2 in area and equal in height to the depth of the peat deposit in that part of the mire massif.'

Such a quantification is well in line with current colloquial meanings of the intransitive verb *to seep*: *ooze out, percolate slowly* (The Concise Oxford Dictionary of current English, sixth edition, 1976). The Dutch *kwel* and German *Quell* are more specifically associated with the first of these meanings, *i.e.*, the oozing out or exudation of groundwater.

Next to *Quell*, *Sickerung* is often encountered in German texts relevant to the seepage hypothesis. This term is more or less equivalent to *seepage* and *percolation* in their colloquial meaning. In the hydrological literature *Sickerung* and *percolation* are mostly used to indicate the (downward) infiltration of water through the unsaturated zone and the capillary fringe, recharging the body of phreatic groundwater (Hooghart 1986, Brockhaus 1961). Throughout this text *percolation* is used in the colloquial meaning as a synonym of *seepage* in the general sense (see below).

I will not use the word 'seepage' when I explicitly mean a groundwater outflow or, more specifically, a regional groundwater discharge, as in the *kwel* definitions (1) and (2), respectively. Hence, 'seepage' is used for percolation in general, regardless of the possible causes and any preferential direction of water movement. The word is italicized in the designation of the *seepage hypothesis for quagfens* and in associated expressions. Although the primary authors reporting *seepage* in Dutch quagfens specifically envisaged a regional groundwater discharge, the non-specific term *seepage* is maintained here in view of the eco-hydrological conditions disclosed in this investigation.

2.3 The *seepage hypothesis for quagfens*

De Wit (1951), Meijer & De Wit (1955), Kuiper & Kuiper (1958), and Segal (1966) have drawn the attention to the occurrence in quagfens in The Netherlands of a vegetation cover supposed to be associated with an exudation of groundwater (*kwel*). This supposed relation was based on (1) visual indications of groundwater outflow in some of the quagfens involved and (2) on the similarity of the floristic composition of the vegetation to phytosociological associations previously described from *Quellsümpfe* in Central Europe. Accordingly, Westhoff & Den Held (1969) denote the *Scorpidio-Caricetum diandrae* as a stage of terrestrialization in fen mires influenced by outflowing groundwater. This also concerns the *Scorpidio-Utricularietum*, which is said to have its optimum in depressions in mesotrophic quagfens, often alternating with the *Scorpidio-Caricetum diandrae*. This statement implies that the presence of a *Scorpidio-Caricetum diandrae* and a *Scorpidio-Utricularietum* in quagfens indicate an outflow of groundwater: the *seepage hypothesis for quagfens*.

Segal (1965, p.12; 1966, p.135) and Gonggrijp *et al.* (1981, p.73-79) leave but little doubt that the *seepage hypothesis* as applied to quagfens in North-West Overijssel specifically refers to a regional discharge of groundwater. This specific form of the hypothesis was widely accepted, and, consequently, one has (vainly!) attempted to isolate quagmires which had been indicated as *seepage sites*, so as to exclude the influence of (possibly) polluted surface water while maintaining the presumed upward flow of groundwater through the subsoil into the mire.

2.4 The source of the hypothesis; main arguments and evidence

Phytosociology

With regard to the indicative significance of the vegetation cover, the *seepage hypothesis* as developed in ecological studies in quagfens in The Netherlands was almost certainly inspired by the notion of calcareous spring and seepage mires (*Kalk-Quellsümpfe*) in the Central European literature (*cf.* Ellenberg 1978, p.421, 427-433). It is noteworthy that the Dutch authors dealing with *seepage sites* based their phytosociological studies largely on the methods of the Zürich-Montpellier school, which enabled them to compare their results more readily with those accumulated in the central European countries. There were also extensive personal contacts and discussions with leading authorities of the above-mentioned school. In his article of 1951 De Wit, who then worked in Montpellier, explicitly mentions that Braun-Blanquet agreed with him as regards the feasibility of classing certain communities with *Carex diandra* in the *Caricion davallianae* alliance, thus stressing the floristic kinship of these communities with those characterized by *Schoenus nigricans* described from calcareous, wet dune slacks in The Netherlands. The *Scorpidio-Caricetum diandrae* was first described by Koch (1926, p.83) from Switzerland, who also noted character species shared with communities dominated by *Schoenus nigricans*. With regard to the latter he remarks:

> 'Den ökologischen Ansprüchen des dominierenden *Schoenus nigricans* gemäss, stellt der Typus der Assoziation hohe Anforderungen an den Kalkgehalt des Bodens. Ihr Vorkommen ist deshalb beschränkt auf den Rand sehr mineralreicher Gewässer, auf alte Seebecken mit Unterlage von Seekreide, bei uns vor allem auf die Nähe sehr kalkhaltiger Quellen, sowohl in der Talebene, als an den Hängen.'

In view of these phytosociological relations, ecologists became interested in the question whether the presence of *Scorpidio-Caricetum diandrae* stands in The Netherlands could be attributable to *seepage* phenomena: the phytosociological scheme of classification indicated the direction of prospective ecological studies (De Wit 1951, p.352). Since the rhizosphere of quagmire vegetation has no direct contact with the mineral subsoil, the possible occurrence of a regional groundwater discharge was emphasized to explain the presumed high calcidity in the environment.

Hydrology

Until the beginning of the presently reported survey (Van Wirdum 1973), further work with regard to the *seepage hypothesis* had not been accompanied by any detailed geohydrological investigations. The conventional argument in this field was the proximity of presumed *seepage sites* to more elevated areas (De Wit 1951, p.346-347; Meijer & De Wit 1955, p.50; Kuiper & Kuiper 1958, p.361; Segal 1966, p.110). In several case studies concerning the seepage hypothesis the visual presence of iron compounds in *seepage pools* is mentioned, especially in Het Hol near Kortenhoef where the hypothesis was first formulated. De Graaf (in Meijer & De Wit 1955, p.69) noted the presence of 'several active iron wells' and thoroughly documented the chemical composition of the water. A visible flow and bubbling of the water in presumed *seepage pools* in quagmires is commonly mentioned. Such phenomena, however, may well be associated with, (1), the forces caused by the weight of the observers on the weak *kragge*, squeezing out water from below, and, (2), the escape of gases under the influence of a lowering barometrical pressure. They obviously do not prove the incidence of seepage of groundwater from elevated areas through the underlying mineral soil.

Ecophysiology

It was long realized that plants are not sensitive to seepage as such. In view of this awareness, Kuiper & Kuiper (1958, p.363) mention two ecophysiological factors which may be the cause of *seepage sites* bearing a characteristic association of plant species, namely, (1), a somewhat lower water temperature during summer, and, (2), the binding of phosphate by the formation of insoluble iron compounds. Segal (1966, p.135) also mentions, (3), the possible input of calcium and bicarbonate ions, and he states that '*seepage* may occur intermittently and may be surprisingly localized.'

The significance of these factors in quagfens in The Netherlands is partially supported by observations, but these observations relate to the phenomena as such, rather than to their physiological effects. Segal (pers. comm. 1969) made continuous temperature recordings in De Stobbenribben and in some other places. He found remarkable differences between shallow pools at a small distance from one another. Within De Stobbenribben and other quagfens, *seepage pools* were thus supposed to exist next to *non-seepage pools*. Using the same measuring equipment, I was unable reliably to reproduce such results during 1969 and 1970 (see also Chapter 8).

The presence of iron is readily observed, both in the form of an 'oily' film on the surface of the water, and, in some cases, in the form of a rusty brown precipitate on macrophytes and the muddy bottom. Especially the oily films are very common in many quagfens. The binding of phosphate seems to have been proved by De Graaf (in Meijer & De Wit 1955, p.69) to occur in the Kortenhoef area.

As regards the supply of calcium and bicarbonate ions, Segal (1966, p.136) reports:

> '... the periodic fluctuations in the recorded environmental factors may be considerable ... In the course of the succession in seepage areas the general trend is a gradual decrease in the specific conductivity, in pH, in the hardness and bicarbonate concentration, and in the chloride and calcium content, and an increase in the organic ammonium and phosphate, only the sulphate content showing a 'peak' in the *Pellia* phase, all this in spite of the fact that, generally speaking, percolated water enriches the environment and normally causes a local increase in the specific conductivity, and in the pH values, the hardness, and the chloride, bicarbonate, ammonium, iron and calcium concentrations, concomitant with a decrease in the phosphate and the sulphate content.'

Apparently, Segal compared the *seepage* environment with more oligotrophic environments which are mainly fed by rain water. It is worthy of note that Kuiper & Kuiper apparently considered *seepage sites* less eutrophic than other ones (p.363), especially with regard to phosphorus compounds. Segal hints at an opposite trend in the nutrient and the base states, respectively, of *seepage sites* as compared with other ones. Any systematic discussion of water analyses is lacking in the cited 'preliminary report', however. De Graaf (in Meijer & De Wit 1955, p.70) pays some attention to the calcium and bicarbonate concentrations in water samples from the area near Kortenhoef, but his report is not very conclusive with regard to the specific relation of these factors with *seepage* or *seepage sites*. The intermittent occurrence of seepage phenomena is not well documented either. There is even an element of contradiction in the statements regarding the supposed significance of, (1), a constant temperature, and, (2), a supposed intermittent activity of wells, resulting in considerable fluctuations of the concentration of solutes in the water.

2.5 Indicator species reported in studies of Dutch quagfens

Although most authors seem to agree that certain plant associations are more characteristic of *seepage sites* than individual plant species, some have ventured to list *seepage indicators*. Only some of these species are unanimously considered so, at least when they occur in quagfens in The Netherlands (Table 2.1). Most of them are character species of the *Caricion davallianae*, the *Scorpidio-Caricetum diandrae*, or the *Scorpidio-Utricularietum*, respectively. Since the above-mentioned associations are the only ones of the *Caricion davallianae* present in quagfens in The Netherlands, and since the *Scorpidio-Utricularietum* in quagfens is strongly associated with the *Scorpidio-Caricetum diandrae*, which is seen as a *seepage community par excellence*, these species, when growing in quagfens, are almost bound to be considered *seepage indicators*.

Liparis loeselii, although mentioned as a *seepage indicator* by Kuiper & Kuiper (1958, p.373), and *Carex diandra* are, according to the same authors (p.395) 'not as characteristic of *seepage sites* as we originally considered them.' The taxonomic reliability of records of *Philonotis fontana* is doubtful. At the sites from which this species was recorded by Kuiper & Kuiper I only found *P. marchica*, which was not mentioned by Kuiper & Kuiper but is represented in a record by De Wit (1951, p.355) from most probably one of the same sites. The presence of *Riccardia chamedryfolia* in quagfens in North-West Overijssel has, until now, not been confirmed. I have seen several samples of *R. multifida*, however, which had mistakenly been identified as *R. chamedryfolia* (compare also Müller 1954, p.500). However, since less typical specimens, which cannot be easily identified, are frequently met with, the occurrence of *R. chamedryfolia* cannot be excluded altogether (Van Wirdum 1983).

According to Kuiper & Kuiper (1958, p.395), *Menyanthes trifoliata* and *Carex lasiocarpa* are abundant in the vegetation cover of transitional sites 'between *seepage* environments and more eutrophic ones', but 'entirely absent' from the more eutrophic environments proper.

Table 2.1 *Seepage indicators* in quagfens in The Netherlands

Spermatophyta		**Bryophyta**	
Calamagrostis stricta	K	*Bryum pseudotriquetrum*	KC
Carex buxbaumii	W	*Campylium elodes*	SC
Carex diandra	*W	*Campylium stellatum*	KC
Carex lasiocarpa	K	*Scorpidium cossoni*	SC
Dactylorhiza incarnata	WC	*Drepanocladus revolvens*	WC
Eriophorum gracile	KD	*Fissidens adianthoides*	KC
Liparis loeselii	*KC	*Philonotis fontana*	*K
Menyanthes trifoliata	K	*Riccardia chamedryfolia*	*KC
Parnassia palustris	WC	*Riccardia multifida*	KC
Sagina nodosa	KC	*Aneura pinguis*	K
Utricularia intermedia	KU	*Scorpidium scorpioides*	KC

K: according to Kuiper & Kuiper 1958, p.373, 395; W: additions from Westhoff *et al.* 1971, p.80-81; S: additions from Segal (pers. comm. 1969); C: character species *Caricion davallianae*; D: character species *Scorpidio-Caricetum diandrae*; U: character species *Scorpidio-Utricularietum*; (Character species from Westhoff & Den Held 1969); *: questionable, see text

2.6 Special remarks with regard to bryophytes

As far as Angiosperms are concerned, the pertaining literature does not abound in references to particular species as seepage indicators. The character species of *seepage communities* are usually considered *seepage indicators*. Additional information, however, is being provided by the bryological literature. This information is marred with confusion, as appears from the following, incomplete, survey, restricted to the species mentioned in the aforegoing section.

Liverworts

Riccardia chamedryfolia, *R. multifida*: ‘auf feuchten Boden in der Nähe von Quellen und Wasserrinnen’ (Boros 1968). *Aneura pinguis*: associated with ‘kalkhaltigen Quellen und anderen feuchten Stellen’ (Müller 1954).

Mosses

(Note that *Drepanocladus revolvens* is synonymous with *Scorpidium cossoni* plus *Scorpidium revolvens*, as explained below.)

Mönkemeyer (1927) uses *Quell*-words in the description of the environments preferred by: *Bryum pseudotriquetrum*, *Fissidens adianthoides*, and *Philonotis fontana*.

Boros (1968) reports a preference of *Quell*-environments for all mosses in Table 2.1, with the exception of *Scorpidium scorpioides* (‘in Schlenken torfiger Seggenmoore’) and *Philonotis marchica* (but: ‘an feuchten, berieselten, kalkhaltigen Stellen, besonders an Wassermühlen, gern an Thermen, auf Kalktuff, seltener an Quellen’).

Several of the *seepage indicators* among the bryophytes are being regarded as glacial relict species in Central Europe, surviving in the usually cool environment of mires, especially in seepage mires. Amann (1928, p.352), for example, enumerates, among other quagfen species, *Drepanocladus spec.*(*D.*

revolvens is given as an example in the text), *Philonotis fontana*, *P. marchica*, and *Scorpidium scorpioides* as 'reliquats nordiques des marais.'

Both Amann (p.89-100) and Boros systematically treat the relation of the occurrence of bryophytes with the calcium content. *Philonotis marchica*, which Boros associates with lime (see the earlier quotation), is considered to be a tolerant, yet calcifugous species by Amann, as is *P. fontana*, but the latter species is also taken for a calcifugous one by Boros (p.337: 'in kalkmeidenden Quellfluren'). *Drepanocladus revolvens* occurs 'an kalkhaltigen, quelligen Stellen' according to Boros (p.368), but is mentioned among the 'espèces calcifuges plus ou moins tolérantes' by Amann.

These are just a few examples of slightly different to rather opposed opinions, which can partially be attributed to the different geograpical areas considered by Boros (Hungary) and Amann (Switzerland), respectively. A similar divergence of opinions is met in the literature concerning the types of vegetation in *seepage* environments, as will be shown in the following section.

The habitat descriptions by Touw & Rubers (1989) probably reflect the wide acceptance of the *seepage hypothesis* in The Netherlands, rather than representing independent information. Although *kwel* is not regarded a strict requirement for any of the moss species considered here, it is mentioned for all but *Bryum pseudotriquetrum* and *Fissidens adianthoides*, as is a preference, or tolerance at least, of calcareous environments.

Drepanocladus revolvens ssp. *revolvens* and *D.r. intermedius* are considered synonymous by Touw & Rubers, who place the species in the genus *Scorpidium* as *S. revolvens*. Hedenäs (1989) includes *Drepanocladus revolvens* in the genus *Scorpidium*, and he ranks the sub-units *D. r. revolvens* and *D. r. intermedius* at the species level as *S. revolvens* and *S. cossoni*, respectively. Dutch quagfen samples certainly belong to the latter. It is worthy of note that, whatever the taxonomic rank, Hedenäs' samples of *S. cossoni* from Southern Sweden mostly originated from calcium-rich areas apparently avoided by *S. revolvens*.

2.7 *Seepage* and calcidity

It is obvious that the singular character of *seepage* quagfen sites, as conceived by Dutch ecologists, is not only distinct from that of more oligotrophic, rain-fed bog or boggy transitional sites, but also from that of the majority of more eutrophic fens. A survey of the pertaining literature confirms that most Central-European authors regard seepage as one way to invoke and preserve particular environmental conditions, rather than as a direct cause of the ocurrence of *seepage indicators* (*cf* Schmidt 1969, p.245). The various types of seepage sites distinguished in Central Europe, each accompanied by characteristic types of vegetation are listed in Table 2.2.

Ellenberg comments that the 'Kleinseggenrieder der Quellsümpfe' owe their preservation to human influences, *in casu*, mowing. According to Ellenberg this type of vegetation closely resembles that of other kinds of fen not characteristic of seepage. In the absence of mowing the cover of vegetation would become overgrown by *Phragmites australis* or replaced by willow and alder carr.

Table 2.2 Types of *seepage sites* and their characteristic vegetation

	kalkarm	**kalkreich**
überrieselte Quellflur	Weichwasser-Quellflure *Cardamino-Montion*	Quelltuff-Fluren *Cratoneurion-commutati*
durchfeuchteter Quellsumpf	saure Kleinseggenrieder *Caricetalia nigrae* *Caricion canescenti-nigrae*	Kalk-Kleinseggenrieder *Tofieldietalia* *Caricion davallianae*

Cited from Ellenberg 1978, p. 421

Seepage is usually considered a prime factor capable of preserving a calcareous, yet oligotrophic fen environment (*cf* Braun 1968, p.8). Westhoff & Den Held (1969, p.203), on the other hand, note a relevant divergence in the floristic composition of the *Caricion davallianae*:

> ‘With regard to The Netherlands, the *Caricion davallianae* can probably be divided into two subunits reflecting the fluctuation of the groundwater level and the nutrient status, especially the calcium content of the environment. We would thus obtain a syntaxon comprising the associations of environments with a constantly high groundwater table and usually low calcium contents in the groundwater, and a syntaxon comprising the associations on mostly calcareous soils with a fluctuating groundwater level.’

There is no doubt that the *Scorpidio-Caricetum diandrae* and the *Scorpidio-Utricularietum* would have to be placed in the first-mentioned syntaxon. The diagnosis comes close to the one given by Rybníček (1974) for the *Scorpidio-Utricularietum*.

Rybníček distinguishes the *Caricion demissae* Rybníček 1964 as a separate alliance in the order *Tofieldietalia* and classifies the *Scorpidio-Utricularietum* association in this alliance. The presence of certain acidophilous species, such as *Drosera rotundifolia*, *Oxycoccuspalustris*, and *Sphagnum contortum*, is mentioned as a typical feature of this alliance which encompasses ‘meistens montane Parallelassoziationen des *Caricion davallianae* Klika 1934 in kalkarmen oder Silikatgebieten.’

Although the three above-mentioned acidophilous species do occur in close proximity of, or even within, stands of *seepage-fen* vegetation in Dutch quagmires, Westhoff & Den Held (1969, p.203) do not accept the *Caricion demissae* for The Netherlands. Rybníček's (1974, p.34) comment about the influence of base ions in both alliances is probably also relevant to the subunits suggested by Westhoff & Den Held, however:

> ‘Für beide Verbände (*Caricion demissae*, *Caricion davallianae*) ist aber die höhere Gehalt an basischen Ionen im Grundwasser und die Höhe des Sattigungsgrades des Sorptionskomplexes der Torfsubstrate kennzeichnend. In unserem Gebiet der Silikatgesteine der Böhmisch-Mährischen Höhe sind die Gesellschaften dieses Verbandes dort vorhanden, wo eine Möglichkeit des ununterbrochenen Nachsättigen des Sorptionskomplexes mit einem an basischen Ionen reichen Grundwasser besteht, d.h. meistens auf den Hangquellmooren.’

2.8 Conclusions and re-formulation of the *seepage hypothesis*

Although the pertaining literature emphasizes the importance of seepage phenomena for the type of vegetation studied, there is insufficient evidence for the attribution of seepage to a regional groundwater discharge, as stated in the *seepage hypothesis for Dutch quagfens*. The rejection of the original *seepage hypothesis* may lead to a re-formulation based on the literature cited in this chapter. This is still a *seepage hypothesis*, but *seepage* is used here in the wider sense of percolation, rather than of an outflow of groundwater specifically.

The re-formulated *seepage hypothesis* considers that the *seepage sites* under discussion derive their very characteristic vegetation cover from the interaction of the substratum, the atmospheric precipitation, and percolating water, as modified by the microrelief. In some cases there may be an influence of a regional groundwater discharge, or of the exudation of groundwater along a slope, while in other instances surface water from nearby canals, rivers, or lakes may seep through the fens involved. The sites are characterized by a relatively high activity of calcium ions. In the long run a somewhat calcareous type of seeping water is required in order to prevent a succession towards a more acidophilic type of vegetation.

The precise species composition will, among other things, depend on the chemical composition and the intensity of the atmospheric precipitation and the seepage, respectively, and on the microrelief. The higher soil strata, and especially the hummocks, will show more acid conditions, both as regards the soil and the interstitial water, while the lower strata, including terrain depressions, are more calcareous, especially as regards the water.

Although the original *seepage hypothesis* cannot be maintained as a general one, the survey of the literature does not allow for a rejection of the hypothesis that a discharge of groundwater occurs in quagfens in The Netherlands or in North-West Overijssel in particular. This point is therefore included in the present investigation. The ensuing questions can be formulated as follows:

1) Are the quagfens that are taken for *seepage sites* usually restricted to the outflow of groundwater from the mineral subsoil into the overlying mire? Obviously, not only the present conditions, but also the historical situation must be taken into account.
2) If this is not the case, which input terms are the most significant in the water balance of the quagmires involved?
3) Are the calcium and bicarbonate contents possibly more important in such quagmires than they are in other ones, and can this be explained in view of the water balances?

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 3

Site properties indicated by the flora of quagfens

3.1 Introduction

The *seepage hypothesis for quagfens* analysed in the aforegoing chapter was to a large extent based on the presence of *seepage indicators* in the local flora. The occurrence of the species involved might be explained by the presence of an appreciable amount of calcium and bicarbonate ions. In the following the significance of indicator species in North-West Overijssel quagfens will be further explored. The problem of ecological indication is first discussed from a theoretical point of view. It is argued that the relation between the presence of individual plant species and measured environmental factors is rather indirect. The concepts of plant Associations, from phytosociology, and mire complexes, from mire ecology, seem to fit the scales of resolution of field observations better than do the individual species with their physiological requirements. These concepts do not easily allow, however, for the recognition of delimited natural entities in the study area. Different levels of environmental variety are proposed as a basis for the understanding of the patterns of species aggregation in quagfens. A statistical survey of the indicator species of *seepage sites* suggests that these are low-lying, base-rich, yet nutrient-poor sites where fen peat has developed under the continued influence of an external water supply.

3.2 Species and associations of species as indicators

Response models and Associations in phytosociology

The relation between the presence of plant species and environmental factors that can be assessed with physical or chemical methods has led to the formulation of so-called response models. Most response models rely on empirical data in a single geographic region and they are not necessarily valid outside that region. The indicator lists used here illustrate a factor-wise indication of the optimum or the range for each species, derived from empirical data.

A site is usually considered homogeneous in response models: all species in the local stand of vegetation are supposed to respond to the very same environmental state, thus representing a 'logical-AND' *Association* as distinguished in the French-Swiss School of phytosociology (Van Wirdum 1987). The milieu in the sites of the stands that belong to such an Association is, by definition (Int. Bot. Congress 1910, Brussels), uniform and it must be considered a realization of the intersection (logical product) of the ecological ranges of the various species present (Fig.3.1a). An Association is itself conceived as the product of an evolution of biological adaptations to the coexistence of species in such realizations (Ellenberg 1978 and a discussion about this subject in Westhoff & Den Held 1969). The implied individuality at the Association level has become the central theme of phytosociology.

The individuality of Associations enables one to determine the 'completeness' or 'degree of saturation' of a given stand of vegetation. Since any plant individual requires some physical space, and since the frequency and abundance in the stands of an Association differ among the various species, a certain minimum area is required for each Association to be represented by its complete species assembly, even under ideal environmental conditions. In practice personal judgement cannot be avoided in the assessment of the environmental uniformity of sites. This has led to different plot sizes for phytosociological field work in mire vegetation (Table 3.1).

Table 3.1 Plot sizes used in phytosociological field work in fen mires

Dierssen 1982	1 m^2
Den Held & Den Held 1973 (p.10)	4-10 m^2
Wheeler 1980	10 m^2
Mueller-Dombois & Ellenberg 1974 (p.48)	10-25 m^2
Braun 1968	25-100 m^2

Dierssen (p.10-11) comments that mostly a plot size of 1 m^2 is quite satisfactory in peat-mires, with the exception of reed fens, which require 4-6 m^2 for a representative sampling. In species-rich calcareous fens with a considerable micro-relief, Dierssen was probably unable to meet the minimum area requirement but he used 1 m^2 plots for reasons of homogeneity. Some of the divergence among various schemes of classification (Appendix B) is attributable to the implicit use of different concepts of uniformity. It is relevant to the problem of hydrological ecology of quagfens that Dierssen distinguishes Subassociations with *Scorpidium scorpioides*

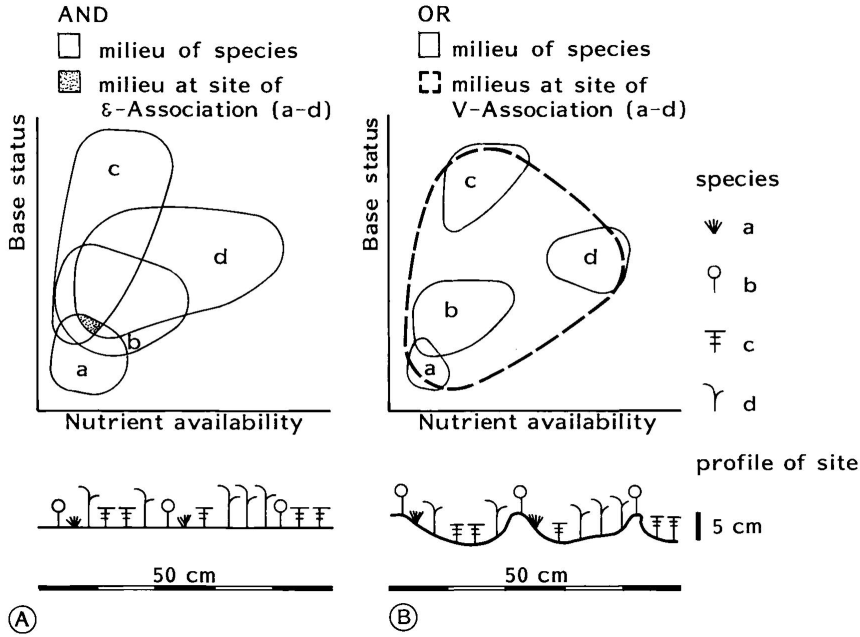


Fig.3.1 The concept of AND and OR Associations

According to the OR theorem (B) the milieu of an Association is the union of the milieus of the various associated species rather than their overlap area, as prescribed by the AND theorem (A); hypothetical example.

in seventeen Associations in five Alliances and three Orders, while Westhoff & Den Held (1969, p.202) mention this species as a character species of the Order *Tofieldietalia* only and of the Alliance *Caricion davallianae* within that single Order. Dierssen obviously recognized environmental differences relevant to the moss layer and found the same moss ‘micro-coenon’ associated with different vascular plants. The evidence from the work of other authors, using larger plot sizes, is that these different vascular plants are also associated among each other.

This problem is partially overcome by the introduction of the concept of different synusiae, or micro-coena, thus allowing for the difference in scale at which the various groups of plants, according to their growth forms and life strategies, explore the available room (Mueller-Dombois & Ellenberg 1974). This principle allows for different micro-habitats within the French-Swiss uniform site of any stand of an Association. Similar moss synusiae can be found within stands of different Associations of vascular plants, but the reverse may also occur.

So far no generally accepted approach to the problems of classification in this situation seems to have been proposed (Segal 1968).

The OR assumption: an additional explanation of species association

The question arises whether the AND assumption is of exclusive validity, or if the association of species may be partially due to recurrent patterns of environmental variety within the sites of plant Associations. If the second alternative obtains, the relatively large environmental amplitude of individual species, as inferred from vegetation studies, may be due to environmentally inhomogeneous sites. Such sites may nevertheless represent a 'uniform habitat' of an Association when the pattern of environmental variety is a recurrent one, comprising different 'micro-habitats'. This will be called the OR assumption here, since it implies the application of the logical OR proposition ('union', 'logical sum', Fig.3.1b; Van Wirdum 1986, 1987). According to this explanation the recurrent environmental pattern, rather than species interaction, is the primary cause of different species being found together. Conceivably the AND and OR assumptions explain different aspects of the association of plant species in nature. OR-type association emphasizes the individuality of species rather than that of whole communities.

The individuality of mire elements

Scandinavian and Estonian authors in particular (Eurola *et al.* 1984, Masing 1984, Sjörs 1983, see also Dierssen 1982) have stressed the individuality of mire complexes, rather than of plant communities. A mire complex of a particular type is characterized by a recurrent pattern of mire elements, such as hummocks and hollows, the various levels of aggregation each contributing to the emerging local milieus of plant individuals. This concept is supplemented by a theory based on the availability of nutrients (Ruuhijärvi 1983). The applicability to Dutch mires is hampered by the fact that the net result in terms of the operational plant environment has not, or only weakly, been defined. The principle of mire individuality is especially useful in situations where natural processes are 'orderly' expressed in the ecology, extent and morphology of mires. The relatively young quagfens in The Netherlands have developed within the confined space of *petgaten* in abandoned turbaries, and they have been subject to a variety of management regimes and hydrological influences, even within a few decades. For this reason they cannot be considered to represent steady states that primarily reflect 'the natural order'. Under these conditions species may become associated, or dissociated, without obeying the empirical rules established elsewhere.

3.3 Different scales of aggregation

Although I do not reject the individuality concept at the mire complex and plant Association levels, individual plant species, rather than complexes and Associations, are taken here as a basis for the study of ecological relations between the vegetation cover and the hydrology of quagfens. In doing so it must be accepted that the physiologically operational milieu of the plants is usually not measured and, thus, stays ill-defined. This is not considered a significant shortcoming in view of the fact that, for most quagfen species, the physiological requirements are unknown anyway.

The following site aggregation model, based on the areal extent of the aggregates (synusiae), is proposed for the understanding of species aggregation in the quagfens under study (Fig.3.2):

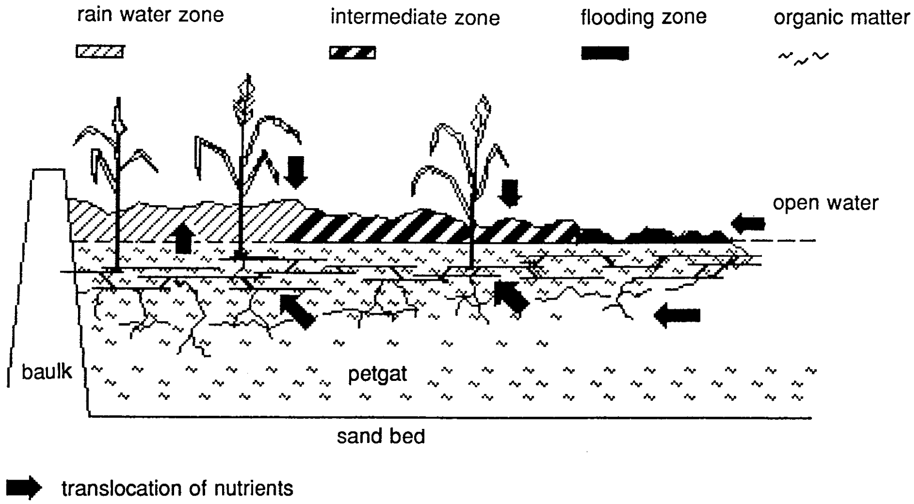


Fig.3.2 Different scales of environmental homogeneity in a quagfen

The picture shows a *kragge* adapted to a certain type of water supplied from below. Within the *kragge* three hydro-environmental zones have developed according to the decreased influence of flooding and the increased influence of rain water as the distance from the body of open water increases. Hummocks and hollows are present in each zone. Micro-zonation is not shown.

Level 1 (*Kragge* synusiae): The quagfen *kragge* in a former *petgat*, 5-30 x10^3 m^2, is ecologically characterized by the magnitude of various terms in the water balance, especially the inflow of water from other sources than local precipitation. It develops during the terrestrialization of the *petgat* from open water to, sometimes within a period of some decades, initial bog or carr vegetation. Some species with a long lifetime may still be present when the environment is no longer suitable for their renewed settling, as is obviously the case for such notorious rhizome builders as *Phragmites australis*, *Typha angustifolia*, *Equisetum fluviatile*, *Cladium mariscus*, *Menyanthes trifoliata*, *Nymphaea alba*, and various species of *Carex*. Their shoots can be considered deciduous parts of few long-lived and extremely extensive individuals. The rhizomes are supplied with nutrients from the body of water underneath the *kragge*. The chemical composition in this body of water is rather constant in some cases, but in other ones it varies considerably, both within and between years. The *kragge* is in fact the most important 'storage organ' of a quagfen and the extent of the rhizomes of several species make it a more or less homogeneous base upon which other patterns become superimposed (levels 2-4). The *kragge*-forming plants contribute to a translocation of elements from the environment underneath the *kragge* to the fen surface, and they provide shade, micro-relief, and substratum for smaller plants. Depending on the hydrological situation large groups of more or less similar *kragge*s may cover 10^3 to even well over 10^5 m^2. Vegetation maps at scales below 1/10 000 usually rely on *kragge* synusiae only (see also Chapter 6).

Level 2 (Hydro-environmental zones): As the *kragge* becomes thicker the influence of an external water supply decreases, especially in the more isolated parts of a quagfen. This decrease is most obvious near the surface of the *kragge*. With the exception of sites with discharging groundwater (Chapter 2), any external water is supplied along one or several sides of a quagfen. Along its route into the fen a gradient develops in which some arbitrarily delimited zones, each about 0.1-2 x10^3 m^2, can be distinguished. In the most isolated parts patches of rainwater-fed, low-herbaceous and moss vegetation can be assessed with a plot size of about 10 m^2. The various hydro-environmental zones can be botanically characterized by the frequency and extent of such patches and by the abundance of the relevant indicator species. An example is provided in the case study of De Stobbenribben (Chapters 7-10).

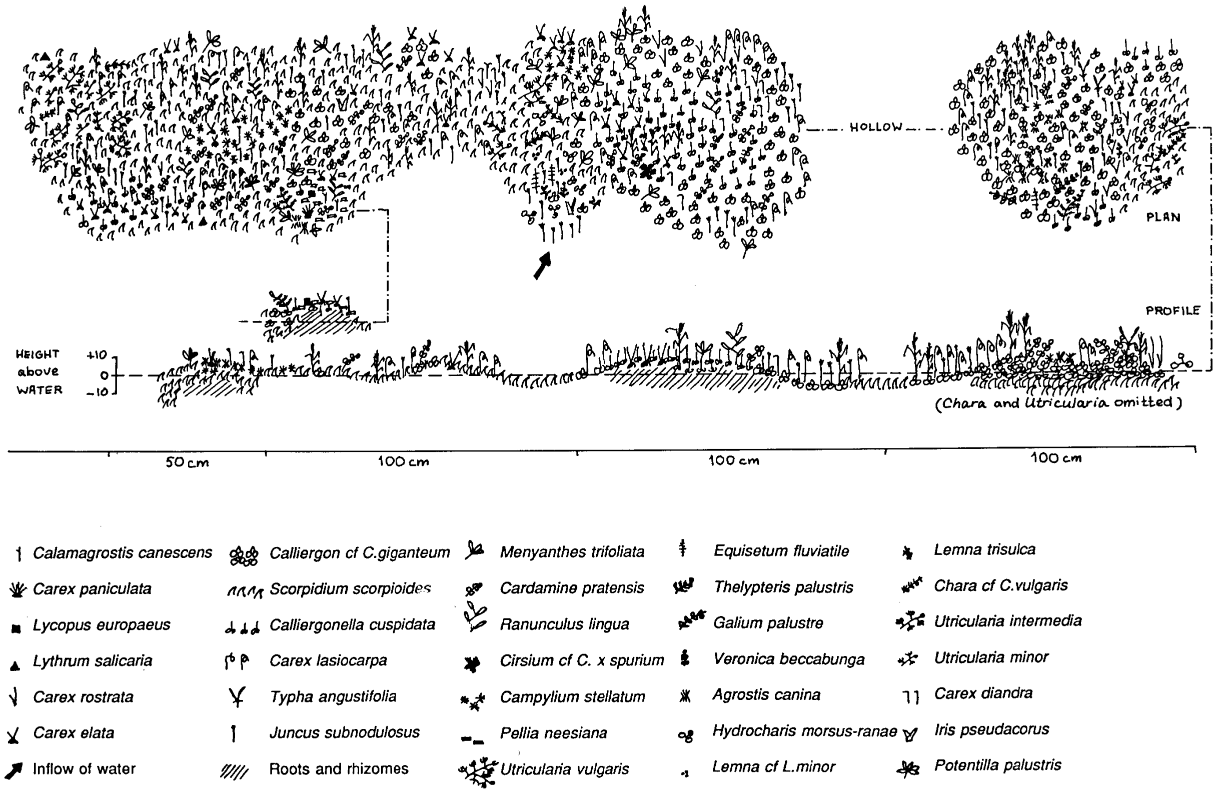


Fig.3.3 Hummock-and-hollow mosaic in quagfen vegetation

October 10, 1969, De Wobberibben; complex of low hummocks and shallow hollows. Sixteen additional species were not mapped. In the course of the 1980s the moss cover at this precise location was almost entirely replaced by *Sphagnum flexuosum*, *S.palustre*, and *S.papillosum*.

Level 3 (Hummock-and-hollow mosaic): The origin of hummock-and-hollow patterns is diverse. In the quagfens under study the hummocks are mostly formed by the growth of such species as *Carex paniculata, C.elata, Molinia caerulea,* and *Sphagnum spec. div.*, while the hollows often originate from the removal of trees and shrubs of *Alnus glutinosa, Betula pubescens, Populus tremula, Salix cinerea, Salix aurita,* and *Myrica gale.* Although hummocks may be a starting point for the formation of larger patches characteristic of the level-2 pattern, the hummock-and-hollow mosaic is essentially superimposed on that pattern. The typical extent of hummocks and hollows is 0.1-1 m^2. Especially Characeae, bryophytes, and such species as *Utricularia spec. div., Drosera rotundifolia, Liparis loeselii, Vaccinium oxycoccus, Valerianadioica,* and *Cirsium palustre* are associated with this pattern. The species composition may differ according to the hydro-environmental zones (level 2). Hummock-and-hollow patterns are illustrated in Fig.3.3.

Level 4 (Micro-zonation): Even within the hummock-and-hollow mosaic, obvious micro-zonations as regards the species composition can be seen, both around the centres of the hummocks and the hollows and along the living or decaying stems of larger plants. Especially mosses and several liverworts, such as species of *Pellia, Aneura, Riccardia, Cephalozia,* and *Cephaloziella* are involved. The extent of each zone is measured in cm^2. It may provide a suitable environment for the germination of various plant species. An example of micro-zonation is provided by Fig.3.4.

The third and fourth levels of aggregation are not studied in any detail in this report, since the patterns involved are largely inherent to the existence of aggregates appropriate to the other, higher levels. In Chapters 6-10 it is attempted to relate the vegetational patterns at these higher levels to hydrological factors. In the remaining part of the present chapter some representative systems of botanical indication are analysed in more detail in order to provide a background for the other chapters.

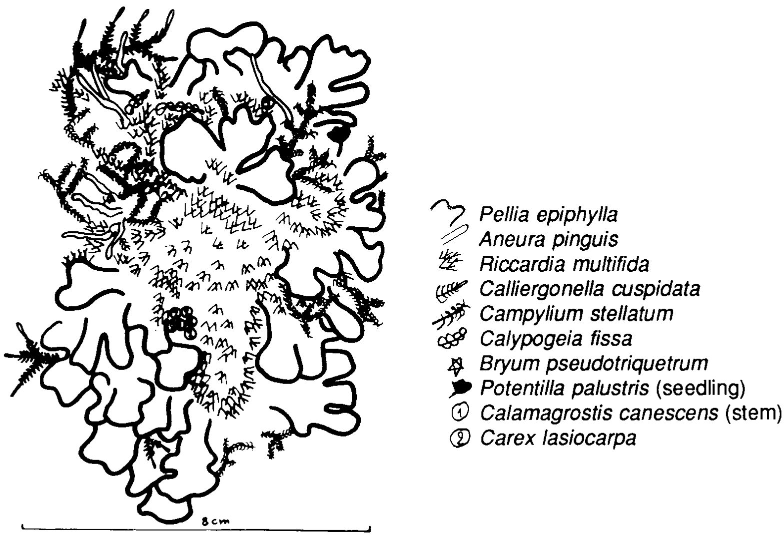


Fig.3.4 Example of micro-zonation in quagfen vegetation

August 6, 1970, Boonspolder; centre of a low hummock of *Carex elata*. The surrounding moss vegetation was dominated by *Calliergonella cuspidata* and *Campylium stellatum*.

3.4 The compilation of a list of indicator species (Appendix C)

From reports by Kuiper & Kuiper (1958), Kuiper & Lapré (1956), Segal (1966), De Wit (1951), and Bergmans (1975), an ‘indicators list’ was compiled comprising all species recorded from supposed seepage sites in North-West Overijssel. The list was later extended with most other fen-mire species of The Netherlands. The list is used here to see what specific information about the environment can be borrowed from the occurrence of *seepage indicators* as compared to the majority of other fen species. In the course of time the list was updated as more recent data became available. All tables and diagrams in the present publication are based on the state of the list and the selection of attributes given in Appendix C.

Phytosociological indications from Westhoff & Den Held (1969), Ellenberg (1978), Oberdorfer (1979), Dierssen (1982), Rybníček (1974, 1984), Balátová-Tuláčková (1972), Braun (1968), Wheeler (1980), and Zijlstra (1981) were compared. The species could be arranged in seven groups as treated in the next section.

Ecological indications from Ellenberg (1978), Kruijne, De Vries & Mooij (1967), Eurola *et al.*(1984), Landwehr (1966, 1980), Pietsch (1982), and Boros (1968), were compared and compiled into two different schemes: one according to acidity and productivity, and the other one according to base state, mire water level, and inherent and supplementary nutrient effects. These schemes reflect the Central European and Finnish traditions, respectively.

From the point of view of nature protection it is important to know whether the sort of environment a certain species requires is threatened by certain human activities. Such species will be called ‘threatened’ species here, although several of them do not yet directly face extinction. The qualification ‘threatened’ or ‘not threatened’, at the national level (The Netherlands), was originally based on data from Londo (1975), Van der Meijden *et al.* (1983) and Margadant & During (1982), but the data for Pteridophyta and Spermatophyta were replaced by those reported in the Red Data List by Weeda *et al.* (1990). All bryophytes marked ! or # in column T, and all species marked 0-5 in column R are considered in the group of 'threatened’ or 'Red-List’ species here.

The phytosociological groups

The basis of the phytosociological grouping is formed by Zijlstra's (1981) species groups. For the present purpose, some of the groups were joined, and they were provided with short names for easy reference. The assignment of species not listed by Zijlstra was derived from the phytosociological literature mentioned above. The following groups were distinguished:

BOG species, including *Oxycocco-Sphagnetea* and *Nardo-Callunetea* indicators, characteristic of extremely nutrient-poor conditions;

FEN species, including *Parvocaricetea* and *Caricion fuscae* indicators, characteristic of oligo-mesotrophic mire. Species with an optimum in Associations characteristic of base-rich sites are not comprised in this group;

LASFEN species, coinciding with Zijlstra's *Caricion lasiocarpae* indicators. Zijlstra classes the *Caricion lasiocarpae* under the *Caricion fuscae*. At the Order and Class levels, it is thus separated from the *Caricion davallianae* (see DAVFEN below). The LASFEN group includes species which have been associated with *seepage* phenomena in The Netherlands, such as *Scorpidium scorpioides,* but it excludes the DAVFEN species often thriving in a slightly dryer, base-rich environment;

DAVFEN species, comprising Zijlstra's *Caricion davallianae* indicators and species of her combined ‘*Caricion lasiocarpae* and *Caricion davallianae*’ group, namely: *Parnassia palustris*, *Campylium stellatum, Fissidens adianthoides, Scorpidium cossoni + S.revolvens, Dactylorhiza incarnata*, and *Drepanocladus lycopodioides*;

MOLFEN species, including species characteristic of *Cirsio dissecti-Molinietum, Molinion*, '*Juncion acutiflori* or *Calthion*', *Molinietalia*, *Molinio-Arrhenateretea*, and *Arrhenateretalia* vegetation. The group is associated with mown and grazed, but undunged sites;

LITFEN (litter fen) species, including the '*Filipendulo-Petasition* or *Soncho-Euphorbion palustris*' indicators in Zijlstra's table and several species of her *Agropyro-Rumicion crispi* group, and species indicating 'disturbance'. This group combines species characteristic of Associations of sites with a periodically fast turn-over of nutrients;

SMP (swamp) species, including Zijlstra's *Phragmitetea* indicators and various indicators of early successional stages.

At later occasions some newly added species were marked AQU (aquatic species) or SMA (salt marsh species characteristic of more or less brackish fens). This concerns few species, and the categories are not separately dealt with here[1].

According to the phytosociological literature (especially Ellenberg 1978, Dierssen 1982) the following ecological relations may be expected between the phytosociological groups:

- When a mire is strongly influenced by surface water, including inundations, it is often dominated by SMP species;
- When, locally, the influence of rain water and the processes in the root zone become important enough to change the environmental conditions appreciably, FEN species are more frequently encountered;
- When, in such places, the acidity is not much increased, LASFEN species constitute a considerable part of the flora;
- In more or less calcareous environments DAVFEN species join the other ones, especially when the sites are somewhat drier in the summer and used for hay-making. The same situation may locally obtain on hummocks in generally wetter mire parts;
- A slight further drainage will lead to MOLFEN sites, especially under a strict mowing regime, when the uppermost soil horizons start to become poorer in bases;
- The natural continuation of an increasing rain-water influence under water-saturated conditions will cause a development into BOG. This development is most pronounced in the case of FEN sites;
- When the vegetation is in direct contact with slightly eutrophic or fluctuating surface water, or when it is burned, mown, or grazed at irregular intervals, or slightly manured or disturbed in any other way, it may progressively obtain a LITFEN character.

Ecological indications according to the Central-European tradition

A first scheme of ecological indications was based on the indicator lists published by Ellenberg (1974, 1978). An analysis of the frequency distribution (Fig.3.5) of 215 vascular plants present both in my species list and in Ellenberg's revealed that not much information could be expected from Ellenberg's light, temperature, and continentality factors. In the case of the moisture factor (F-figure), an accumulation of species can be noticed in the wettest classes covering 'permanently moist', 'wet', 'frequently inundated', and aqauatic sites (F8-F12). Many remaining species are indifferent with regard to either of the factors soil reaction (pH), and nitrogen.

[1] They are treated as a rest group (DIV) in Table 3.2.

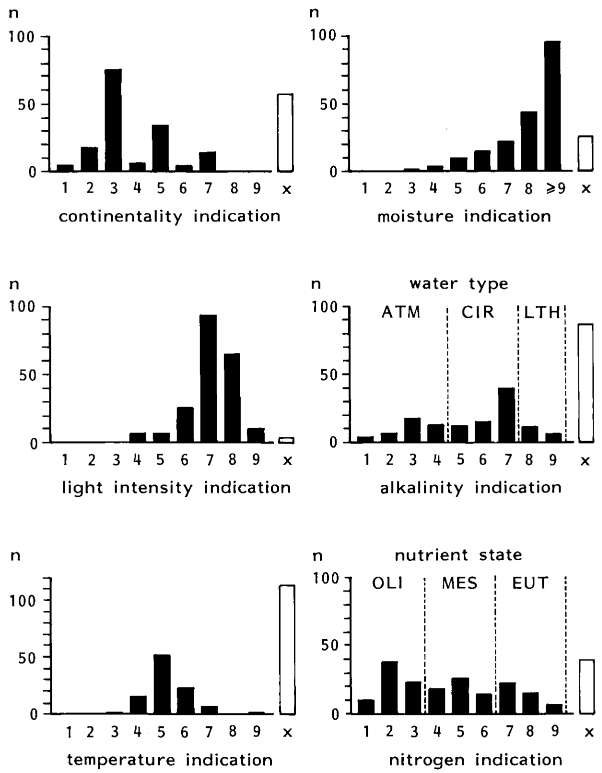


Fig.3.5 Frequency distribution of 212 quagfen species according to Ellenberg's indicator scales

The x-axis reflects an ordinal arrangement of classes from low (1) to high (9, in case of moisture: 9-12) values of the appropriate factor. The correspondence between Ellenberg's alkalinity and nitrogen indications and the water type and nutrient state classes, respectively, as introduced here is also shown. The class X includes indifferent species.

With regard to soil reaction (R-figure), 86 species are indifferent, while the remaining ones are distributed in a somewhat bimodal manner:

A, species of mostly acid sites (Ellenberg: R-figure 1-4);

B, species with an optimum in circumneutral or alkaline sites (R-figure 6-9);

In the quagfen environment the soil reaction and base state are determined by the dominant water type in the hydro-environmental zones.

The frequency distribution in relation to the inorganic nitrogen (N-figure) supply does not show any clear pattern, although there is a strong tendency towards a preference of poorer sites. Since the nitrogen figure is well correlated with the preference of species to phosphorus and potassium as listed by Kruijne, De Vries & Mooij (1967) (Van Wirdum & Van Dam 1984), it is regarded here as an indication of the general nutrient state. The species with N=7-9 , when occurring in mires, are mostly indicative of early successional stages of only marginal interest in the present study.

Some vascular plants, and all bryophytes, are lacking in Ellenberg's list. Even if only five groups are formed on the basis of the frequency distributions, the numbers of species in each class are too small to draw reliable conclusions. The cited literature was studied in order to estimate the missing indications, to replace certain less representative values, and to further reduce the number of 'neutrals'. Even a species with a conceivably wide amplitude may be indicative of an ecological tendency when it is reported to avoid one of the extreme types. Since the list is intended for use in wet mire environments only, the possibility of a different behaviour of species in other environments was disregarded. The following classes were used:

1) Water type (reaction):
- (UNK): Unknown or indifferent, considered undefined;
- (ATM): Atmotrophic; Base state low, acid, usually ombrotrophic environments (Ellenberg: R 1-4);
- (CIR): Circumneutral; Intermediary base state, mostly weakly acid sites (Ellenberg: R (5-)6-7);
- (LTH): Lithotrophic; High base state, often calcareous, slightly or strongly alkaline sites, pronounced influence of groundwater or surface water (Ellenberg: R 8-9);

2) Nutrient state, especially with regard to productivity:
- (UNK): Unknown or indifferent, considered undefined;
- (OLI): Oligotrophic (Ellenberg: N 1-3);
- (MES): Mesotrophic (Ellenberg: N (4-)5-6);
- (EUT): Eutrophic (Ellenberg: N 7-9).

The distribution of the 308 species over these classes is given in Table 3.2 and discussed later in this chapter.

The Finnish mire types

Since the beginning of this century students of Finnish mires have developed and applied a system of mire types. Details concerning the most recent version of this system have been published by Eurola *et al.* (1984), who claim that the system can be used in an extensive geographical area. The various ecological types recognized in this system are inferred from the species composition.

The theoretical basis is formed by a consideration of the ease with which a plant, according to its physiological properties, is able to obtain nutrients at a site with a particular wetness, nutrient and base state, and inherent and supplementary 'nutrient effects'.

According to the definition of the classes one may expect rather strong correlations between the various factors. This was investigated for 255 species in an early version of the indicators list, of which 145, including both vascular plants and bryophytes, are also mentioned by Eurola *et al.* (1984). Owing to the fact that these authors often assigned a species to more than one class of a single factor, thus in fact creating new, combined classes, their indicative system allows for more than 5000 combinations. A close analysis of the distribution of the North-West Overijssel

Table 3.2 The distribution of species in the systems of indicators

Species group	ALL	SEP	RED	BOG	DAV	LAS	FEN	MOL	LIT	SMP	DIV
Nr of Species	**308**	**21**	**78**	**31**	**16**	**18**	**41**	**46**	**67**	**73**	**16**
Water type:											
ATM	71		25	24	2	1	20	10	12	2	
CIR	110	6	20		2	8	13	23	25	36	3
LTH	60	12	25		10	9	3	4	13	18	3
UNK	67	3	8	7	2		5	9	17	17	10
Nutrient state:											
OLI	113	16	52	24	11	10	19	26	17	6	
MES	104	5	23	3	5	8	19	18	20	27	4
EUT	61						1		20	33	7
UNK	30		3	4			2	2	10	7	5
Co-occurrence of indications according to the Central-European tradition (see Fig.3.6):											
LTHOLI	20	9	16		8	5		1	4	2	
LTHMES	24	3	9		2	4	2	3	4	7	2
ATMOLI	51		20	21	1		11	9	8	1	
CIROLI	31	6	23		1	5	6	12	5	2	
REST	182	3	20	10	4	4	22	21	46	61	14
Finnish system:											
Nr of Species	**162**	**16**	**48**	**19**	**15**	**13**	**35**	**17**	**26**	**33**	**4**
Base state:											
OMB	22		10	14			4	2	2		
POR	9	2	3		1		8				
TRL	59	2	8	4	2	3	16	5	15	11	3
WMS	57	8	17	1	5	8	7	9	9	18	
XRC	15	4	10		7	2		1		4	1
Groundwater level:											
HUM	41		9	13	2		10	4	10	2	
INT	45	4	14	4	7	2	8	9	8	6	1
FLK	76	12	25	2	6	11	17	4	8	25	3
Supplementary nutrient effects:											
SEP	36	3	14	5	8	1	4	5	6	6	1
FLD	68	7	13	1		6	22	6	10	21	2
ANY	33	4	9	1	4	5	5	4	8	6	
NON	25	2	12	12	3	1	4	2	2		1
Inherent nutrient effects:											
MOS	16		6	9			4	2	1		
NVA	17	4	10	5	1	3	8				
RFN	26	9	17	1	7	7	2	5	3	1	
NON	103	3	15	4	7	3	21	10	21	32	4

RED: Red-list species and threatened bryophytes; SEP: *Seepage* indicators; DIV: SMA + AQU;
other abbreviations: see text

species led to a reduction to a four-dimensional 5x4x3x4 representation. Of these 240 combinations only 47 were indeed occupied by species. The following definitions were used to revise the classification of the species represented in the original scheme published by Eurola *et al.*:

1)'Base state', reflecting the sum total of physical and chemical growth factors of the peat, including the influence of climate, pH, electrolyte content, the amount of individual nutrients, peat thickness, water movement, and the height of the water table. Note that, although the term 'nutrient state' was used by Eurola, the calcium content and pH are key factors in the actual estimation, justifying the name 'base state' (see below). The naming of the factor states below reflects the distinction of poor, transitional, rich (here named wide-range mesotrophic), and extremely rich fen by Scandinavian authors. The following classes are distinguished:
- (OMB): Ombrotrophic (relying on rain water). The species which, in the original Finnish system, are listed in the ombrotrophic class, as well as those exclusively mentioned for the oligotrophic class, were all grouped into this new 'ombro' class;
- (POR): Base-poor (with a low base state). This class holds the species marked both in the oligotrophic and in the mesotrophic class by Eurola *et al.*
- (TRL): Transitional. This class is identical to Eurola's mesotrophic-only group. As explained below, it appears that this class holds a number of species which are considered indicators of an unstable environment in The Netherlands, as well as species characteristic of so-called transitional fen;
- (WMS): Wide-range mesotrophic (with an intermediate or moderately high base state). This class holds the species marked both in the mesotrophic and in the eutrophic class of the original scheme;
- (XRC): Extremely rich (with a definitely high base state). Identical with Eurola's class 'eutrophic-only';

2) Groundwater level. The groundwater level in mires is especially important with regard to the adaptation of plants to anaerobic conditions. Plants which are adapted to anaerobic conditions are supposed to have a greater difficulty in obtaining nutrients, and thus generally indicate a higher nutrient state than species of aerobic sites. The following levels are distinguished:
- (HUM): Hummock level (water level lying, in a normal summer, more than 20 cm below the site surface level). The class includes some species also occurring in the 'intermediate level' class of the Finnish scheme;
- (INT): Intermediate level (water level lying, in a normal summer, only 5-20 cm below the site surface level). Identical to Eurola's intermediate level;
- (FLK): Flark level (water level lying, in a normal summer, above or only a few centimetres below the site surface level). The class includes some species that were also scored in the intermediate level by Eurola;

3) Supplementary nutrient effect, defined in accordance with the question whether or not the surface peat is continually being supplied with additional nutrients from other sources than rain water. The stronger this influence, the more eutrophic the site will usually be. According to an increasing effect on the availability of nutrients for plant growth, the following supplementary nutrient effects are distinguished:
- (SEP): Seepage influence (moving groundwater with a more or less constant temperature, and a relatively high oxygen content). This influence is called 'groundwater influence' in the Finnish system. The authors indicate a type of groundwater that is relatively rich in oxygen which is, in The Netherlands, not typical of discharging groundwater. I have, for this reason,

chosen the term ‘seepage influence’, in the general sense of seepage. The ‘spruce mire’ effect tabulated in the Finnish scheme is included here;

- (FLD): Flooding influence (fluctuating surface water, in particular derived from streams, rivers, and lakes). This influence is named ‘surface water influence’ by Eurola *et al.*, and renamed flooding influence here in order to distinguish it from the influence of surface water that reaches the mire sites by seeping through the peat. The latter is more properly included in the ‘seepage influence’;
- (ANY): Any supplementary nutrient effect. This class holds all combinations of supplementary nutrient effects;
- (NON): None: no supplementary nutrient effects were mentioned for the species in this class;

4) An ‘inherent nutrient supply’, produced by the autochthonous nutrient state of the site under consideration, and, consequently, associated with the latter:

- (MOS): Moss influence. Species marked under hummock-level bog influence in Eurola's table. The influence is renamed here in order to avoid confusion with other indications. A hummock-level bog, according to the Finnish system, is a type of complex; it may well include flarks;
- (NVA): *Neva* influence (typical of intermediate and, usually not eutrophic, flark-level mire sites). Only exclusive *neva*-influence species are included in this class;
- (RFN): Rich-fen influence (typical of intermediate and flark-level mire sites with a high base state). Includes species that combine this indication with others;
- (NON): None: no inherent nutrient effects were mentioned for the species held in this class.

Table 3.3 The indicative significance of eutraphentous (extremely rich) sites in the Finnish system

Species	**Base**	**Level**	**Suppl.**	**Inher.**	**Water**	**Nutr.**	**Type**
Triglochin maritima	XRC	INT	NON	NON			SMA
Solanum dulcamara	XRC	FLK	FLD	NON		EUT	SMP
Fissidens adianthoides	XRC	FLK	ANY	RFN		MES	DAV
Carex panicea	XRC	INT	NON	RFN	ATM	OLI	MOL
Fraxinus excelsior	XRC	HUM	ANY	NON	CIR	EUT	SMP
Sphagnum contortum	XRC	FLK	ANY	RFN	CIR	MES	LAS
Carex paniculata	XRC	FLK	SEP	NON	LTH	EUT	SMP
Cratoneuron filicinum	XRC	FLK	SEP	NON	LTH	MES	DAV
Plagiomnium elatum	XRC	FLK	SEP	NON	LTH	MES	DAV
Campylium stellatum	XRC	INT	SEP	RFN	LTH	OLI	DAV
Carex appropinquata	XRC	INT	SEP	NON	LTH	OLI	SMP
Eleocharis quinqueflora	XRC	FLK	SEP	RFN	LTH	OLI	DAV
Epipactis palustris	XRC	INT	SEP	NON	LTH	OLI	DAV
Scorpidium cossoni	XRC	INT	NON	RFN	LTH	OLI	DAV
Scorpidium scorpioides	XRC	FLK	FLD	RFN	LTH	OLI	LAS

Extract from Appendix C, sorted on nutrient state within water type indications

The overall distribution of the species revealed an accumulation in the classes representing the intermediate and flark levels in base-poor and transitional (or unstable, see below) sites with flooding influence. Supplementary nutrient effects are indicated by 137 species, while only 59 species are indicative of any inherent nutrient supply. A relatively large proportion (Table 3.2: 17 out of 26 species) of rich-fen indicators appears to be ‘threatened’. Threatened species are also over-represented (10 out of 15, against 78 out of 308 for all species) among the indicators of an ‘extremely rich’ base state. However, only a minority (8 out of 59) of species which are classed as ‘transitional’ are threatened ones.

At first sight this result seems somewhat anomalous, since it is generally agreed that, in The Netherlands, eutraphentous species are less likely to become threatened than (meso- and) oligotraphentous ones. Apparently, the Finnish ‘nutrient state’ is quite different from Ellenberg's nitrogen figure. Eutrophic sites, in the sense of the Finnish definition, usually have both a high alkalinity and a high base content. Especially phosphorus is not always easily available to plants at such sites. This is apparent from Table 3.3, listing the ‘eutrophic-only’ species (present class: extremely rich) in comparison with the indicatory values assigned to them in the Central-European system: they are mostly threatened DAVFEN and LASFEN species with a clear tendency towards base-rich (lithotrophic), yet oligotrophic environments. For this reason I have preferred the name ‘base state’ over ‘nutrient state’ for this factor.

A relatively large number of species in the ‘transitional’ class of base state is known in phytosociological circles as indicators of disturbance in The Netherlands, and is not threatened. They are associated with weakly acid sites where the availability of nutrients largely depends upon a fluctuating supplementary nutrient effect. This has been expressed by the mention of ‘unstable environments’ in addition to truly transitional fen.

3.5 The ecological significance of the phytosociological groups

The phytosociological groups can be relatively well defined in terms of the occurrence of ecological indicators, as shown in Table 3.2 and in Fig. 3.6:

According to the condensed Central-European system of indications, the BOG-FEN-LAS-FEN-DAVFEN series corresponds to a gradient from atmo- to lithotrophic sites. The nutrient state in this series, however, shows a (mesotrophic) maximum in the FEN ‘stage’. Species reported as *seepage indicators* by Dutch authors are mostly LASFEN and DAVFEN species; they strongly indicate an oligotrophic nutrient state, combined with a distinctly lithotrophic water type (see also Table 3.4). MOLFEN species indicate about the same nutrient state as do LASFEN species, but their base state appears to be much less lithotrophic. LITFEN and SWAMP species include indicators of eutrophic sites.

This presumed ‘response’ of the phytosociological species groups to the factors ‘water type’ and nutrient state is highlighted in so-called radar diagrams in Fig.3.6. The highest score in each species group was used as the response unit, reflected by one radius length. In the ALL-species diagram absolute species numbers were entered, but in the other diagrams a correction was applied for the uneven distribution in the ALL group. This means that the circle (or, more exactly, the inscribed regular pentagon) serves as the ALL-species reference in those diagrams. The differences relative to the ALL-species distribution are significant at the 0.99% level (chi-square test) for all groups but the FEN, LIT, and DIV ones.

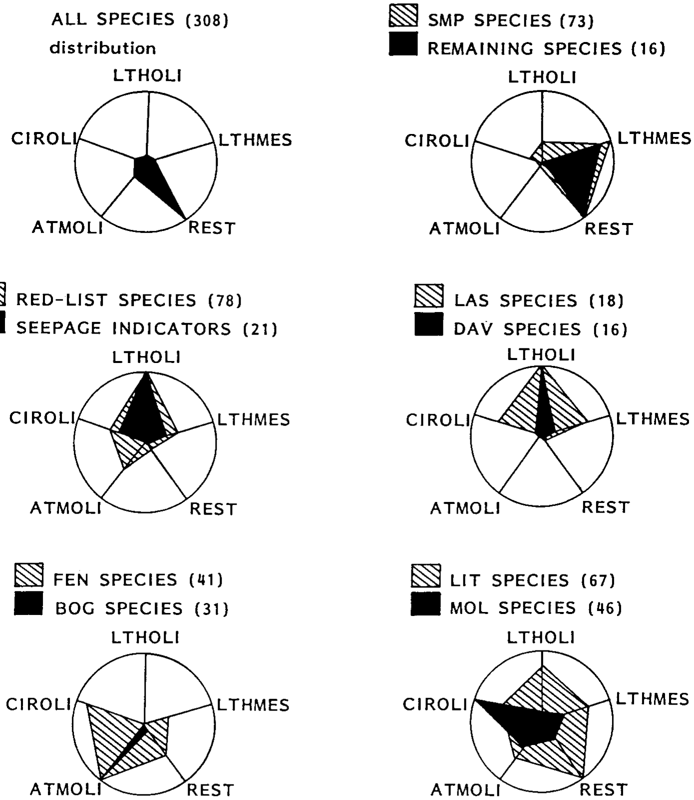


Fig.3.6 Radar diagrams highlighting differences between species groups as regards the indicated water type and nutrient state in combined classes (see Table 3.2)
Note that radars representing specific group distributions have been corrected for the inequality in the ALL-species distribution given in the first radar.

The Finnish 'nutrient state' (base state) shows the same pattern (Table 3.2) as the water type in the Central-European system, confirming that it is indeed an indication of base state, rather than one of nutrient state proper. The wetness factor shows a difference between the LASFEN and DAVFEN groups, the latter indicating a slightly deeper water table. The dominance of flark level indicators, both in the LASFEN and SWAMP groups, and among the Dutch supposed 'seepage' indicators, is obvious.

The 'inherent nutrient effect' is not easily interpretable in the Dutch situation. The pattern is remarkable, however, especially in the general absence of indications for this type of effects (high numbers in row 'None'). Relatively low figures are found in this column for the BOG, LASFEN, and, less so, DAVFEN, MOLFEN, and FEN groups. These figures, and the extremely low figure for the group of Dutch *seepage* indicators, suggest that the locally developed peat substratum might play an important rôle in the explanation of the occurrence of these species. It could play this rôle by its exchange capacity for ions or by the release of nutrients and carbon dioxide through decomposition processes (remember the indication of the *kragge* as a ‘storage organ’ in Section 3.3!).

The general importance of flooding influences in North-West Overijssel is very obvious from Table 3.2. The attention is drawn, therefore, to the absence of indicators for this effect in the DAVFEN group, which includes a large number of indicators of seepage influence. The latter is described by Eurola *et al.* (p.21-22) as groundwater influence, a phenomenon

> ‘distinguished by moving groundwater with a more or less constant temperature or, in the case of a less pronounced groundwater influence, a fluctuating temperature and oxygen content of the water and peat of 6-8 mg/l with a saturation percentage of over 50 and a fairly high reduction potential (Eh=200-400mV)...Groundwater influence includes not only the immediately visible influence as in the case of springs, but also the minerotrophic effect brought about by the seepage of water from the mineral soil (seepage effect).’

Table 3.4 The *seepage* indicators according to Dutch authors

	Centr.Eur.		**Finnish system**			
	Water	**Nutr**	**Base**	**Level**	**Suppl**	**Inhrt**
FEN species						
Menyanthes trifoliata	UNK	OLI	POR	FLK	FLD	NVA
Carex lasiocarpa	CIR	OLI	POR	FLK	FLD	NVA
LASFEN species						
Riccardia multifida	CIR	OLI				
Carex diandra	CIR	OLI	WMS	FLK	ANY	RFN
Calamagrostis stricta	CIR	OLI	TRL	FLK	FLD	NON
Liparis loeselii	LTH	OLI				
Aneura pinguis	LTH	OLI	TRL	FLK	SEP	RFN
Eriophorum gracile	LTH	OLI	TRL	FLK	FLD	NVA
Scorpidium scorpioides	LTH	OLI	XRC	FLK	FLD	RFN
Utricularia intermedia	LTH	OLI	TRL	FLK	FLD	NVA
Sagina nodosa	LTH	MES				
Drepanocladus lycopodioides	LTH	MES				
Bryum pseudotriquetrum	LTH	MES	WMS	FLK	ANY	RFN
DAVFEN species						
Fissidens adianthoides	UNK	MES	XRC	FLK	ANY	RFN
Dactylorhiza incarnata	CIR	OLI	WMS	INT	NON	RFN
Parnassia palustris	LTH	OLI	WMS	INT	ANY	NON
Philonotis marchica	LTH	OLI	WMS	FLK	SEP	NON
Scorpidium cossoni	LTH	OLI	XRC	INT	NON	NVA
Campylium stellatum	LTH	OLI	XRC	INT	SEP	RFN
MOLFEN species						
Campylium elodes	UNK	MES				
Carex buxbaumii	CIR	OLI	WMS	FLK	FLD	RFN

Extract from Appendix C as regards the species comprised in Table 2.1; *Riccardia chamedryfolia* excluded, *Philonotis fontana* included as *P. marchica*

The seepage influence is much less strongly indicated, however, by the explicit group of Dutch *seepage indicators.*

At this point it is possible to conclude that existing schemes of indicators suggest that the Dutch *seepage indicators* are mostly LASFEN and DAVFEN species of the flark level, associated with base-rich, yet nutrient-poor sites, where rich-fen or *neva* peat has developed under the continued influence of seepage or flooding, as summarized in Table 3.4. It is worthy of note that, in the quagfen situation, surface water usually reaches the root zone by penetration below the floating *kragge*, where it should be able to acquire a physico-chemical character similar to the 'groundwater' described by Eurola *et al.*

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 4

The area of North-West Overijssel

4.1 Introduction

The north-western part of the province of Overijssel (The Netherlands) is a portion of the North Sea tectonic basin and forms a section of the former marshy fringe of the North-West European lowland plain. It is located at 6° E long., 52°45' N lat. (Fig.4.1).
The area lies within the major climatic region of the Marine West Coast, as a constantly moist subtype characterized by a rainy climate with mild winters (The Times Atlas of the World 1980, comprehensive edition). The climate graph, Fig.4.2, summarizes 1931-1960 data (KNMI 1972, sheets 4, 16, and 24). The mean annual precipitation for North-West Overijssel is about 765 mm. There is an excess of water in winter and a shortage in summer (April-July).

North-West Overijssel is a polder-and-wetland landscape. The present mire surface is about 0.5 m below *NAP*, whereas the water level in the *boezem* area is maintained at 0.7-0.8 m below *NAP*. The polders are kept drained to various levels (Fig.4.3). The wetland area, which is part of the *boezem*, comprises the nature reserves ‘De Weerribben’ in the north and ‘De Wieden’ in the south. The quagfens investigated in this study developed in abandoned turf ponds originating from extensive peat dredging until the beginning of the 20th century.
The underlying strata consist of sandy infillings of a Pleistocene (Saalian) melt-water valley, deeply eroded in older Pleistocene river sands. Impermeable layers are not expected to occur above a depth of about 200 m below *NAP*.

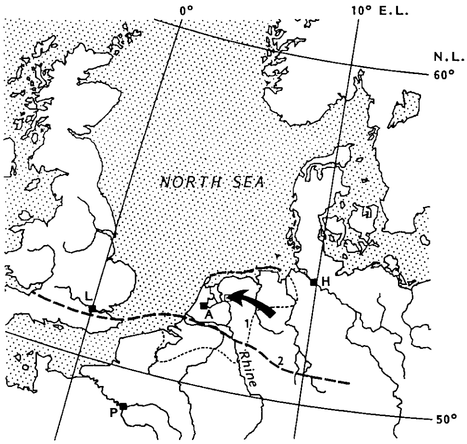


Fig.4.1 Location of North-West Overijssel (arrow)
A: Amsterdam; H: Hamburg; L: London; P: Paris;
1: Southern and eastern boundary of area with mainly Quarternary deposits
2: Southernmost extension of the Saale glaciation

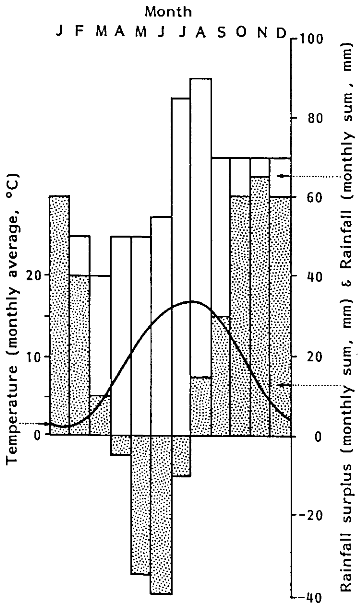


Fig.4.2 Climate diagram for the North-West Overijssel area, based on 1931-1960 records
The smooth curve reflects the average monthly temperature. Bars represent rainfall, the dotted part after subtraction of the evapo-transpiration (data from KNMI 1972)

4.2 Surface structure, land-use, and water management

The original mire

It is generally agreed that the North-West Overijssel area was virtually uninhabited mire till a few hundred years BC. Both climatic and hydrological influences, and possibly also land-use by early inhabitants, led to the cessation of the active growth of peat at about 200-300 AD. From soil surveys (Veenenbos 1950, Haans & Hamming 1954, 1962) it appears that two expanses of ombrotrophic mire, *i.e.*, of bog, existed at the time, roughly coinciding with the central parts of the present nature reserves 'De Weerribben' and 'De Wieden' (Fig.4.3e,g). Although the bogs were presumably of a level type (Veenenbos, p.122), their expanses may have been up to 6 m in thickness at the end of the growing stage. A sand bottom is reached at a depth of 2-4 m below *NAP*.

The bogs were surrounded and separated by fen mire in the valleys of small rivers originating from the Drenthian and Frisian bog areas, and, in the southern part of the area, connected to branches of the Rhine-and-IJssel system. Sand dunes flanking the former river beds are found in several places. The growth of the fen peat was influenced by flooding with water from these rivers, and by the discharge of the local bogs. As a result, the peat is locally very rich in iron, and clay and loam deposits are represented as well. Veenenbos (p.121) noted the presence of low sandy ridges under the mire area, which might have protected the growing bog area against the direct influences of river water.

Human occupation and peat industry (Table 4.1)

The present surface structure of the area was determined by the expansion of Lake Flevo (the later Zuyderzee) from the north-west, and by human occupation and land-use. In the early Middle Ages, goat- and cattle-grazing, some form of cropping, and shallow peat-cutting must have constituted the primary forms of land-use in the mire area, including some superficial drainage. The general tendency of a rising sea level, combined with subsidence and oxidation of peat as an effect of land-use, made the local mire surface unsuitable for further habitation, thus forcing the people to shift to the east, ultimately to the more elevated moraine area. Such movings of settlements have been traced in several places, such as Giethoorn, Wanneperveen, and IJsselham (Kroes & Hol 1979, p.97, 279).

During transgressions clay was deposited over the peat along the western margin of the area (*e.g.*, Fig.4.3, i). As the expansion of the Zuyderzee became a threat to the area, dike building was undertaken since about 1000 AD. Dike bursts can be traced in the morphology of the area, *e.g.*, by the occurrence of pot-holes, and also in written documents, such as those about the devastating floods of 1776 and 1825 AD.

Peat excavation for commercial purposes became of some importance in the late Middle Ages. Although the minable peat mass extended to 2-4 m below the groundwater level, only the superficial peat could be extracted. Later, (manual) dredging techniques were developed and used from the 17th century onward, at first in the southern bog area (Slicher van Bath 1957). Extensive peat excavations were still going on by the beginning of this century in the northern bog area and in parts of the area where the peat had been covered by clay deposits. Peats with a high ash content in the former river beds were not mined, but used as pastures for hay-making and cattle-grazing. The peat was dredged in rectangular parcels, about 30 m wide and a few hundred m long, the so-called *petgaten*. Narrow standing baulks were left in between, but still

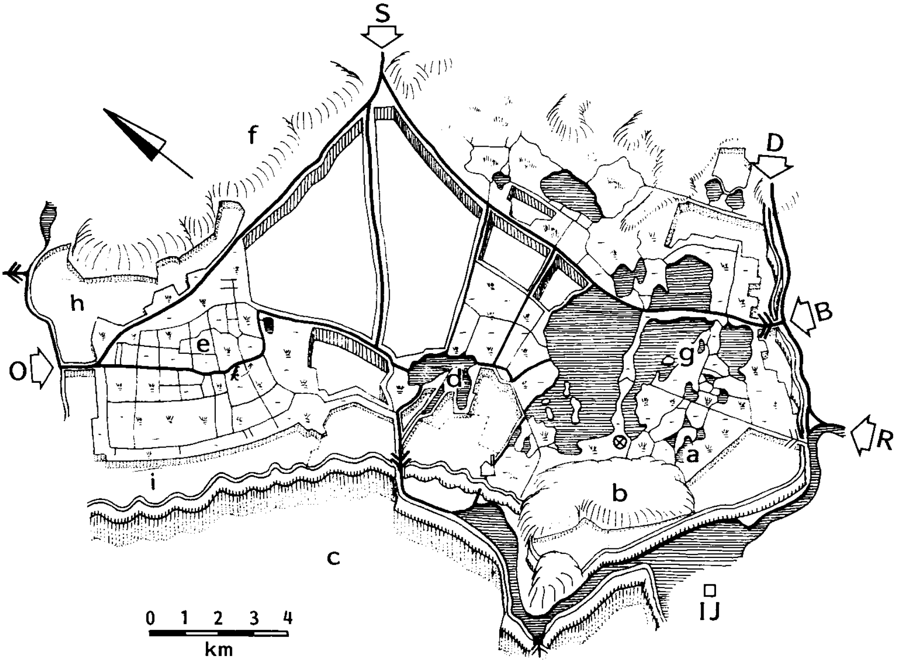


Fig.4.3 Hydrographic setting of the North-West Overijssel mire reserves
from Van Wirdum 1979

nominal water levels in polders

- <0.3 m below *boezem*, partially clay covered
- ca. 0.5 m below *boezem*, partially clay covered
- ca. 2 m below *boezem*, reclaimed peat dredgings
- ca. 4 m below *boezem*, reclaimed from IJsselmeer

boezem area

- mire vegetation, largely reeds
- grassland
- lakes
- pumping station for drinking water withdrawal
- pumping station 'Stroink' for *boezem* discharge

Pleistocene area

- morainic land, soil surface upto 20 m above *boezem*

other map symbols

- large canal with locks, pointing towards highest level
- smaller canal; most of these omitted
- boundary between polder water-level classes
- main (former) sea or river dike

Lettering

a Lake Venematen; b Vollenhove height; c Noordoost-Polder; d Lake Giethoornsche Meer; e nature reserve De Weerribben; f Paaslo morainic ridge; g nature reserve De Wieden; h IJsselham polder area; i Blankenham polder area; k Kalenbergergracht (canal); B Beukerssluis locks (main *boezem* inlet up to 1973); D Meppelerdiep (Pleistocene discharge in wet seasons); O Ossenzijl (connexion to inlet from Frisian *boezem*); R Zwarte Water river (locked from river IJssel); S Steenwijker Aa rivulet (Drenthe Pleistocene discharge); IJ Connects to IJsselmeer.

the area proved very sensitive to water erosion, especially during gales. The main broads (*wieden*) of North-West Overijssel result from this form of erosion. Later phases of the peat-dredging industry proceeded according to strict regulations prescribing the dimensions of *petgaten* and baulks. This prevented the formation of large lakes in the northern part of the area.

In the beginning of our century, the area consisted mainly of a complex of broads, *petgaten* and standing baulks, bordered and interspersed by grassland in the river valleys and protected by dikes along the coast of the Zuyderzee. Fishing was an important means of subsistence in the former mire area, next to some continued peat dredging and the beginning exploitation of reeds (*Phragmites australis*). Locally, rushes (*Scirpuslacustris s.l.*) were cut for matting, but the main area for rushes was the delta of the river IJssel and its branches, rather than the peat district itself.

Water management

In the present century agricultural improvement became a goal for the development of the area. This was accompanied by a progressively increasing rate of organization and planning, resulting in large reclamations and a general improvement of the water management for this purpose.

The institutions responsible for the care of dikes, going back to 1363 AD, evolved into the water board 'Waterschap Vollenhove' in 1889. The water-level in the area was maintained by sluicing the excess water off at low tide to the Zuyderzee, the Meppelerdiep, and the Linde. Although a water level of 0.3 m below the average sea level was strived for, prolonged high-water levels in the Zuyderzee and the rivers frequently inhibited adequate drainage. Winter and spring inundations were a common phenomenon. It was only after the extremely high internal water levels of 0.1 m above *NAP*, in 1910, that the responsible authorities were forced to prepare a plan for a pumping station (Stroink), which was put into operation in 1920. The target water-level was 0.5 m below *NAP*. The pumping station Stroink was provided with an additional pump in 1929, so as to maintain acceptable water-levels also in the bordering Meppelerdiep area. The water board was, by official regulation, obliged to take Meppelerdiep water in whenever this exceeded a certain level. From 1930 on the official level in the Vollenhove *boezem* area was 0.7 m below *NAP*, and from 1942 onwards the winter water-level was lowered to 0.8 m below *NAP*. The obligations with respect to the Meppelerdiep area lapsed in 1972, when the new pumping station Zedemuden took care of that area.

The pumping station Stroink was the main factor enabling the agricultural development of North-West Overijssel, which was pushed ahead by state initiatives, especially since the world wars during this century stressed the importance of a self-supporting production of food at the national level.

Reclamations

The realization of an appropriate water-level control system resulted in 1928 in the foundation of a reclamation company, in which State, Province, and Water Board participated. Its task was to drain the lower parts of the area and to render the conditions for agricultural use as favourable as possible. Much of the work was carried out as unemployment relief. In this way several large and deeply drained polders (ca 2 m below *boezem* water level) were reclaimed (Fig.4.3) and subsequently used for farming. Most of these polderlands are used as pastures to-day.

Table 4.1 The development of the North-West Overijssel mire area

250 -	800	Cessation of active peat growth by the combined influence of climate, hydrology, and early land-use. Formation of shallow lakes in the Zuyderzee area, erosion of mires, deposition of a clay cover in a brackish marsh environment over the peat in the west;
1100 -	1500	Human occupation of the bog surface. Increased transgressive influences from the Zuyderzee and subsidence and peat loss resulting from land-use force the inhabitants to shift to the eastern mire margin and the morainic area;
ca. 1300		The building of dikes against the expansion of the Zuyderzee begins as a first co-operative effort in water management;
1400 -	1600	Extraction of superficial peat layers for fuel;
1600 -	1900	Large-scale fuel peat excavation, shifting from the south to the north during the 18th century. Formation of large broads by wind erosion and floods. Inhabitation by peat workers, fishermen, and some farmers;
ca. 1825		The lower coarse of the Linde river is blocked from the open sea by the construction of sluices, so enabling an improved drainage, for agriculture, of the mire area;
1920		The pumping station ‘Stroink’ becomes operational. The water level in the area is lowered and held under control;
1930 -	1945	Closure of the Zuyderzee from the open Wadden Sea. The Noordoost-Polder is reclaimed, increasing the water demand of the mire area. The influence of brackish water is now excluded;
1928 -	1968	Further reclamations for agriculture (‘polders’) and realization of a canals plan. The *boezem* becomes a reservoir for temporary storage of excess water from polders. Fen vegetation develops in the terrestrializing *petgaten* and is mown for thatching (reed) and for hay making;
1945 -	1970	Biological inventories. The value of the area for nature conservation is discovered. Increased supply of water from the IJsselmeer (the former Zuyderzee), which has become a storage reservoir for Rhine water;
1970 -	now	Reed farming, recreation and nature conservation. Discontinuation of management for economic reasons. Carr vegetation develops. Water quality problems arise: the vegetation of aquatic macrophytes almost disappears.

The ultimate extent of the polders has been a much-debated issue (Het Oversticht 1939, Haans 1951, and other sources), until economical changes towards the end of the 1950s necessitated the government to discontinue the reclamation activities. The reclamation company was liquidated in 1968, when the value of the remaining mire area for nature conservancy and for recreational purposes had become recognized.

The reclamation also resulted in the need for a canals plan to ensure and maintain the communication between different parts of the area left as a *boezem*, primarily for water-management purposes. As the *boezem* area decreased in size, the temporary storage of excess water from the increasing polder area was more clearly defined as a critical *boezem* function.

In the meantime other large undertakings involving water management in The Netherlands were important for the area under investigation. In 1932 the Zuyderzee was dammed in and renamed Lake IJsselmeer, nowadays a freshwater lake with a controlled water level. In 1942 the Noordoost-Polder (Fig.4.3, c) was reclaimed within the IJsselmeer. This polder extends inland as far as the former Zuyderzee dike, thus including a narrow strip of forelands. The average water-level in the Noordoost-Polder is about 4 m below that in the *boezem* waters of North-West Overijssel. This caused a lowering of the average groundwater-levels in part of the area and it put an end to the seepage of brackish groundwater underneath the Zuyderzee dike.

During many years parts of the area that had not been excavated for peat were mainly used for cattle grazing. Most of these have been polders for a considerable length of time, but their water-levels were only 0.1-0.3 m below that in the *boezem*. In the last 25 years the target levels have been lowered for most of these shallow polders, and their area has been increased.

Present land-use in the mire area

The impoverishment of the local economy, the hardships of fishermen and reed cutters, and the discontinuation of reclamations brought large areas of mire in the hands of organizations for the conservation of nature. The whole remaining mire area, including the lakes, has been declared a nature protection area with different degrees of strictness. This change in land-use made additional demands on the water management (Jol & Laseur 1982).

The reed production was severely affected during the 1960s by the import of cheap reed from the Danube area. At present reed cutting in North-West Overijssel is recognized as an important factor in nature management. The cropping of reed often involves extensive irrigation of the reed beds by means of small wind-pumps and tractor-driven motor-pumps. More than 75% of the area in De Weerribben and a smaller part in De Wieden has been under irrigation for a longer or shorter period (Muis 1974).

The importance of the *boezem* of North-West Overijssel for water recreation has grown enormously since 1970, and this has been accompanied by an increasing amount of provisions and regulations.

During dry summers the natural inflow of water into the *boezem* of Vollenhove is insufficient to maintain the target water-level. Additional supply, during such periods, is provided by the intake of water through sluices. This was formerly done from the Meppelerdiep at the Beukerssluis (Fig.4.3, D, B), but that canal suffered from an increasing pollution, especially during the dry season. At present the main water intake is at the Linthorst-Homan sluices which connect the area with the Frisian water-storage system (Fig.4.3, near O).

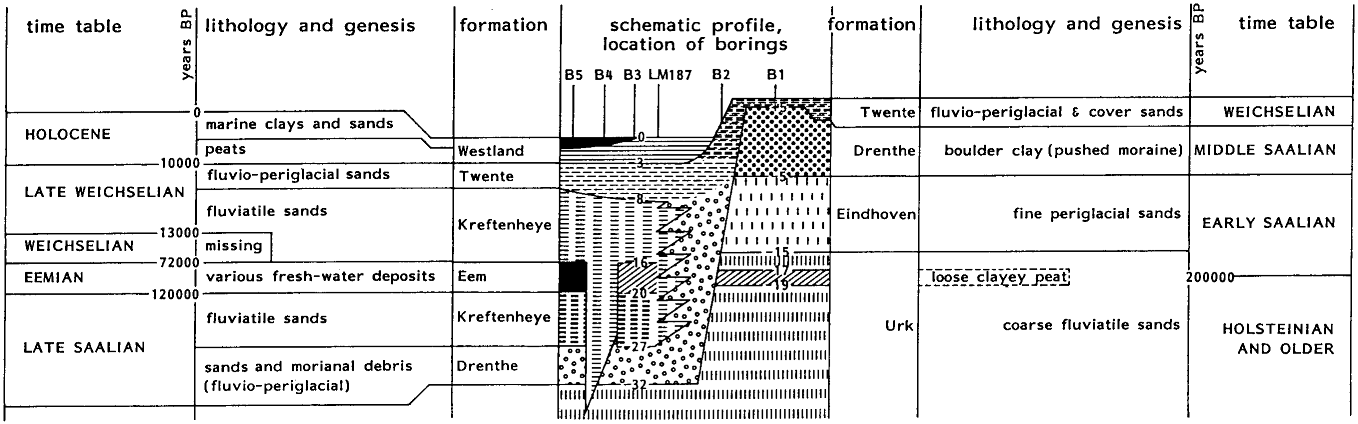


Fig.4.4 Diagram of the chrono- and lithostratigraphy of deposits in the ice-marginal valley of the Oer-Vecht, North-West Overijssel
The schematic profile across the valley includes approximate depth figures in m below *NAP*; the locations of borings have been indicated by the codes of the appropriate piezometers (Chapter 5)

4.3 Geology

Several ecological reports dealing with the mire area in North-West Overijssel suggest the possibility of seepage of groundwater into the mire as a result of artesian pressure in the deeper aquifer which was supposed to be overlain by a loamy morainic deposit. Meanwhile, however, evidence has accumulated that the mire was formed in the deeply eroded (20-40 m deep) valley of a Pleistocene (Saalian) melt-water river, the Oer-Vecht, where the sand infillings immediately overlie lower-Pleistocene river sands (Faber 1960, p.463, 495-499; Ter Wee 1962, Jelgersma & Breeuwer 1975, p.91, profile A-A'). The profiles in Geologische Dienst (1979) suggest a fluvio-glacial origin for the lowermost 3-5 m of the sediment in the original river valley. Impermeable layers are not expected to occur above a depth of about 200 m below *NAP* (Fig.4.4).

The Late Saalian period contributed considerably to the sedimentation of sands in the Oer-Vecht valley, but this deposition came to an end in the Eemian period. In some places an alteration of layers of fresh-water clay and sandy clay rich in humus can still be found at a depth of 16-20 m, often with peat and wood remains. The extent of these less transmissive Eemian deposits is uncertain. They are certainly missing at several places due to strong erosion during the Weichselian, preceding a new period of deposition of fluviatile sands (Ter Wee 1966). There is no evidence of impermeable layers of any appreciable horizontal extent in the Oer-Vecht sediments in North-West Overijssel.

During the Weichselian the Oer-Vecht changed into a local river system filling-up with materials of mainly local origin. These deposits include fluvio-periglacial sands and loam layers of relatively small horizontal extent. The top of the Twente Formation forms the basis of the Holocene peat deposits in the mire landscape. The Twente strata cannot be considered impermeable either, except for a low-permeability zone at their upper boundary with the Holocene peat deposits.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 5

Aspects of the hydrology of De Weerribben

5.1 Introduction

The hydrology of De Weerribben has been strongly influenced by reclamations and by the changing water management. Although in the past some outflow of groundwater will have occurred, De Weerribben is now an area of groundwater recharge. The chemical composition of the underlying body of groundwater is largely determined by infiltrating surface water. Interestingly, older records of groundwater composition show slightly brackish influences, and it seems that no conspicuous upward flow of groundwater existed even before the reclamation of the deep Noordoost-Polder in 1941. Still, a lithotrophic (akin to groundwater, see Appendix D) character of the surface water is obvious from water samples taken between 1960 and 1969. Although such a character is still found at some places in the area, and at some instances, in more recent records the influence of the intake of polluted surface water from the adjacent *boezem* of Friesland has become a dominant feature from 1970 onwards. The associated type of water was not found in earlier records. A detailed study of the chemical composition of surface water in De Weerribben has shown a considerable lag of processes within more isolated parts of the local *boezem* system as compared to the large canals. It is concluded that the surface water management is a key factor for the water quality in the area.

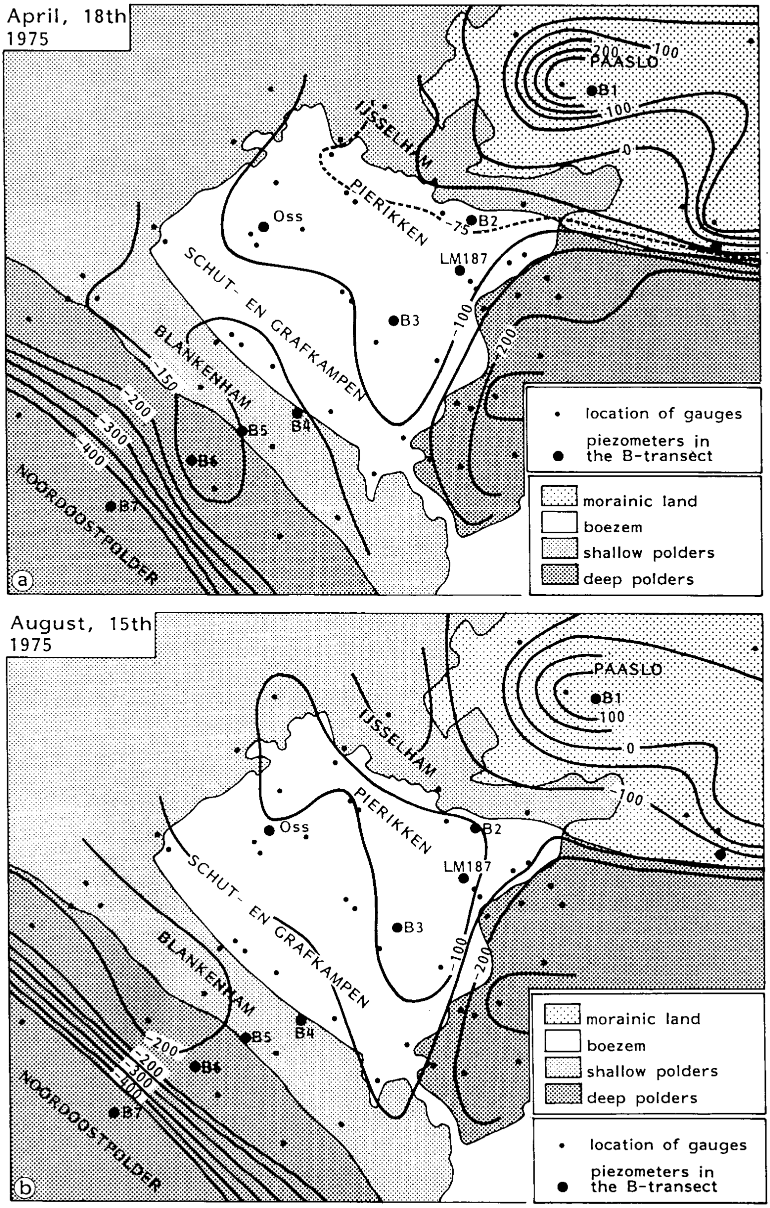


Fig.5.1 Isopotential pattern and location of piezometers in De Weerribben

a April, 18, 1975 (after a very wet winter); b August, 18, 1975 (extreme drought period)

5.2 The hydraulic potential distribution

Available data

The distribution of the hydraulic potential in the area can be studied on the basis of two sets of numerical data. The first set comprises the hydraulic head in piezometers along a transect through 'De Weerribben', the 'B-transect' (Fig.5.1), installed in order to study the effects of the reclamation of the Noordoost-Polder (Rijksbureau voor Drinkwatervoorziening 1938, Volker 1948). Data from this transect from 1940 onwards are contained in the archives of the TNO organization and the Rijkswaterstaat. The 1974-1976 measurements were carried out as part of the present study in close cooperation with the ICW Institute (presently the Winand Staring Centre; Bon 1975). In this joint study additional piezometers were installed and regularly controlled. The records obtained constitute the second set of numerical data.

A correction was applied for the greater density of brackish water in the calculations of the hydraulic head from the observed water levels in the piezometers. This was done by reference to 'complete' chemical analyses and analyses of the chloride concentration. Errors due to an expected inaccuracy of this correction are ±10 cm for the B5 **c** and **d** filters, ±4 cm for the B5, B6, and B7 **b** filters, ±1 cm for the B5, B6, and B7 **a** filters. No correction was applied for the other filters, where the correction was less than 0.5 cm.

Observational errors are in the range of 1-2 cm. Systematic errors due to inaccurate absolute height references are probably smaller than 2 cm for the various gauges at one location, but they may be as large as 5 cm between locations. Most data refer to *NAP*, the Dutch datum level, which roughly equals mean sea level.

The equipotential pattern in the top of the sand-bed

Fig.5.1 reflects the equipotential distribution in the uppermost part of the sandy subsoil below the former mire area and in the phreatic aquifer in the morainic land. Fig.5.1a (April 1975) reflects an extremely wet period, Fig.5.1b (August 1975) an extremely dry one. Note that even in April the hydraulic head in the sandy subsoil of the mire area is well below the *boezem* water level (0.79 m below *NAP*): this is an area of groundwater recharge. In the south, the east, and the west, the groundwater potential decreases sharply towards the various polder areas. Only along the borderline with the IJsselham polder area there may have been some discharge in April. It must be borne in mind, however, that several wind-pumps and motor pumps used for irrigation in spring raise the water level 20-60 cm over a considerable area of reed fields and so locally influence the hydraulic head in the underlying mineral soil.

The potential distribution in the B-transect

The hydraulic potential distribution in the B-transect, at the same measuring dates, is shown in Fig.5.2. The equipotential lines indicate a general E-W flow of water. The recharge by rainfall, in the Paaslo area, and, by *boezem*-water, in the mire area are clearly demonstrated. It is confirmed that discharge of groundwater into the IJsselham polder area and the neighbouring margin of the mire area can only involve a rather shallow groundwater flow: below ca. 10 m the general pattern is not interrupted.

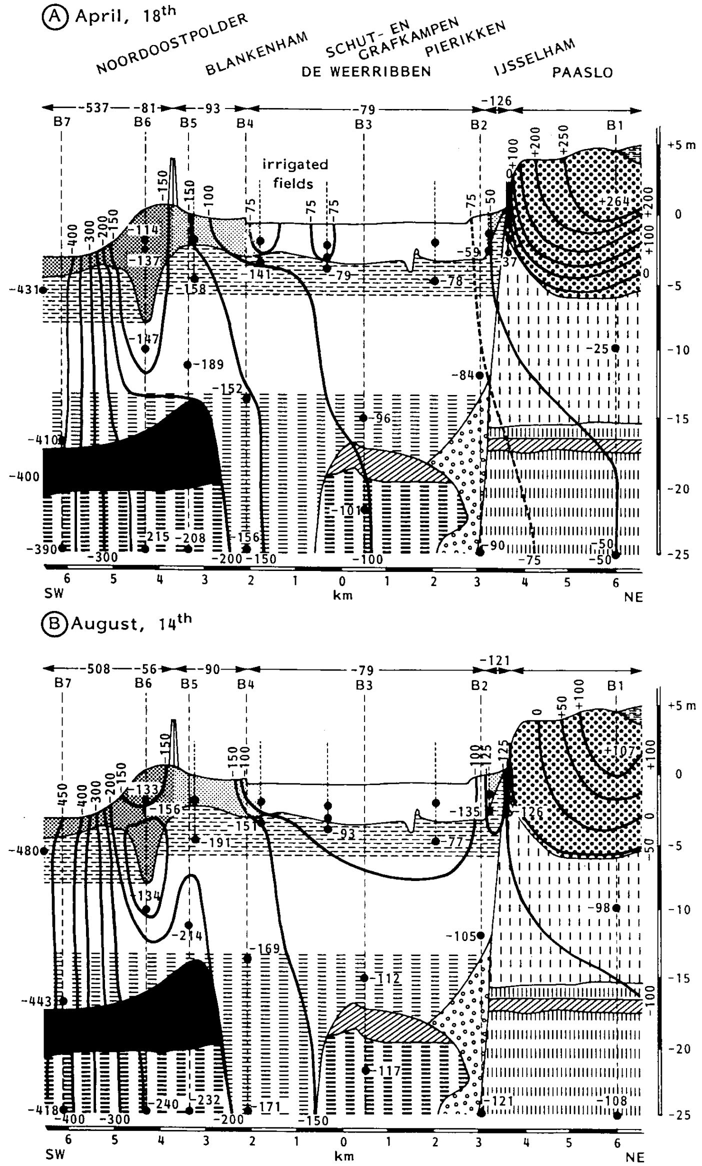


Fig.5.2 Distribution of the hydraulic potential (cm) in the B-transect

a April, 1975 (after a very wet winter); b August 1975 (during extreme drought);
The numbers above each diagram refer to the water level in the surface water system (cm);
Shading applied to indicate lithology as in Fig.4.4 (in the blank area between –5 and –13 m the transition between lower and upper strata is not accurately known)

Table 5.1 The hydraulic potential in the *boezem* and in several piezometers from 1940 to 1975

period:	**1935-'37**	**<>**	**1942-'44**	**<>**	**1953-'55**	**<>**	**1965-'67**	**<>**	**1974-'75**
boezem	64		?	*-9*	73	*-4*	77		77
B1a-10	2	*-29*	31		28		28	*-22*	50
B1b-25	21	*-25*	46		49		47	*-21*	68
B2a-12	62	*-7*	69		65	*-15*	80	*-7*	87
B2b-25	60	*-13*	73		77	*-9*	86	*-10*	96
B3a-16	63	*-18*	81			*-16*			*97
B3b*-22						*-19*			*100
B3b-29	63	*-18*	81						
B4a-14	50	*-82*	132!	*-12*	144	*-7*	151		154
B4b-30	50	*-79*	129!	*-14*	143	*-9*	152		158
B5a-12	54	*-87*	141!	*-33*	174	*-16*	190	*-8*	198
B5b-30	43	*-109*	152!	*-38*	190	*-11*	201	*-11*	212
B5c-75	31	*-109*	140!	*-44*	184	*-16*	200	*-9*	209
B5d-120	16	*-108*	124!	*-21*	145	*-28*	173	*-17*	190
IJsselmeer	5								
B6a-10					215		214	*+63*	151
B6b-29					250	*+18*	232	*+11*	221
B7a-17									435
B7b-27									393

See Fig.5.1 and 5.2 for locations of piezometers; All potentials in cm below *NAP*; Significant decreases or increases between periods in *italics*; Piezometer codes: location-depth, the latter being the depth of the filter in m below *NAP*;
! significantly decreasing during 3-year period; * new filter

5.3 The decrease of the hydraulic head in the aquifer, 1935-1975

The B-transect allows for a historical account of the decrease of the hydraulic head in the aquifer, as shown in Table 5.1. The numerical data for 1935-'37 reflect the situation before the reclamation of the Noordoost-Polder in 1940-'42. The rainfall does not show a significant trend during the 1935-'76 period. The following can be concluded:

(1) The reclamation of the Noordoost-Polder had a strong effect on the hydraulic head in the B4 and B5 filters, and a weaker effect in the B3 ones. The decrease in the B1 and B2 filters is due to other causes, such as the digging of the Steenwijk-Ossenzijl canal along the borderline

between De Weerribben and the IJsselham polder area, and the reclamation of polders within North-West Overijssel and the adjacent Frisian area. Between 1935-'37 and 1940 (not shown in the table), the hydraulic heads in B1a and B1b already fell to 27 and 45 cm below *NAP*, respectively.

(2) All filters show a trend towards a decreasing hydraulic head from 1952 to 1975. This trend probably results from combinations of various causes, such as the reclamation of polders within North-West Overijssel, the lowering of the water table in existing polders, and the increase of groundwater extraction.

(3) Since 1945 the B1, B2, and B3 filters all reflect a 'recharge profile', *i.e.*, the gradient in the hydraulic head enables a downward flow of groundwater towards the deeper parts of the aquifer. At the B4 location, such a situation only exists since ca. 1965. At the B2, B3 and B4 locations a 'discharge profile' was frequently observed until 1941. The difference between the hydraulic heads at ca 15 and ca 30 m below *NAP* was remarkably small, however. The hydraulic properties of the soil layer between the depths of the **a** and **b** filters having remained unaltered, any upward flow of water through that layer, before 1941, must have been less conspicuous than the present downward flow. At B5 a discharge profile existed before the reclamation of the Noordoost-Polder. The upper part of the profile became recharging afterwards. The hydraulic head decreased by more than 1 m, even at 120 m, however. An increase of the hydraulic head is seen in the B6 filters after 1953-'55. This was probably due to the introduction of water supply to the sandy soils in the border area of the Noordoost-Polder in 1949-'51 (Lindenbergh 1956).

5.4 The alteration of the hydraulic head gradient, 1935-1975

In order to summarize the alteration of the horizontal and vertical hydraulic gradients, the 1935-'37 and 1974-'75 data from the B-transect have been represented together in the diagram of Fig.5.3. Next to the terms 'discharge' and 'recharge' of the aquifer, 'exfiltration' and 'infiltration' are used here. The former denotes the transfer from groundwater to surface water, the latter the reverse. Before the reclamation of the Noordoost-Polder, the drainage control level, *i.e.*, de *boezem* water-level, in De Weerribben was slightly below the hydraulic head at 15 m below *NAP*, which, in turn, was slightly lower than the hydraulic head at 25 m below *NAP*. This situation, indicating a modest discharge, is shown by the 1935-'37 records in Fig.5.3. The gradient of the hydraulic head along the transect was remarkably level.

The occurrence and rate of exfiltration or infiltration of groundwater in De Weerribben not only depends on the hydraulic gradients, but also on the presence of resisting layers. Such a layer is notably present in the Schut- en Grafkampen area, where a clay cover had to be removed before the peat could be dredged. The clay was disposed of in already existing *petgaten*. As a result, the bottom of many *petgaten* in this area is now lined with clay. It is noteworthy that the *boezem* water level was 0.5 m below *NAP* until 1930, and even 0.3 m below *NAP* before 1920. Before 1920 it could only be controlled by discharge through sluices into the Zuyderzee at low tide.

The very level gradient before 1940 suggests that small local flow systems may have existed within the mire area, involving the transfer of water between the mire and the uppermost few meters of the underlying sand bed. From a survey of the chemical composition of the groundwater (Section 5.5) it appears that the B3 filters at 12 and 16 m below *NAP* contained water with a chloride content of 169-208 mg/l from 1935 to 1950 (10 samples), while a variation between 24 and 30 mg/l was found in the filters at 22 and 29 m below *NAP*.

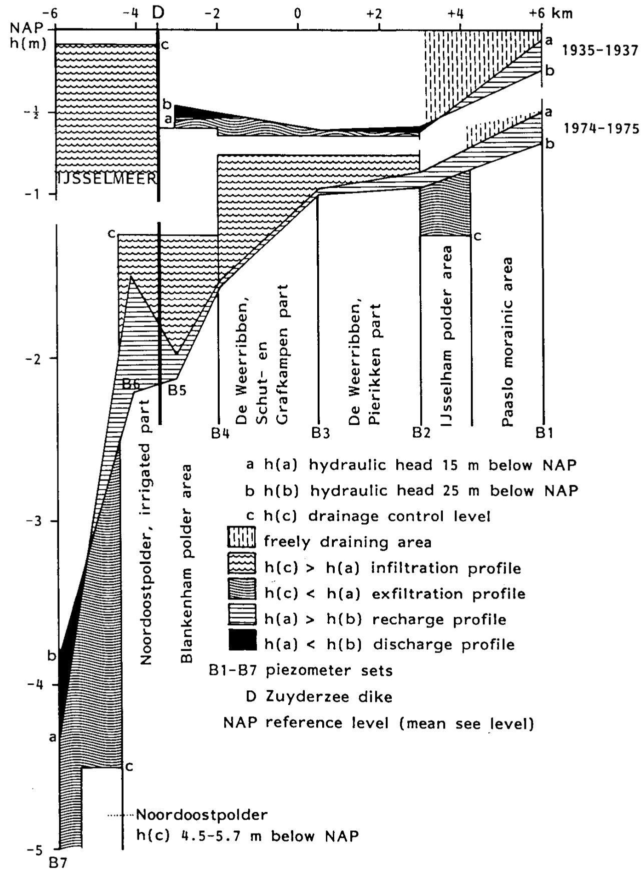


Fig.5.3 The alteration of the hydraulic head gradient in the B-transect, 1935-1975
The distance of the piezometers from the centre of the mire area has been indicated along the axis

This almost conclusively proves that brackish water, originating from floodings, was able to infiltrate into the sandy subsoil due to its higher density, and that the deeper fresh groundwater did probably not discharge in any substantial quantity into the mire area at the B3 location. The B2 and B4 filters contained fresh water in the same period.

In the 1974-'75 situation the gradient of the hydraulic head is steeper. Only in the Noordoost-Polder and in the IJsselham polder area is the drainage control level kept below the hydraulic head of the groundwater at a depth of ca 15 m below *NAP*, so that exfiltration may occur. As mentioned before, the hydraulic head in the IJsselham area is lower at 25 m below *NAP* than at 15 m: the exfiltration profile is a local phenomenon, superimposed on a deeper recharge profile which extends from the Paaslo morainic land to the Noordoost-Polder.

Extending conclusion (3) in Section 5.3, it is of some interest to include the much increased difference between the hydraulic head in the *boezem* and that in the body of groundwater in the underlying sand bed. It appears that any exfiltration of groundwater into the *boezem* in the early period must have been of a much smaller magnitude than the present infiltration. It is almost sure that the influx of fresh groundwater into the *boezem*, in historical times, was less important quantitatively than the discharge of surface water from neighbouring areas.

Table 5.2 Chloride and isotope analyses of groundwater in the B-transect, 1935-'82

Nm-dpth	'35	'37	'38	'40	'41	'42	'43	'44	'47	'50	'58	'61	'63	'74	'75	'79	'80	'80	'81	'82	^3H	^{14}C
B1a-10	52	55	52	39	32	28	26	23		26		(26)				29	48	30°	21		68.7	
B1t-17	33																					
B1b-25	29	29		31	32	32	30	29		38		(31)				27	37	50°	35		25.1	76.1
B2a-12	20	20	22		22	21	18		69							37	52	49°	56		60.1	
B2b-25	24	23			24	23			29								54	51°	47		76.9	112.5
LM187a-10																		115	110°		11.9	
LM187b-14																		330	335			
LM187c-29																		540	510°		<1.1	59.2
B3t-12	172																					
B3a-16		169	177	169	175	176	195	195	202	208				-new filter B3a-:		59	74	73°	73		56.6	
B3t-22	29													-new filter B3b-:		73	72	63°	62		45.1	71.8
B3b-29	27	26	27	26	25	27	28	24	29	30												
B4a-14	29	26		28	31	28	32	34		47												
B4a*-22																		-new filter B4a-:		74°	43.4	
B4b-30	32	28		32	34	33	33	27		44												
B4b*-50																		-new filter B4b-:		28°	<1.0	50.0
B5a-12	3656	3729	3727	3507	3564	3325	973	760	153	93			71	84		119	160	130°	130		56.7	
B5t-26	1424																					
B5b-30		1577	1597	1620	1630	1520	1480	1534	1275	1067			251	156		124	120	78°		76	32.3	79.6
B5t-39	1618																					
B5t-54	1547																					
B5t-69	1862																					
B5c-75		2127	2130	2143	2146	2137	2100	2087	1917	1815			1075	428			250	180				
B5t-90	2662																					
B5d-120	3251	2978	3337	3351	3318	3332	3243	3302	2995	3235			3150	3044			3000	2750°	2790		<1.6	67.7
B6a-10						2876	2955	3195	2245	1055	564						115	94°	100		42.9	
B6b-29						1250	1345	1333	(99	1540)	2060						820	339°	360		50.5	95.2
B6t-31						1278																
B7a-17						1048	909	335	129	284	576						1330					
B7b-27						122	119	115	177	212	334				1210							
B7t-34						233																

Depth in m below *NAP*; Cl^- in mg/l; ^3H in TU (Tritium Units); ^{14}C in % of recent concentration.
Notes: t temporary test-filter; * new filter; ° isotope analyses apply to this sample; () uncertain data.

5.5 Chemical composition and age of groundwater

The chloride content of the groundwater in the various filters has been rather frequently analysed. The pertaining data have been collected in Table 5.2 and in Fig.5.4, together with the results of ^3H and ^{14}C determinations made around 1980. W.G.Mook (pers.comm.) reported

Table 5.3 The chemical composition of groundwater in North-West Overijssel

smpl	date yymmdd	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	EC_{25} mS/m	IR %	x %	y %	pHsat	rLI %	rAT %	rTH %	rRH %	Ca %	Mg %	Cl %	Note
B1a (16D8): 10 m below NAP																						
B1a	370122	6.0?	8.0	3.9	40.7i	7.0?	55.3	19.5	28.8	26.8	20	0	-11	9.45	-20	49	8	51	16	13	63	1#
B1a	790905	6.0?	12.0	3.6	22.0	7.9	29.0	18.9!	44.8!	25.4	42	(0)	(2)	9.29	-4	62	14	53	29	15	40	2
B1a	80....	6.0?	18.0	12.0	26.0	8.0?	48.0	35.0	53.0	38.0	40	3	4	8.87	12	33	46	75	28	31	45	4
B1a	801119	5.9	13.0	9.0	16.0	8.0	30.0	19.0	60.0	27.6	43	-2	-3	9.26	-8	58	16	38	28	33	35	3
B1a	810827		9.5				21.0			26.5	45											5
B1b (16D8): 25 m below NAP																						
B1b	370123	6.2?	8.1	4.1	29.9i	10.0?	29.0	25.6	38.7	21.1	33	0	-16	9.32	-15	59	-5	36	20	17	40	1#
B1b	790905	6.2?	11.0	5.5	21.0	10.0	27.0	25.0	48.4!	22.1	42	(0)	-17	9.21	-10	63	-5	32	25	21	35	2
B1b	80....	6.2?	14.0	9.0	18.0	10.0!	37.0	26.0	49.0	28.0	40	(0)	-6	9.09	-1	49	17	51	28	30	42	4
B1b	801119	6.2	20.0	12.0	25.0	13.0	50.0	34.0	68.0	37.5	42	1	-6	8.84	6	43	38	66	29	29	42	3
B1b	810827		18.5				35.0			38.6	48											5
B2a (16D30): 12 m below NAP																						
B2a	370122	7.2?	48.0	5.5	19.6i	2.0?	20.4	191.5	tr.	32.9	81	-1	-12	7.71	95	-51	4	30	65	12	15	1
B2a	790905	7.2?	66.0	5.2	21.0	2.2	37.0	218.2!	4.0?	45.3	76	(0)	-3	7.54	97	-49	21	48	70	9	22	2
B2a	80....	7.2?	103.0	9.9	19.0	2.0?	52.0	400.0	<3.0	72.0	78	-8	1	7.12	98	-54	42	58	75	12	18	4
B2a	800918	7.2	105.0	18.0	24.0	2.0	49.0	374.0	4.0	71.8	79	2	-2	7.14	98	-56	43	58	67	19	18	3#
B2a	810827		115.0				56.0			74.0	78											5
B2b (16D30): 25 m below NAP																						
B2b	370122	7.2?	43.7	8.4	12.0i	1.0?	22.8	150.0	14.8	30.9	77	-0	-11	7.86	94	-49	3	30	64	21	19	1
B2b	80....	7.2?	100.0	9.4	22.0	1.0	54.0	366.0	<3.0	68.0	77	-6	-2	7.17	98	-53	39	57	74	12	20	4
B2b	800918	8.0	105.0	11.0	26.0	1.0	51.0	352.0	3.0	68.5	79	0	-2	7.16	98	-53	40	59	72	13	20	3
B2b	810827		112.0				47.0			67.3	81											5
B2b	880719	7.1	75.0	5.5	33.0	1.4	57.0	228.0	3.0?	56.4	70	2	1	7.47	94	-44	37	65	66	8	30	8
LM187a (16D41): 10 m below NAP																						
LMa	801119	6.7	108.0	13.5	83.0	3.0	115.0	440.0	9.0	97.2	63	-2	-5	7.08	82	-40	67	84	53	11	30	5
LMa	810309	6.8	108.0	13.0	88.0	3.0	110.0	471.0	7.0	108.2	64	-3	4	7.05	78	-39	75	86	52	10	28	6
LMa	820308	6.8	100.0	17.0	78.0	3.0	102.0	446.0	8.0	102.8	64	-2	5	7.11	80	-41	74	85	51	14	28	6
LMa	851206	6.6	127.0	17.2	61.4	2.8	83.0	514.0	2.0	101.7	73	-1	1	6.95	89	-48	66	77	60	14	22	6
LM187b (16D41): 14 m below NAP																						
LMb	801119	6.7	137.0	11.5	180.0	4.1	330.0	415.0	13.0	154.6	42	-2	-7	7.04	48	-16	88	98	44	6	57	5
LMb	810309	6.8	135.0	10.0	190.0	5.0	335.0	423.0	2.0	169.1	42	-1	1	7.04	46	-16	91	97	42	5	57	6
LM187c (16D41): 24 m below NAP																						
LMc	801119	6.7	275.0	20.0	165.0	4.1	540.0	455.0	15.0	215.3	47	-1	-9	6.75	46	-17	92	96	61	7	66	5
LMc	810309	6.8	262.0	18.0	150.0	4.0	510.0	476.0	1.0	243.1	48	-2	8	6.75	44	-19	96	93	62	7	65	6
LMc	820308	6.8	246.0	25.0	176.0	5.0	535.0	447.0	6.0	227.7	45	-1	-1	6.80	43	-17	95	95	55	9	67	6
LMc	851206	6.7	282.0	19.4	178.0	3.7	541.0	453.0	4.3	237.6	48	2	0	6.75	44	-18	95	95	60	7	67	6
B3a 1937 (16D14): 16 m below NAP, *B3a new piezometer (16D37): 15 m below NAP																						
B3a	370121	6.8?	163.0	5.7	98.4i	4.0?	169.0	494.0	2.3	123.8	63	-0	-3	6.88	76	-34	77	91	63	4	37	1
*B3a	790905	6.8?	90.0	5.3	47.0	1.6	59.0	322.1!	4.0?	68.5	73	(0)	-0	7.26	94	-46	45	68	64	6	24	2
*B3a	80....	6.8?	103.0	6.6	40.0	1.5?	74.0	368.0	<3.0	75.0	71	-4	-2	7.16	94	-47	48	69	69	7	26	4
*B3a	801119	6.8	98.0	5.8	36.0	1.4	73.0	300.0	7.0	65.1	70	-1	-8	7.26	95	-44	39	65	70	7	29	5
*B3a	810827		95.0				73.0			67.3	70											5
B3b 1937 (16D14): 29 m below NAP, *B3b new piezometer (16D37): 22 m below NAP																						
B3b	370121	7.0?	109.0	15.2	37.5i	2.0?	26.4	403.0	tr.	65.0	88	6	-13	7.10	99	-57	29	47	65	15	10	1
*B3b	790905	6.8?	114.0	6.5	46.0	3.2	73.0	377.2!	4.0?	79.5	73	(0)	-2	7.11	94	-47	51	71	68	7	25	2
*B3b	80....	6.8?	105.0	7.7	51.0	13.0?	72.0	434.0	<3.0	83.0	72	-4	-3	7.08	93	-49	53	70	62	8	22	4
*B3b	801119	6.8	117.0	7.2	47.0	2.4	63.0	410.0	13.0	77.3	77	-1	-8	7.06	96	-48	45	65	68	7	20	5
*B3b	810827		113.0				62.0			78.4	76											5
B4a 1937 (16D15): 14 m below NAP, *B4a new piezometer (16D51): 22 m below NAP																						
B4a	370216	7.0?	106.0	6.8	25.3i	1.0?	26.3	380.0	tr.	61.1	88	-0	-7	7.12	99	-54	26	45	76	8	11	1
*B4a	821026	6.9	122.0	8.7	51.0	1.5	74.0	435.0	5.0	88.3	75	-1	-0	7.03	93	-47	57	73	67	8	22	5
*B4a	880719	7.1	140.0	9.1	34.0	1.3	57.0	418.0	5.0	88.4	81	4	4	6.98	95	-50	55	70	76	8	19	8

smpl	date	pH	Ca	Mg	Na	K	Cl	HCO_3	SO_4	EC_{25}	IR	x	y	pHsat	rLI	rAT	rTH	rRH	Ca	Mg	Cl	Note
	yymmdd		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m	%	%	%		%	%	%	%	%	%	%	
B4b 1937 (16D15): 30 m below NAP, *B4b new piezometer (16D51): 50 m below NAP																						
B4b	370126	7.0?	105.1	8.3	16.7	1.0?	28.2	360.0	0.8	62.9	87	-0	-1	7.15	100	-56	31	48	78	10	12	1
*B4b	821026	7.0	106.0	8.0	12.5	1.3	28.0	350.0	7.0	61.8	87	-1	-2	7.16	100	-55	30	47	81	10	12	5#
B5a (16D1): 12 m below NAP																						
B5a	370128	7.5?	293.0	91.7	2286.0i	40.0?	3729.0	965.0	35.4	1282.6	12	0	8	6.62	29	-15	100	85	12	6	86	1
B5a	630327	7.9	58.0	15.0	67.0i	30.0?	71.0	256.0	38.5	66.6	59	0	-9	7.55	85	-43	58	77	41	18	29	1a
B5a	790905	7.8?	53.0	17.0	66.0	28.0	119.0	217.9!	35.0?	79.5	44	0	-2	7.67	60	-25	76	94	35	19	44	2
B5a	80....	7.5?	57.0	24.0	81.0	25.0?	160.0	314.0	<3.0	91.0	39	-4	-6	7.49	60	-31	73	90	32	22	46	4
B5a	801119	7.5	63.0	17.0	75.0	25.0	130.0	290.0	30.0	87.2	46	-3	-4	7.48	66	-29	75	92	37	17	41	3#
B5a	810827		62.0				130.0			88.3	46											5
B5a	880719	7.5	55.0	19.5	58.0	2.6	74.0	282.0	6.0	67.4	57	1	-1	7.53	81	-44	53	74	39	23	31	8
B5b (16D1): 30 m below NAP																						
B5b	370126	7.5?	222.0	225.0	525.0i	30.0?	1577.0	398.0	73.3	560.2	20	0	6	7.02	29	-15	99	87	21	36	85	1
B5b	630327	7.3	112.0	14.4	215.0i	30.0?	251.0	427.0	94.3	149.5	44	0	-10	7.12	47	-14	89	97	35	7	44	1a
B5b	790905	7.5?	65.0	14.0	67.0	37.0	124.0	164.8!	100.0?	86.1	48	0	-6	7.71	50	-7	84	99	39	14	42	2
B5b	80....	7.0?	152.0	33.0	100.0	4.0?	120.0	356.0	238.0	138.0	69	2	-5	7.08	58	-15	90	91	51	19	24	4
B5b	801119	7.0	155.0	28.0	85.0	4.0	78.0	332.0	350.0	127.0	78	-4	-14	7.10	58	-5	83	83	56	17	15	3#
B5b	821026	6.9	183.0				76.0			127.0	81											5
B5c (16D1): 75 m below NAP																						
B5c	370126	7.0?	350.0	44.8	1113.0i	30.0?	2127.0	376.0	168.5	728.6	23	0	3	6.87	29	-13	100	87	25	5	86	1#
B5c	630327	7.2	272.0	33.6	532.0i	10.0?	1075.0	531.0	12.2	393.4	31	0	-3	6.75	32	-13	98	91	34	7	77	1a
B5c	80....	7.0?	143.0	13.0	98.0	3.0?	250.0	448.0	<3.0	126.0	50	-7	-9	6.98	66	-27	80	95	57	9	49	4
B5c	801119	6.9	130.0	16.0	94.0	3.0	180.0	442.0	30.0	121.4	56	-4	-3	7.02	70	-30	82	93	54	11	39	3#
B5d (16D1): 120 m below NAP																						
B5d	370126	7.0?	211.0	192.0	1652.0i	40.0?	2978.0	275.0	388.0	1174.4	11	1	18	7.28	29	-15	100	84	11	16	87	1#
B5d	630327	7.3	208.0	196.8	1744.0i	40.0?	3150.0	305.0	347.5	1005.3	10	1	0	7.25	28	-14	100	85	10	16	88	1a
B5d	80....	7.0?	300.0	175.0	1550.0	40.0?	3800.0	387.0	158.0	905.0	12	-9	-19	6.99	27	-13	99	87	15	15	92	4
B5d	801119	6.9	305.0	140.0	1350.0	42.0	2750.0	380.0	300.0	913.1	16	-2	4	6.97	29	-14	100	86	18	13	86	3
B5d	810827		295.0				2790.0			828.1	16											5
B6a (16D2): 10 m below NAP																						
B6a	421111	7.3?	149.0	111.0	1709.0i	40.0?	2876.0	324.0	247.0	923.1	8	-0	1	7.34	28	-13	100	86	8	10	89	1
B6a	581103	7.3	83.5	67.4	375.0i	30.0?	564.0	380.0	196.3	248.5	21	-0	-9	7.36	27	-7	96	92	16	22	61	1a
B6a	80....	7.4?	60.0	13.0	68.0	20.0	115.0	279.0	3.0	77.0	48	-2	-3	7.50	72	-35	64	86	40	14	41	4
B6a	801007	7.4	66.0	12.0	62.0	20.0	94.0	224.0	73.0	81.7	55	-2	1	7.56	68	-21	79	94	44	13	34	3
B6a	810827		107.0				100.0			103.8	66											5
B6t (16D2): test filter 31 m below NAP, B6b (16D2): 29 m below NAP																						
B6t	421021	7.3?	349.0	17.0	516.0i	30.0?	1278.0	386.0	tr.	408.6	33	-1	-7	6.79	31	-12	98	92	42	3	85	1
B6b	421022	7.3?	368.0	16.7	496.0i	30.0?	1250.0	376.0	16.1	414.1	34	-0	-5	6.78	32	-12	98	91	44	3	84	1
B6b	581103	7.1	426.5	38.3	947.0i	30.0?	2060.0	427.0	75.4	574.0	27	-1	-17	6.73	29	-12	99	90	32	5	87	1a
B6b	80....	7.2?	100.0	40.0	360.0	30.0?	820.0	465.0	<3.0	244.0	18	-11	-22	7.19	28	-7	92	94	20	13	75	4
B6b	801007	7.2	86.0	33.0	220.0	31.0	339.0	460.0	27.0	185.5	31	-1	3	7.21	39	-16	94	94	25	16	54	3
B6b	810827		86.0				360.0			171.1	30											5
Oss: irrigation well in reed bed, 15 m below NAP (geohydrological code not yet available), test filter 6 m below NAP																						
Oss-06	880427	6.2	12.0	2.0	64.0	1.6	48.0	98.0	12.0	40.9	31	6	12	8.59	28	5	30	64	17	5	42	8
Oss-15	880613	6.8	105.0	7.7	120.0	2.9	170.0	415.0	14.0	114.9	52	-3	-1	7.13	66	-26	79	94	47	6	40	8
Oss-15	880720	6.6	125.0	8.2	130.0	1.7	165.0	450.0	5.0	119.4	57	2	-3	7.02	69	-29	79	93	49	5	38	8

Next to the piezometer `B' codes, the codes used in the Geohydrological Archive have been indicated, along with the approximate depth of each filter in m below NAP

Explanation of items: Appendix D; x electro-neutrality error; y conductivity error; pHsat pH at which satured with respect to calcite, at 10°C; Ca, Mg, Cl (%) f(c)1/2Ca^{2+}, f(c)1/2Mg^{2+}, and f(c)Cl^-, respectively; () Results from assumptions made to compute missing values; ? Assumed value; ! Calculated from electro-neutrality or conductivity, or from both; i (Na+K), given as mg/l of Na; tr trace

Notes: 1 By RID for Dienst Zuiderzeewerken (archives); pH and K assumed, Na includes K (determined by analysis); 1a As 1, but pH computed from free CO_2 and HCO_3; 2 By Waterlaboratorium Zwolle for Zuiveringschap West-Overijssel (pers.comm.); pH and either one of HCO_3 and SO_4 assumed, the other one computed; 3 By Waterlaboratorium Oost for Dienst Waterhuishouding en Waterbeweging and for RIN (present survey); 4 By Oranjewoud Consulting Engineers for DGV-TNO (Uil & De Heer 1985); pH and K assumed; 5 By Waterleidingbedrijf Midden-Nederland for RIN (present survey); 6 By RIVM, groundwater monitoring network; 8 By Waterlaboratorium Zwolle for Zuiveringschap West-Overijssel (pers.comm.); # Maucha diagram in Fig.5.5

Table 5.4 Additional analytical data for groundwater in North-West Overijssel

Sample	Date	NO_3	NH_4	orgNH_4	$KMnO_4$	PO_4	P_{tot}	SiO_2	Fe	Mn	CO_2	^3H	^{14}C	Conversions	
	yymmdd	<----------N, mg/l--------->mg/l			<---P, mg/l---->		mg/l	mg/l	mg/l	mg/l	TU	%	N,P		KMnO4
B1a	801119	0.07	0.05	0.19	12	<0.01		15	1.7	0.20	38	68.7		x	
B1b	801119	2.03	0.02	0.08	4	<0.01		17	0.07	0.45	35	25.1	76.1	x	
B2a	800918	<0.02	3.42	0.68	119	0.15		27	18	0.49	38	60.1		x	
B2b	800918	<0.02	0.93	0.09	38	0.10		27	10	0.40	6	76.9	112.5	x	
	880719	<0.05	0.6	0.7		0.27	0.28								
LM187a	801119	0.14	6.92			0.43		20	18					x	
	810309	<0.1	(8.2	= 8.2)	57		0.83					11.9			x
	820308	0.1	(8.9	= 8.9)	62		0.14								x
	851206	<0.3	10.2				0.9								
LM187b	801119	0.09	6.07			0.30		20	19					x	
	810309	<0.1	(7.2	= 7.2)	52		0.46								x
LM187c	801119	<0.02	3.11			0.02		27	17						
	810309	<0.1	(2.9	= 2.9)	17		0.20					<1.0	59.2		x
	820308	<0.1	(4.3	= 4.3)	14		0.01								x
	851206	<0.3	4.07				0.19								
B3a	801119	0.07	3.19			0.30		19	10			56.6		x	
B3b	801119	0.02	2.41			0.04		26	13			45.1	71.8	x	
B4a	821026	0.02	4.05			0.01			21			43.4		x	
	880719	<0.05	3.3	0.1		0.06	0.27								
B4b	821026	0.05	1.17			<0.01			19			<1.0	50.0	x	
B5a	630327	0.0	1.24		60	0.40		19	0.84	0.27	8			x	
	801119	0.16	2.18	0.52	50	0.90		26	0.65	0.58	14	56.7		x	
	880719	<0.05	3.2	0.9		0.95	1.4								
B5b	630327	0.0	2.88		48	0.25		33	7.5	0.33	49			x	
	801119	0.18	2.80	0.48	35	0.25		24	11	0.71	60	32.3	79.6	x	
B5c	630327	tr.	4.20		40	0.28		24	26.4	0.62	83			x	
	801119	0.18	2.18	0.26	31	0.30		30	12	0.56	86			x	
B5d	630327	tr.	3.03		43	0.47		30	15.0	0.80	39			x	
	801119	0.27	3.50	1.40	42	0.47		26	17	1.9	86	<1.6	67.7	x	
B6a	421111								1.6						
	581103	0.0	6.69		118	1.33		39	14.3	0.47	46			x	
	801007	0.77	1.40	0.26	18	0.70		21	13.4	0.39	15	42.9		x	
B6t	421021								30						
B6b	421022								8.4						
	581103	0.0	6.85		41	0.50		26	44.8	1.9	91			x	
	801007	0.59	7.78	0.46	68	1.00		34	16	0.51	50	50.5	95.2	x	
Oss-06	880427	0.09	3.6	1.0			0.53								
Oss-15	880613	<0.05	7.9	2.1			0.32								
Oss-15	880720	<0.05	8.0	0.9		0.08	0.30								

x marks conversions applied
Laboratories: see notes in Table 5.3; ^3H and ^{14}C by Isotope Physics Laboratory, University of Groningen, for RIN
NO_2 concentrations (mg/l) all <0.02 (Waterlaboratorium Oost), <0.01 (Waterleidingbedrijf Midden-Nederland), "0" (RID), or included in NO_3 (Waterlaboratorium Zwolle)

the age of the relevant groundwater samples. Further data with respect to the chemical composition of the groundwater in the B transect are available for 1937, 1980-'82, and some other years. They have been summarized in Tables 5.3 and 5.4 and in the EC-IR, rTH-rLI, and Maucha diagrams of Fig.5.5-5.6. But little attention is being paid here to the 1979 results. Their position is often more or less intermediate between the 1937 and 80-'82 ones, but this may be due to difficulties met while emptying the piezometers prior to sampling.

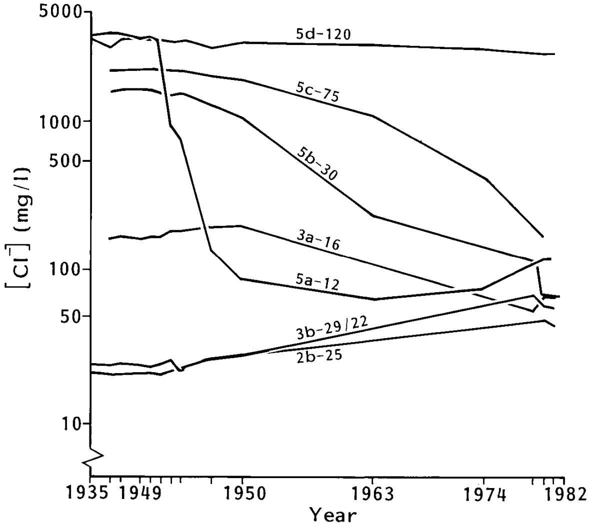


Fig.5.4 Variation of the chloride concentrations at some locations in the B-transect
Note the logarithmic scale for the chloride concentrations

The results of this part of the survey are summarized below:

B1 (Paaslo morainic area)

Of all samples, the B1 ones are the most similar to rain water, although the IR and EC values are somewhat higher. The samples are definitely unsaturated as regards calcite. The chloride content at 10 m below *NAP* decreased from ca 50 mg/l in 1935-1938 to 20-30 mg/l afterwards. This may be due to a decreased chloride content in the precipitation since the IJsselmeer became a freshwater lake in 1932. The filter at 25 m below *NAP* shows a variation of the chloride content around 30 mg/l. The ^{3}H figures indicate that in 1980 both filters contained water that must have infiltrated after 1960.

The sulphate concentrations in the B1 samples are much higher than those in most other samples, and they almost doubled between 1937 and 1980. The magnesium concentration also showed a notable increase. This possibly reflects the application of manure and fertilizers.

B2 (Border between De Weerribben mire and IJsselham polder areas)

The 1937 analytical results reflect a lithotrophic type of groundwater, possibly a stage of development between freshly infiltrated rain water and aged groundwater, such as found in the B3b (1937) and B4 piezometers (Fig.5.5). The recent samples reveal a notable increase of the overall concentration, which is mainly due to the calcium and bicarbonate concentrat-ions. The chloride content in both B2 filters was 20-25 mg/l until 1944. The present values (1981-1982) are ca 50 mg/l. In 1980 both filters contained water that must have infiltrated after 1960. The increased chloride content may be due to local influences including the infiltration of *boezem* water.

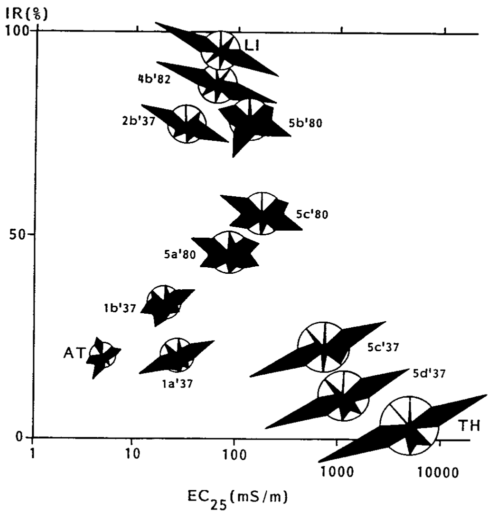


Fig.5.5 Maucha diagrams of representative groundwater analyses arranged in an EC-IR diagram

LI, AT, TH: benchmark samples for litho-, atmo-, and thalassotrophic water, respectively (see Appendix D)

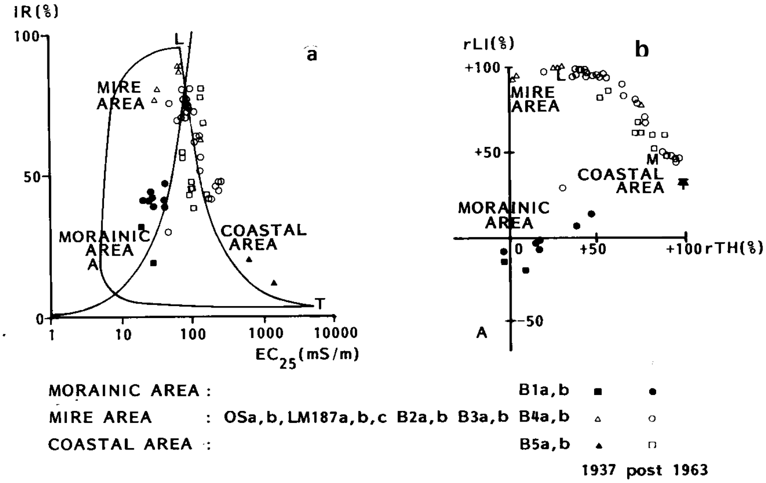


Fig.5.6 EC-IR (a) and rTH-rLI (b) diagrams of groundwater analyses above ca 40 m below *NAP*, showing the decreasing variation between 1937 and ca 1980

L, A, T, M: litho-, atmo-, thalasso-, and molunotrophic benchmark samples; Mixing contours and the line IR(%)=EC_{25}(mS/m) added to Fig.5.6a for convenience (see Appendix D)

The local infiltration involves a steady supply of carbonic acid, produced in the root zone of the pastures in this area, which facilitates the solution of calcium in the sand bed. The recent B2b samples are only slightly supersaturated in calcium and bicarbonate, especially due to the high pH. *In situ* the calcium concentrations should possibly be considered to be just saturated.

LM187 (Pierikken area)

These filters were installed in 1980. The chloride contents of the water were consistently high: ca. 110, 330, and 500 mg/l at depths of 10, 14, and 24 m, respectively. According to the isotope determinations, which were only carried out in the 10 and 24 m filters, the deepest filter contains water that may be about 2000 years old. The water in the filter at 10 m has probably in part infiltrated before 1960. It is rather similar to recent Rhine water (see rRH in Table 5.3), but there is certainly no genetic relation with the latter. There may be some connexion with a body of fossil brackish groundwater which was mapped by Senden (1980) on the basis of geo-electrical surveys. The well 'Oss' drilled in 1988 in the Schut- en Grafkampen part of the mire area, near Ossenzijl, also provides slightly brackish water. The situation shows, anyway, that there was probably no discharge of fresh groundwater from a regional groundwater flow system at this location in historical times.

B3 (Centrally in De Weerribben mire area)

As referred to before (Section 5.4), the B3 filter at 16 m below *NAP* contained water with a chloride content of 169-208 mg/l from 1935-1950, while the chloride content at 29 m below *NAP* varied from 24-30 mg/l. The higher values are confirmed by the analysis in the test filter at 12 m, 1935. The slightly brackish B3a sample from 1937 is not very different from the recent LM187a samples. The same final conclusion seems justified: there was probably no regional groundwater discharge in historical times. The B3b sample is very similar to the lithotrophic water found in the B4a piezometer in 1937 and in the B4b piezometers in 1937 and 1982. The latter must be considered to be aged fresh groundwater. Note, however, that the magnesium concentration in B3b is higher than in B4.

The filters were not maintained after 1950. In 1974, however, new filters were installed at a distance of ca 200 m from the original location. The variation of the chloride content in the new filters was 59-73 mg/l, and, in 1980, both filters contained water that must have infiltrated after 1960. The origin of this infiltration water is probably the *boezem*.

B4 (Border between De Weerribben mire and Blankenham polder areas)

The chloride content of the water in the B4 filters varied around 30 mg/l from 1935 to 1944. The 1950 values are slightly higher: ca. 45 mg/l. The filters were removed in 1977. New filters were installed nearby in 1982. The 1982 water samples from 22 and 50 m below *NAP* contained 74 and 28 mg/l of chloride, respectively. The water in the 22 m filter had very recently infiltrated (after 1960). The deeper groundwater, however, has a low ^{14}C content (50.0 %), and its age was estimated as slightly less than 4000 years. It is a strongly lithotrophic type of water in equilibrium with calcium carbonate.

B5 (Blankenham polder area)

As shown in Fig.5.4 the chloride content in the B5 filters exhibits a very regular variation. The original brackish water is gradually being replaced by fresh water. At a depth of 12 m below *NAP* the freshwater stage was reached around 1950. At 30 m below *NAP* it may have been reached in 1981, while the desalinization process is still under way at 75 m below *NAP*. The chloride content in the groundwater at a depth of 120 m below *NAP* only shows a slight decrease. The isotope concentrations in the 1981 sample of this deep water indicate an age between 30 and 1000 years; this brackish water obviously infiltrated from the former Zuyderzee. Samples from the 12 and 30 m filters were also subjected to isotope analyses. The results reveal that the brackish groundwater is being replaced by locally infiltrated water of recent (post-1960) origin, rather than by aged groundwater. The B5b samples are especially remarkable for their high and still increasing sulphate concentrations.

B6 and B7 (Noordoost-Polder)

The variations of the chloride concentration in water samples from the B6 and B7 filters, with the exception of the B6 10 m filter, demonstrate an increase following the sharp decrease immediately after the reclamation of the Noordoost-Polder. In the B6 30 m filter this increase is in turn followed by a decrease, which may be due to the supply of fresh water in this part of the Noordoost-Polder. A further discussion of the chemical composition of the B6 and B7 samples lies outside the scope of the present study.

Conclusion

It is apparent from these data that the fall of the hydraulic head in the body of groundwater under the mire area has caused a local, ongoing infiltration of *boezem* water to a considerable depth. This water is mainly of external origin, being supplied to the *boezem* via the surface water system. Only the B4 50 m filter contained aged freshwater which may have infiltrated during the growth phase of the virgin mire, in the Subboreal period. The body of groundwater under De Weerribben comprises one or more local pockets of brackish water which may have been more important before the Noordoost-Polder was reclaimed.

From the young age of the groundwater at 20-25 m below the present mire surface the rate of infiltration can be estimated at more than 1 mm/d, assuming a porosity of 30% in the sand bed. Since, from Table 5.1, the average difference between the hydraulic heads in De Weerribben and its surroundings (Paaslo, Noordoost-Polder) is ((0.5-0.75)+(4.5-0.75))/2 = 1.75 m, while it was roughly -0.5 m from 1920 until 1941, the average rate of exfiltration may have been about 0.3 mm/d in that period. This corresponds with a 6 m upward movement of the groundwater in 20 years. Similarly, for the period 1889-1920 (hydraulic head difference -0.35 m) the upward movement may also be estimated at 6 m. These very rough estimates show that the earlier influence of slightly brackish water may indeed have long persisted before the deep polders were reclaimed. The polder Wetering-West, bordering De Weerribben in the southeast, still discharges water with a raised chloride concentration.

With respect to the question of exfiltration of groundwater into the mire, the calcium and bicarbonate concentrations provide another clue. The fresh groundwater is saturated with calcium ions at a concentration of 100-120 mg/l. Since the bicarbonate concentrations in the groundwater are consistently high, the carbonic acid content at the prevailing pH values are also high and must drop considerably when the water becomes exposed to the atmosphere. This should have resulted in the precipitation of calcium carbonate, but no traces of such calcareous deposits have ever been reported from the peat in this area. This seems to confirm that exfiltration of groundwater will not have been a significant phenomenon within the area as a whole.

The increased local infiltration of *boezem* water is clearly demonstrated in Fig.5.6. Obviously atmotrophic, lithotrophic, and thalassotrophic samples are rare in the collection of recent samples. This is partially due to the changed composition in the B1 and B5 piezometers. When only B2, B3, and B4 are considered, however, it is still obvious that the plotting field for the recent samples is narrowed to a rather uniform type somewhere between the lithotrophic and the molunotrophic (Rhine water) benchmark. Its still relatively high IR is due to the dissolution of calcium from the sand bed.

5.6 The chemical composition of *boezem* water in the 1970s and 80s

Introduction

The surface water in the main canals of the *boezem* was repeatedly sampled and analysed in a sampling program 'Weerribbennet' (WRNET) from 1972 to 1982. The aims were:

1) A characterization of the chemical composition of the *boezem* water;
2) An identification of the origin of the *boezem* water;
3) More specifically: an answer to the question in how far groundwater influx could modify the *boezem* water composition;
4) During the course of the investigations a description of the influence of water supply during dry seasons was identified as an additional aim.

The Weerribbennet program was undertaken as a joint effort of the Research Institute for Nature Management (RIN, field sampling) and the Hugo de Vries Laboratory of the University of Amsterdam (HdV-Lab, chemical analyses). Originally 20 sampling stations were selected for bimonthly sampling (Fig.5.8). Since the sampling stations nrs. 3 and 19 were abandoned during the course of the study, and since the bimonthly scheme could not be strictly followed, 801 analyses became available, covering 46 dates. The analyses will be referred to by a number **s.d**, where **s** is the station number (WRN1-WRN20), and **d** is the sampling day number (1-46). A selection of results is presented in Tables 5.5 and 5.6. They were processed with the MAION program (Appendix D). It appears that the station-average values (Table 5.6) are fairly similar although remarkable differences may exist on single sampling dates. For this reason the spatial comparison made hereafter is primarily based on patterns of variation with time.

The analysis of calcium concentrations often failed in 1973-'74. Only 614 samples passed the MAION electroneutrality test with a rejection limit of 8% for the absolute value of (cations - anions) as compared to (cations + anions). Values for the electrical conductivity (EC_{25}) and the chloride, phosphorus and nitrogen concentrations have been regarded correct for all samples; all other analytical results have only been considered for the 614 above-mentioned samples. In addition to the calculation of the ionic ratio IR for these samples, an estimation of IR was made for all 801 samples available, using the MAION relation:

$IR_{Cl}(\%) = 100 - 1380\ ([Cl^-] / EC_{25})$ (Appendix D).

Table 5.5 Average analytical results for WRNET sampling dates

s	n=	date	pH	Ca	Mg	Na	K	Cl	HCO_3	SO_4	EC_{25}	IR	x	y	pHsat	rLI	rAT	rTH	rRH	Ca	Mg	Cl
		yymmdd		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mS/m	%	%	%		%	%	%	%	%	%	%
1	(18)	720500	7.0	66.2	8.6	31.9	4.4	57.6	188.8	33.3	56.3	68	1	-1	7.62	90	-35	44	72	60	13	30
2	(17)	720700	7.0	47.6	8.5	29.4	3.4	50.8	148.9	37.1	48.1	62	-2	?	7.86	86	-27	40	71	53	16	31
4	(18)	721130	6.8	51.2	12.7	33.2	5.5	51.1	88.8	93.6	53.0	64	4	-4	8.06	61	3	51	76	50	20	30
5	(18)	730100	7.0	60.4	12.1	38.3	4.9	62.7	138.3	59.1	59.0	63	5	0	7.80	75	-17	58	85	52	17	34
7	(2)	730529	7.5	34.5	10.0	30.5	4.0	50.5	152.5	32.0	47.3	55	-7	4	7.97	83	-29	45	73	44	21	31
10	(15)	740128	7.1	25.6	17.3	41.4	8.5	61.1	89.1	99.1	60.3	43	-5	7	8.35	34	14	74	85	27	30	33
11	(6)	740402	7.5	33.5	13.7	41.0	6.2	62.0	132.2	78.0	67.3	49	-7	17	8.07	55	-7	81	91	37	24	31
12	(9)	740809	7.5	45.6	10.8	48.6	4.4	83.0	149.8	41.0	59.2	51	-3	0	7.87	66	-16	57	86	43	17	40
13	(16)	741107	7.4	48.6	14.2	41.3	5.1	68.1	130.4	69.9	60.3	55	0	2	7.92	64	-10	64	88	44	21	36
14	(17)	750314	7.9	40.6	14.2	42.2	7.2	57.9	116.3	84.2	60.7	56	-1	6	8.04	58	-2	71	89	39	22	31
15	(6)	750514	8.0	39.5	10.3	28.8	4.3	44.3	136.2	59.3	50.7	62	-6	6	7.96	81	-18	55	79	47	21	27
16	(18)	750800	7.6	50.4	13.3	83.8	7.6	150.9	122.3	64.8	86.2	37	-1	3	7.94	36	3	80	99	34	15	56
17	(15)	751020	7.4	51.1	13.5	69.9	5.6	128.7	146.0	54.9	80.6	43	-2	5	7.86	48	-6	76	96	38	16	50
18	(18)	760121	7.2	56.9	17.0	46.7	6.3	75.7	102.0	103.8	70.7	57	4	4	7.98	50	2	76	91	44	22	36
19	(9)	760405	7.3	44.9	13.7	37.3	5.2	61.2	152.5	71.8	62.8	57	-5	7	7.87	71	-15	71	89	44	22	30
20	(18)	760600	8.0	47.9	15.3	87.6	7.8	155.6	119.6	76.6	91.2	36	-2	5	7.98	33	4	83	99	31	17	55
21	(18)	760800	7.8	56.9	18.0	143.2	9.4	262.2	119.0	89.8	126.3	28	-2	3	7.93	24	4	88	97	26	14	66
22	(12)	761000	7.4	52.2	13.2	87.0	5.4	148.3	186.1	50.6	87.9	39	-5	2	7.75	47	-8	77	97	35	14	50
23	(17)	770223	7.2	72.4	26.2	65.8	7.8	111.8	99.0	165.9	92.6	54	4	0	7.93	39	5	84	91	41	24	38
24	(18)	770426	7.3	55.3	15.9	48.1	9.3	80.5	142.3	93.2	71.3	56	-1	2	7.84	61	-8	74	90	44	20	34
25	(7)	770929	7.5	40.3	11.3	44.6	4.0	78.9	156.9	44.9	59.3	48	-7	3	7.90	67	-16	60	87	41	19	38
26	(15)	780309	7.3	46.9	13.6	43.6	5.0	73.0	140.3	74.0	59.7	53	-3	-3	7.90	65	-5	63	90	43	21	35
27	(14)	780512	7.7	43.4	12.4	41.4	9.0	68.4	130.7	77.4	63.1	53	-4	6	7.96	62	-6	74	93	42	20	34
28	(16)	780724	6.9	43.8	12.9	61.0	6.8	108.8	119.3	63.1	68.4	42	-2	0	8.00	44	3	71	97	36	18	48
29	(9)	781103	8.1	52.4	10.8	42.6	4.6	81.4	175.5	45.0	63.4	60	-6	3	8.71	84	-23	62	94	54	18	41
30	(15)	790412	6.7	44.3	12.1	33.5	7.6	59.7	95.2	78.3	52.8	57	0	-2	8.12	56	7	56	83	46	21	34
31	(15)	790613	6.9	47.9	11.1	34.7	4.2	54.3	119.6	56.0	48.3	61	3	-7	7.95	75	-12	43	77	48	19	33
32	(18)	790831	7.3	73.9	9.4	34.3	2.5	65.7	204.4	32.6	54.7	67	2	-12	7.56	89	-33	35	66	61	13	31
33	(17)	791024	7.3	72.6	9.0	31.7	3.4	64.0	196.6	29.8	56.9	67	2	-5	7.58	90	-35	41	70	62	13	31
34	(18)	800306	7.1	54.1	12.3	31.3	6.8	48.9	115.2	79.3	53.5	66	4	-3	7.96	69	-4	53	77	51	20	28
35	(17)	800412	8.4	74.5	8.9	32.2	4.2	59.2	195.9	44.7	60.8	69	1	-1	7.57	89	-32	49	74	62	13	28
36	(18)	800716	6.8	48.3	10.1	35.0	5.4	63.6	126.1	39.8	49.2	57	2	-5	7.93	75	-18	44	79	49	17	38
37	(15)	800912	7.5	69.1	8.2	31.8	3.7	63.1	192.4	35.1	56.5	66	0	-4	7.61	89	-32	42	71	61	12	31
38	(7)	801128	7.0	51.4	12.7	29.0	8.2	45.7	94.1	76.6	49.4	67	7	-5	8.03	68	-6	45	71	51	20	29
39	(13)	810313	6.8	39.6	8.6	22.1	7.8	33.2	72.3	70.2	37.3	68	4	-11	8.27	62	9	24	55	51	19	26
40	(11)	810604	7.0	80.4	10.2	34.5	2.9	65.2	204.1	34.5	60.3	69	5	-6	7.52	89	-35	44	71	63	13	31
41	(17)	810730	7.1	75.2	7.3	28.8	2.9	52.8	179.1	33.6	52.8	72	5	-6	7.58	91	-34	35	65	66	11	29
42	(17)	811210°	6.6	40.3	11.9	26.3	6.6	42.2	87.2	61.4	34.6	63	5	-30	8.15	64	0	9	49	47	23	31
43	(16)	820318	6.9	45.3	12.8	27.6	7.9	43.0	86.2	76.4	50.0	65	6	1	8.14	63	-2	53	76	48	22	29
44	(18)	820527	7.0	75.7	8.9	32.9	3.8	60.2	204.0	32.2	60.2	69	3	0	7.55	90	-36	47	73	62	12	29
45	(17)	820918	6.7	57.8	14.2	79.5	8.0	143.7	133.8	59.8	78.3	42	2	-6	7.84	42	1	72	98	37	15	54
46	(18)	821021	7.7	65.8	11.7	55.3	5.9	108.2	169.4	46.7	67.1	52	0	-9	7.69	65	-14	59	90	48	14	45

The values in the columns IR-Cl(%) represent averages too, they differ slightly from values computed on the basis of the average concentrations

Explanation of items: Appendix D; x electro-neutrality error; y conductivity error; pHsat pH at which satured with respect to calcite, at 10°C; Ca, Mg, Cl (%) $f(c)_{1/2}Ca^{2+}$, $f(c)_{1/2}Mg^{2+}$, and $f(c)Cl^{-}$, respectively

° In the 811210 samples EC measurements were systematically in error

The data from the water analyses show much redundancy. A separate analysis of correlations was carried out for time series and for spatial patterns. In order to extend the analysis of the time series over the period 1982-'87 chloride and conductivity data reported by the regional water quality board (Zuiveringschap West-Overijssel 1981-'88) for the sampling station Kalenberg, have been used.

In Section 5.7 comparison is made between the WRNET results and earlier analyses, selected from reports and RIN archives.

Table 5.6 Average analytical results for WRNET sampling stations

station	n=	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	EC_{25} mS/m	IR %	x %	y %	pHsat	rLI %	rAT %	rTH %	rRH %	Ca %	Mg %	Cl %
1	(27)	7.2	62.8	12.0	50.0	5.1	89.9	165.2	52.2	67.5	56	1	-1	7.75	69	-17	60	86	49	16	39
2	(35)	7.2	54.4	12.2	48.5	5.8	84.1	146.1	55.4	63.9	55	1	0	7.85	66	-13	59	85	46	17	38
4	(35)	7.2	51.9	11.8	47.9	6.0	83.2	139.3	56.9	62.7	54	0	0	7.89	65	-12	59	85	45	17	39
5	(30)	7.2	64.9	12.7	50.1	5.5	90.5	168.8	58.8	69.2	56	1	-1	7.74	68	-16	61	85	49	17	38
6	(31)	7.3	65.7	13.4	50.1	5.8	89.5	173.2	65.4	70.1	58	0	-2	7.73	68	-15	62	84	49	17	36
7	(35)	7.3	56.8	12.5	49.5	5.9	88.2	148.3	62.3	65.6	55	0	-2	7.83	65	-11	60	85	46	17	38
8	(36)	7.2	52.1	12.6	48.2	5.8	83.8	140.6	62.5	64.2	54	0	0	7.88	64	-11	61	85	45	18	38
9	(38)	7.1	51.6	12.2	45.4	5.6	78.7	136.3	60.8	61.5	55	0	-1	7.91	63	-9	57	82	46	18	37
10	(37)	7.2	53.1	12.8	45.6	5.7	79.6	133.5	67.5	62.4	56	0	-1	7.91	63	-9	57	81	46	18	36
11	(37)	7.1	51.3	13.4	44.7	6.1	77.2	117.4	76.0	62.4	56	1	0	7.98	59	-5	58	81	45	19	36
12	(35)	7.3	49.1	12.6	47.3	6.0	81.8	120.8	68.6	62.5	54	0	0	7.97	59	-5	60	84	44	19	38
13	(37)	7.2	48.8	12.8	45.8	6.2	79.3	115.9	71.5	61.3	55	1	0	7.99	60	-5	58	82	45	19	37
14	(33)	7.2	52.2	13.8	48.0	6.7	81.0	122.0	78.1	64.1	57	1	-1	7.96	57	-5	58	79	45	19	36
15	(35)	7.5	56.1	13.3	46.7	5.9	77.0	143.3	71.9	64.2	59	1	-1	7.84	66	-14	56	78	49	18	34
16	(33)	7.3	53.7	13.1	46.7	6.5	79.4	128.3	71.2	62.7	58	1	-2	7.90	63	-9	57	80	47	18	36
17	(32)	7.4	56.1	13.0	47.3	6.5	81.1	136.9	69.4	64.6	57	1	-1	7.86	65	-11	60	83	47	18	36
18	(36)	7.3	46.7	11.6	44.5	5.6	76.9	121.8	57.6	58.1	54	1	-1	7.98	63	-9	54	81	45	18	38
20	(32)	7.5	59.9	8.7	35.6	5.3	65.6	155.4	46.3	58.0	66	0	2	7.76	81	-27	46	70	59	13	31

The values in the columns IR-Cl(%) represent averages too, they differ slightly from values computed on the basis of the average concentrations
Explanation of items: Appendix D; x electro-neutrality error; y conductivity error; pHsat pH at which satured with respect to calcite, at 10°C; Ca, Mg, Cl (%) f(c)1/2Ca^{2+}, f(c)1/2Mg^{2+}, and f(c)Cl^-, respectively

Although the time series reveal differences between the various stations, one dominant pattern is found in all of them. This dominant pattern is discussed first.

The dominant pattern of the time series

According to the high correlations, the dominant pattern of fluctuation of the chemical composition is sufficiently reflected by the average for all stations (Table 5.5). Fig.5.7a illustrates the fluctuation of EC_{25} and IR_{Cl}, as an approximation of IR. EC_{25} was especially high during the drought of 1975-'76. IR_{Cl} was low in this period. In general, EC_{25} and IR_{Cl} are negatively correlated during water intake, while they show a slight positive correlation in other periods. Sulphate, phosphorus, and nitrogen show an irregular seasonal rhytm, which dominates over other variations.

Spatial patterns and asynchronous variations

Spatial patterns are different at the various sampling dates. A study of the '(a)synchronity' of variations enables an ordering of the stations on the basis of the locally observed time series. The spatial distribution of the average values of some variables (Table 5.6) is shown in Fig.5.8a-d. For chloride and sulphate the patterns are more or less complementary: the chloride concentrations are high in the south-east (near WRN5), where polder surplus water enters the area, while high sulphate values are especially found in the north (near WRN15), where water is taken in during droughts. This water originates from the Frisian *boezem,* which in turn is supplied with IJsselmeer water, for which the river Rhine is the main source (see Chapter 4 for a description of the area).

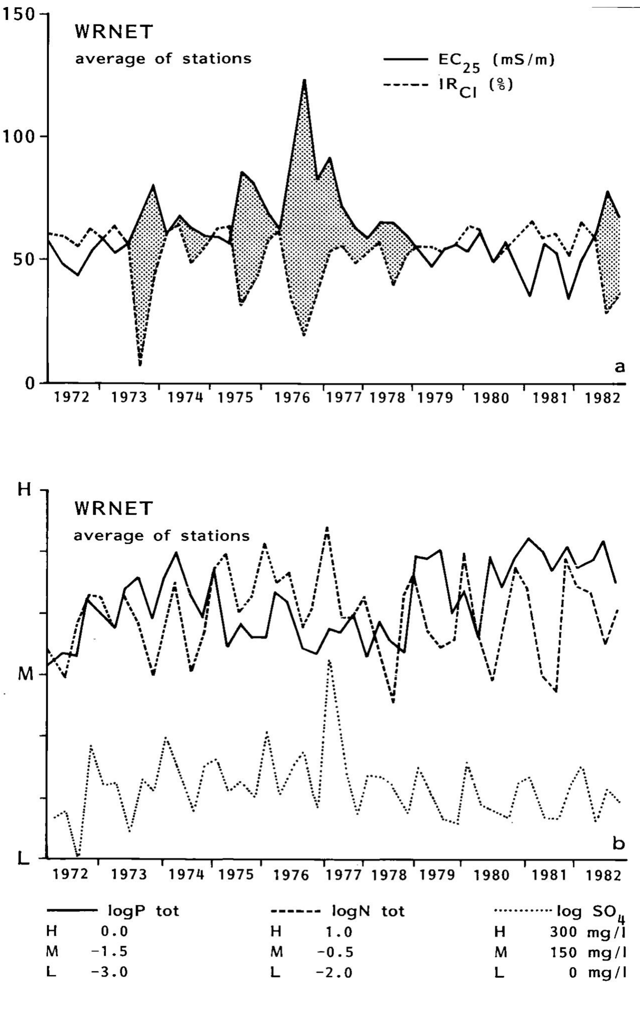


Fig.5.7 Fluctuation of EC and IR_{Cl} (a), and of $[P_{tot}]$, $[N_{tot}]$, and $[SO_4^{=}]$ in De Weerribben 1972-'82, average for all stations; Note the different scales for the various constituents (concentrations and logarithms of concentrations in mg/l); The highlighted areas in Fig.5.7a, where EC_{25}(mS/m)>IR(%), indicate the presence of molunotrophic water, and they systematically co-occur with an inlet of substantial quantities of water from elsewhere (> 7 10^6 m^3 at each occasion)

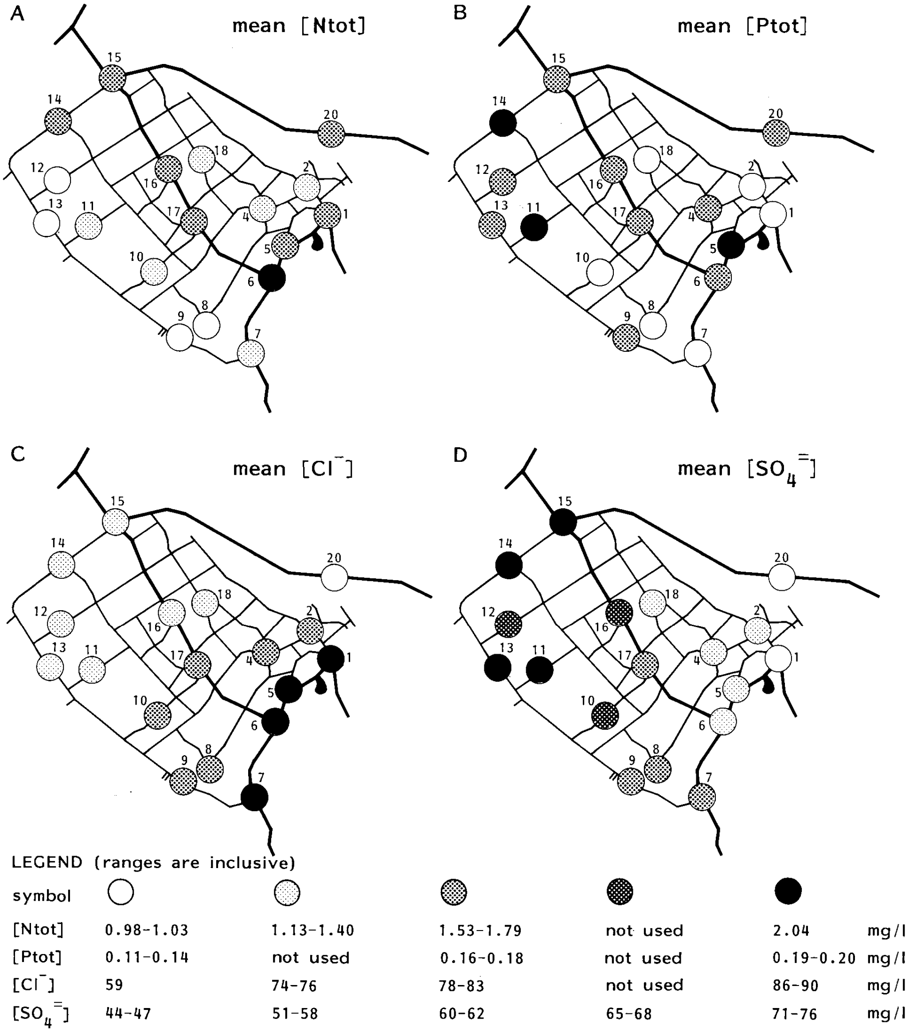


Fig.5.8 Mean values of [N_{tot}], [P_{tot}], [Cl^-], and [$SO_4^=$] at the various sampling stations in De Weerribben (nr)

The patterns for phosphorus and nitrogen are different. There is a tendency for high values in the main canals, but this is not consistent.

The spatial pattern of mean values of EC_{25} is equal to that of chloride. This factor is highest at WRN5 and WRN6, situated near the entry point of the Wetering, a canal which receives

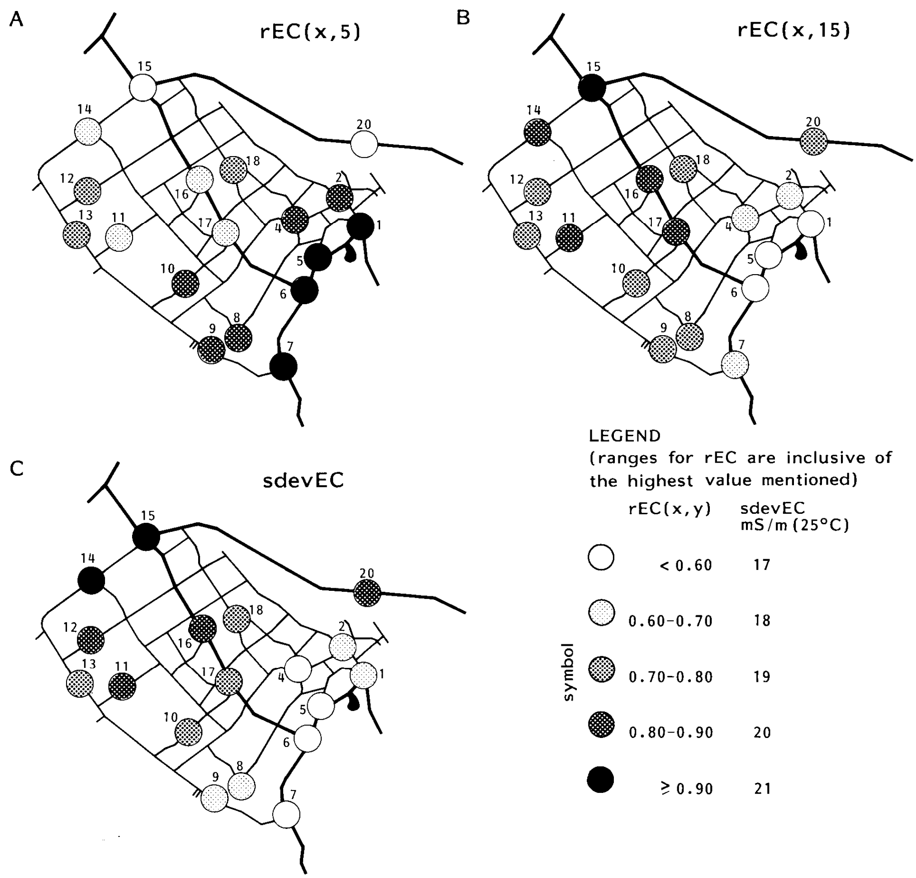


Fig.5.9 Correlations between time series of EC_{25}, with WRN5 (a) and WRN15 (b) as 'leading points', and standard deviation of EC_{25} (c)

the discharge of some large polders to the south-east of De Weerribben. The lowest mean value was recorded at WRN20. The standard deviation of EC_{25} (Fig.5.9c) varies but little, but it is lowest at the WRN5 end of the area and highest at the WRN15 end.

A cartographic representation of the correlations between time series (Fig.5.9a) reveals that the variation of EC_{25} at sampling stations in the neighbourhood of WRN5 (WRN6,1,7,2,4) is strongly correlated with that at WRN5, *i.e.*, EC_{25} varies synchronously in this area with WRN5 as a possible 'source' of the pattern of variation. The lower coefficients of correlation at the other end of the area (WRN15) suggest that the variation is of a different kind there: the value of the coefficient of correlation decreases with the distance from WRN5. Fig.5.9b, with WRN15 as a point of reference, consequently shows a complementary pattern: high correlations in the neighbourhood of WRN15, and low ones near WRN1,5,6. No indications were found that this could have been caused by a simple time-lag.

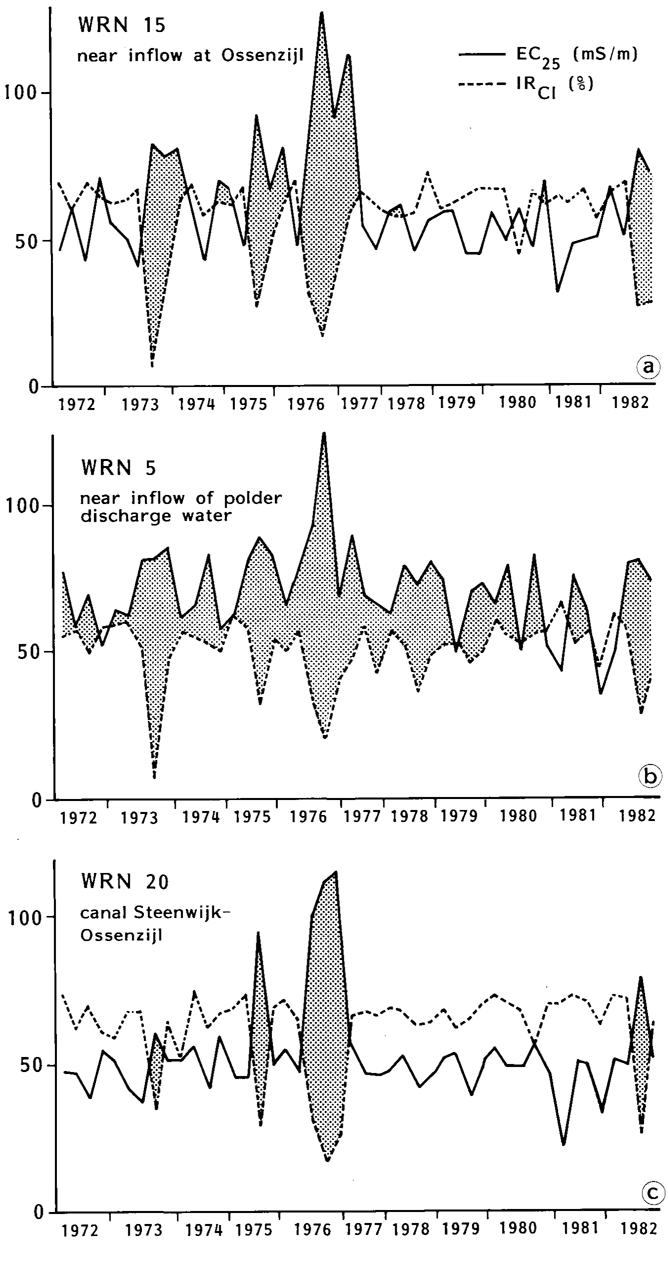


Fig.5.10 Time series of EC_{25} and IR_{Cl} at WRN15 (a), WRN5 (b), and WRN20 (c)
Highlighted areas, where EC_{25}(mS/m)>IR(%), indicate a presence of molunotrophic water due to inlet or polder discharge; compare Fig.5.7a for the all-stations mean

The variation of total phosphorus (P_{tot}) and total inorganic nitrogen (N_{tot}) at the various sampling stations is less strongly correlated than that of the other parameters and it is as yet unsufficiently understood.

It is concluded that the variation of EC_{25} and most major ions is ruled by regional processes while the variation of P_{tot} and Ntot rather seems to be governed by local processes. Since, in the present report, the emphasis is on the regional processes, the P_{tot} and N_{tot} results will not be treated in any greater detail here. The time series observed at WRN 5, 15, and 20 are shown in Fig.5.10 for EC_{25} and IR_{Cl} as a basis for the following discussion of distinct regional influences.

Surface water flow through the area (Fig.5.10a, 5.11)

Apparently the water entering De Weerribben near WRN15 is an important source of variation in EC_{25}. The strong overall correlations of EC_{25} are probably caused by the circulation of substantial quantities of water with a characteristic EC_{25} through the area. This circulation is driven by pumping, water inlet, and winds (Lyklema & Van Straten 1977, Jol & Laseur 1982), and it also penetrates deeply into secundary canals and locally residing bodies of water.

The overall effect of such a circulation is that an incoming body of water with a strongly different EC_{25} can usually be traced nearly everywhere in De Weerribben at the next WRN sampling day, *i.e.*, within 1-3 months. This effect is shown in Fig.5.11, which also includes analyses of samples collected in the southern part of the *boezem* area, the mire area De Wieden. Apparently, at this date the sampling stations in De Wieden had not or not yet been reached by the inlet water. Note that this may be partially due to the inlet strategy. When, shortly after water intake, it starts raining, the pumping station Stroink is used to remove the water surplus, so attracting the water towards the pumping station, which is located in between De Weerribben and De Wieden (Chapter 4). Shortly after pumping the water level near the pumping station is still somewhat lower than elsewhere. An eventual intake at such a moment will meet the same attraction. In the early Seventies it was common practice to 'overshoot' the target levels with the pumping and intake measures. In feed-back terms, the authorities, as it were, prepared for a continuation, or even worsening, of the 'threat' to the target level, thus diminishing the retention time of water in the *boezem* area. This does, of course, not mean that all water in the main canals and ditches is entirely replaced: the analysis of time series shows a considerable lag in the changes in chemical composition of the water in more isolated parts of De Weerribben.

At present a more 'prudent' strategy is followed. Rather than 'overshooting' the target levels, just enough water is removed or let in to conserve the highest or lowest allowed water levels during pumping or intake periods, respectively, so conserving the local body of water as much as possible. Of course a still greater effect could be achieved if the discharge and inlet works were located at the same side of the area.

The inlet water, flowing in through WRN15, originates from the Frisian *boezem* system. The latter contains surplus water from several polders in the province of Friesland and inlet water from lake IJsselmeer, *i.e.*, ultimately, Rhine water. It can be recognized at WRN15 by an EC_{25} value (mS/m) numerically exceeding IR (%), as shown in Fig.5.10a. Especially during drought periods the inlet water may be even slightly brackish, and it was so in the summers of 1975 and 1976.

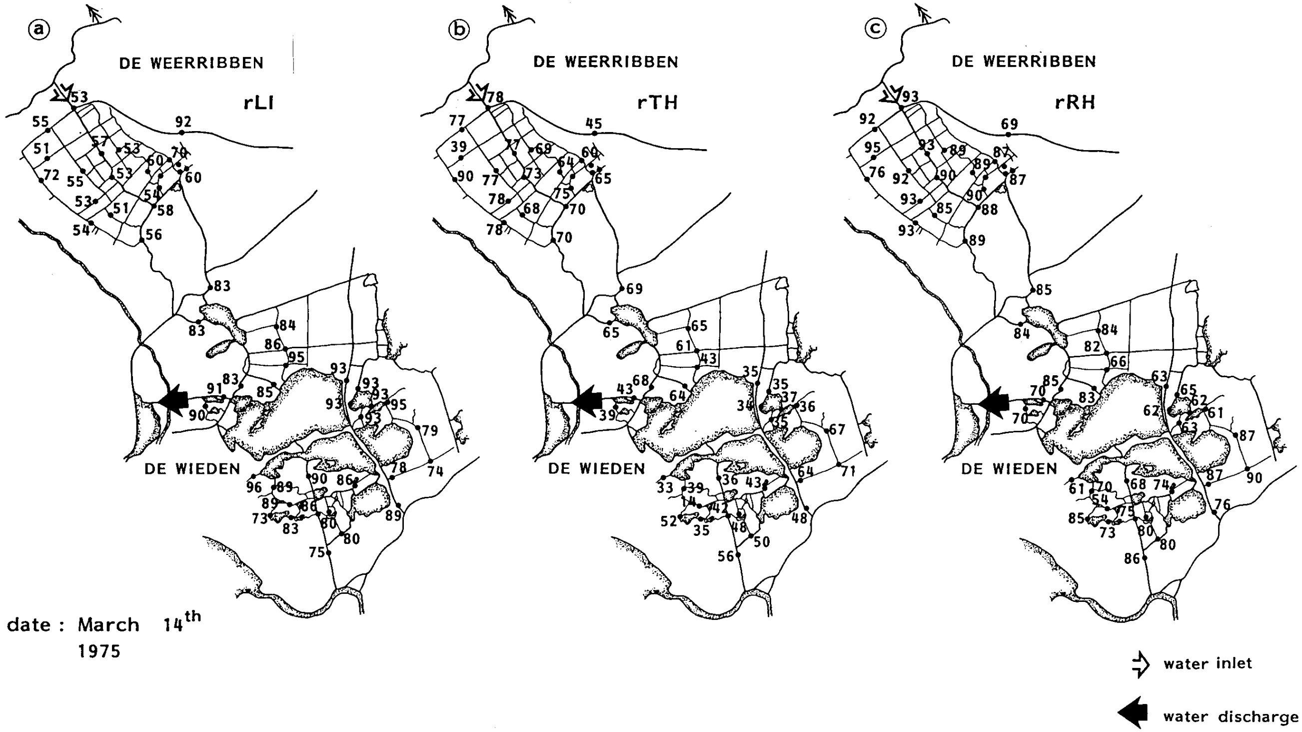


Fig.5.11 The inlet water (March 1975, in De Weerribben) can be traced by its lower similarity to the lithotrophic benchmark sample (rLI, a), and higher similarity to the thalassotrophic (rTH, b) and molunotrophic (rRH, c) benchmarks, as compared to the mire water still present in De Wieden

Inflow of surplus polder water (Fig.5.10b)

The relatively high and constant values at WRN5 are due to the inflow of discharge water from the polders in the south-east. This discharge water can often be recognized by its opaque, greenish-brown appearance, and strongly resembles, both chemically and visually, the polder water at the intake of the pumping station concerned (Rengersen 1979, Hack 1973). It contains a fair amount of groundwater, mixed with *boezem* water which seeps into the deep polders from where it is 'recycled' into the *boezem*. In the inlet canals of the pumping station of these polders it could be noticed that the surplus water of the polder Wetering-West is characterized by high chloride concentrations, which must be due to the influence of slightly brackish local groundwater (Section 5.5). This water is characterized by EC_{25} (mS/m) in excess of IR (%). At WRN5 its presence alternates with that of the inlet water (Fig.5.10b).

The lithotrophic influence of the Steenwijk-Ossenzijl canal (Fig.5.10c)

The Steenwijk-Ossenzijl canal (WRN20) is usually filled with water rich in calcium and bicarbonate. Most of this water originates from the Drenthian catchment area of the Steenwijker A rivulet, along with a share of surplus water from the polders to the north-east of De Weerribben. Most of these are shallow polders. The influence of the WRN20 water reaches De Weerribben mainly via WRN15, but it is only an important source of water for the *boezem* during moderately wet periods. In still wetter periods the *boezem*-discharge pumping station Stroink causes a flow of canal water in the opposite direction (Jol & Laseur 1982, Lyklema & Van Straten 1977). During extreme droughts the inlet water at WRN15 also reaches WRN20, as can be traced by EC_{25} (mS/m) exceeding IR (%) (Fig.5.10c).

The lithotrophic influence of discharging groundwater

There is no evidence of any significant influx of groundwater into the De Weerribben mire area proper. This conclusion is well in line with the conclusions from the groundwater survey.

An extension of the time series into the 1981-'87 period

While the WRNET monitoring system was in existence, the water quality board 'West-Overijssel' (ZWO) set up a sampling scheme in a large area, including North-West Overijssel. The sampling station K158 in Kalenberg is very close to the WRNET station WRN17.

The time series for EC_{25} and IR_{Cl} from both stations have been combined in Fig.5.12, where K158 data were used from 1981 onwards. It is apparent that, since 1982, EC_{25} has stabilized at about 50 mS/m, while IR_{Cl} slightly increased and stabilized at about 60%. Short periods of considerable water intake, however, are clearly visible by a higher EC_{25} and a lower IR_{Cl}, as, for example, in the summer of 1986.

Summary of water quality influences during the 1970s and '80s (Fig.5.13)

A summary of water quality influences in the surface water system of the *boezem* is given in Fig.5.13. The extent of the average spheres of influence of waters from different sources was calculated on the basis of a principal component analysis for 1972-'78 WRNET data. This picture not only depends on the weather conditions and total amounts of inflow, supply, and

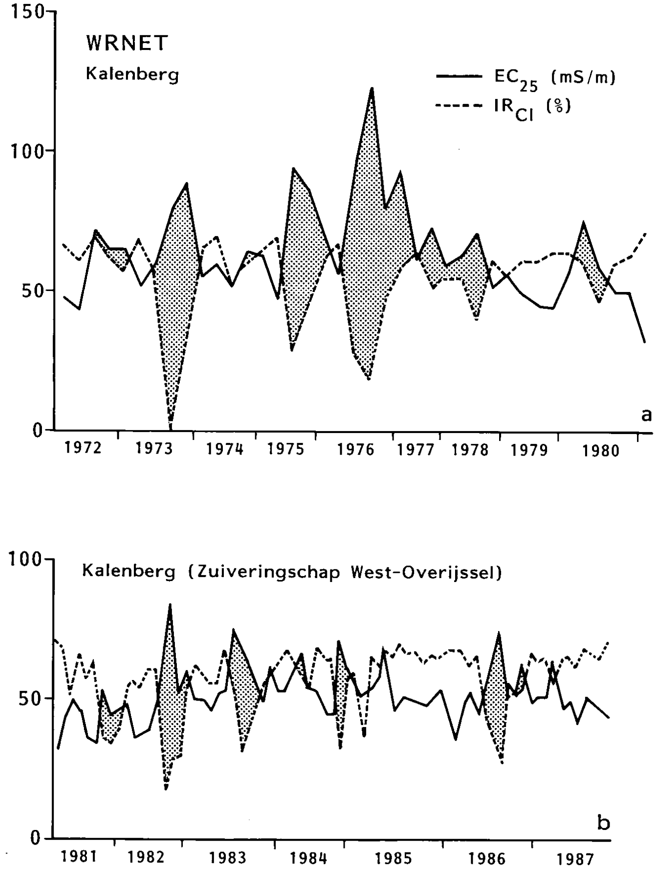


Fig.5.12 Fluctuation of EC_{25} and IR_{Cl} at Kalenberg, 1972-'81 (WRNET, a), and 1981-'87 (Zuiveringschap West-Overijssel, b)
Highlighting as in Fig.5.7a and Fig.5.10

discharge of water during that period, but also on the hydraulic parameters of the canals network and operational aspects of the water management.

It must be concluded that the 1972-'78 period is strongly influenced by the dry summers of 1975-'76. Consequently, the processes and mechanisms seen during this period can only be used in a more general way if it is possible to formulate a functional relation between the observations and the relevant conditions. Among these conditions the resistance in the various canals (aquatic macrophytes, strongly decreased in abundance since 1972!), the amount of water lost by seepage from the *boezem* (polders, drinking water supply), and the inlet strategy (‘prudent’ since ca 1980 versus ‘overshooting’ before) must be considered, together with the weather (droughts, rainy periods, wind influence). In the absence of more and, preferably, longer series of observations it is difficult to interpret the changes noticed during the 1980s.

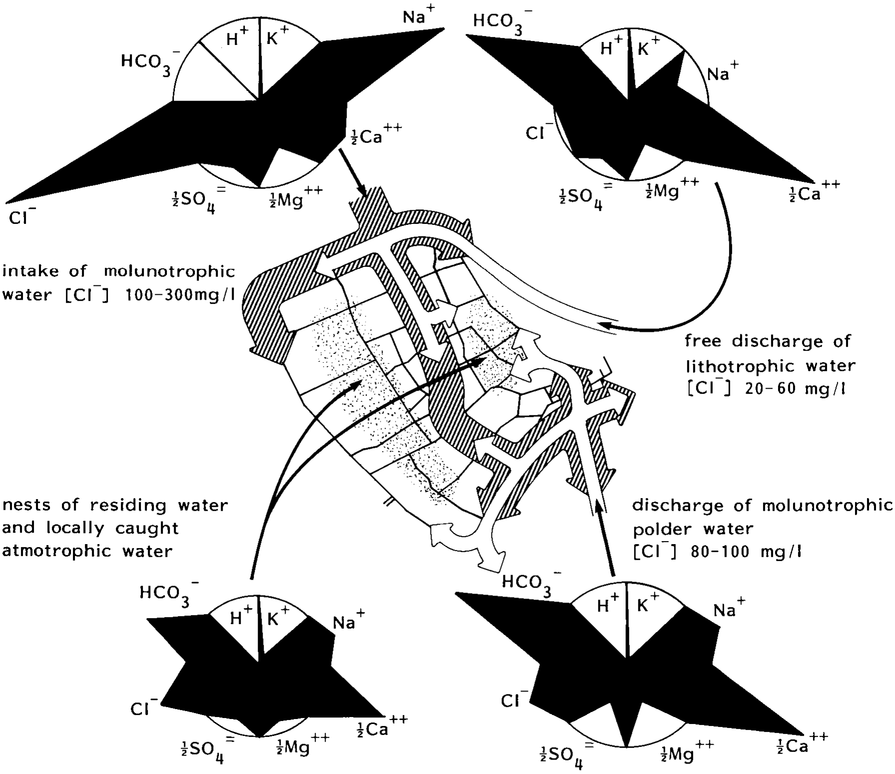


Fig.5.13 Summary of water quality influences in the surface water system of De Weerribben, 1972-'78
From Van Wirdum 1989, based on a 1978 advisory note to Zuiveringschap West-Overijssel

5.7 Comparison of surface water composition 1960-'82

Data sets OLD and WRNET

A comparison was made between the WRNET records and earlier analyses from the *boezem* water in De Weerribben. The earliest data from which IR could be reliably calculated and whose EC values are known are from 1960. In the archives of RIN and HdV-Lab 93 such analyses were found (data set OLD). Since these analyses do not fit in time series the comparison with WRNET results is based on the distribution of similarity values and on EC-IR diagrams.

From Fig.5.14 it becomes apparent that lithotrophic water is dominant in the OLD set. Although the frequency distribution of rLI (the similarity to calcareous groundwater, see

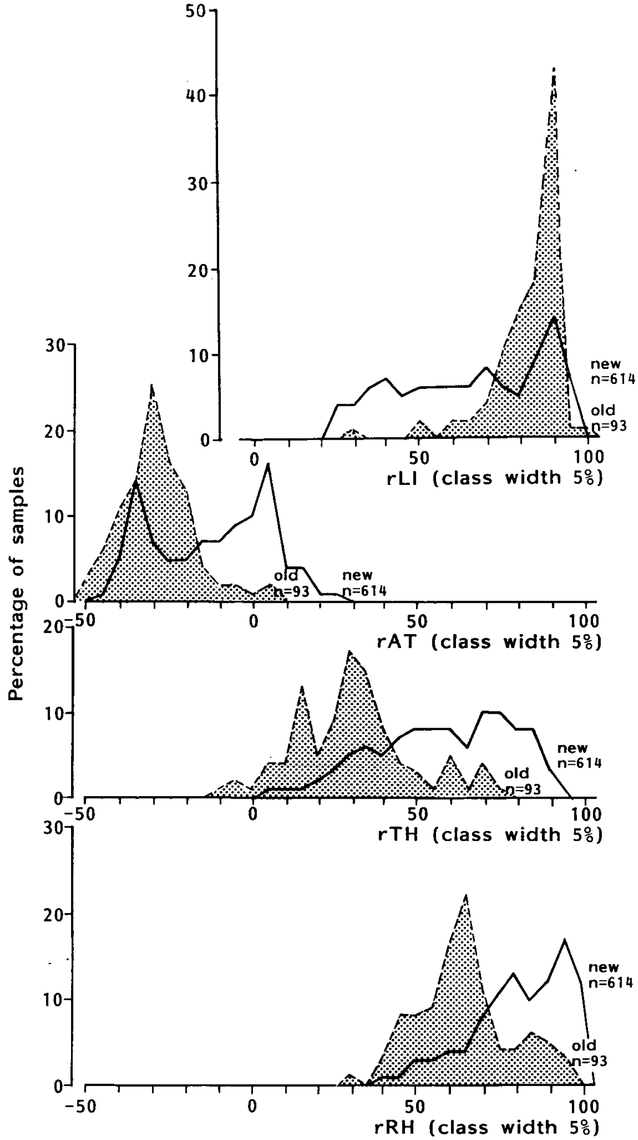


Fig.5.14 The frequency distribution of the similarity to the litho-, atmo-, thalasso-, and molunotrophic benchmarks; data sets 'old' (93 1960-'70 analyses) and 'new' (614 1972-'82 analyses)

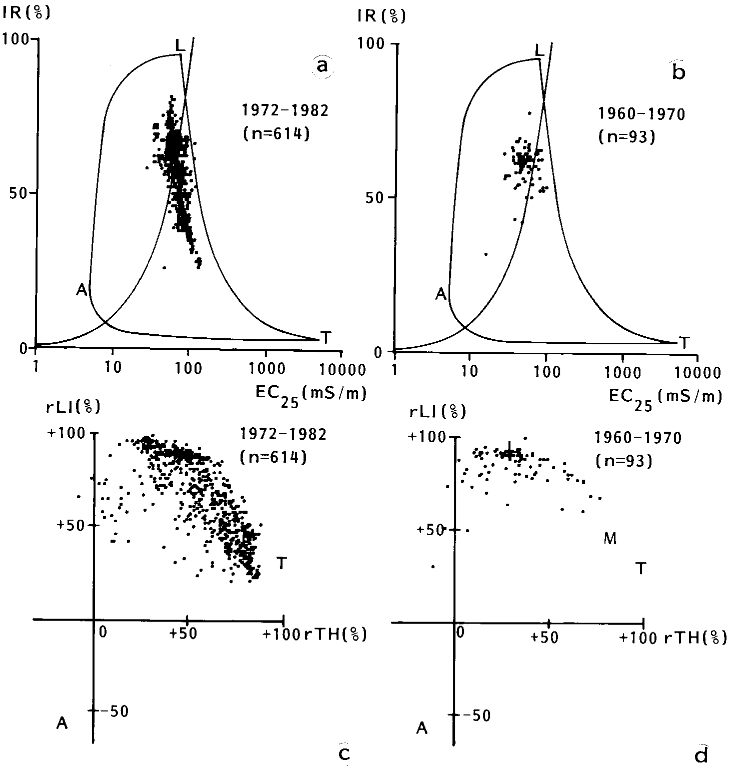


Fig.5.15 EC-IR and rTH-rLI diagrams showing *boezem* water analyses from De Weerribben

The analyses demonstrate a litho-thalassocline in 1972-'82 (a,c), and a litho- to slightly molunotrophic cluster (b,d) in 1960-'70; L, A, T, M: Litho-, atmo-, thalasso-, and molunotrophic samples, respectively; Mixing contours and the line IR(%)=EC_{25}(mS/m) added to Fig.5.15a,b for convenience (Appendix D)

Appendix D) also shows a peak between 75% and 100% in the WRNET set, lower values are more common in the latter. These analyses with a low rLI value cause the increased presence of high values of rTH (similarity to sea water) and rRH (similarity to polluted Rhine water) in the WRNET set, as compared to the OLD analyses (Fig.5.14a,b). This is partially due to the presence of the extremely dry seasons 1975 and 1976 in the WRNET sampling program. The higher rTH and rRH values in WRNET were especially found between 1975 and 1978. However, many of the WRNET samples not considered here for reasons of electroneutrality discrepancies, would, according to their IR_{Cl} and EC values, also fall in the high rTH and rRH classes, especially the analyses of 1973-'74. It can be concluded that the molunotrophic water type, resembling Rhine water (high rRH), is rare in the data set OLD, while it is abundant in the WRNET set. This is due to the fact that only since 1972 the water from the Frisian *boezem* system is supplied to the *boezem* system under investigation (see Chapter 4). This increased the influx of water from the IJsselmeer in De Weerribben.

The plotting area for *boezem* water in the EC-IR and rTH-rLI diagrams has been indicated in Fig.5.15a,c on the basis of all WRNET sampling dates which yielded reliable analyses. The boundary line EC_{25}(mS/m) = IR(%) was also drawn in this diagram since this condition can be easily scanned in the time series shown for WRNET results. The OLD analyses are shown in Fig.5.15b,d. The same trend is reflected by these diagrams: molunotrophic (RH) water was considerably less abundant in De Weerribben before 1972.

Discussion: Did anything really change?

As introduced before, the main aim of this part of the study was to describe the prevailing situation as regards the hydrology. The chemical composition and the origin of the *boezem* water have been described, and no exfiltration of groundwater from the underlying aquifer was found. Chemically, the surface water was akin to groundwater (lithotrophic) during the 1960s. In the WRNET monitoring scheme the Steenwijk-Ossenzijl canal (WRN20) could be indentified as a source of lithotrophic water, mainly carried from the bordering Drenthe Pleistocene area.

Only in the course of the investigation, ca 1974, it became obvious that a major change might have occurred while the observations were carried out. Lithotrophic surface water was no longer common in the area after 1973. In 1973-'74, many water analyses showed large deviations from electroneutrality, so they must be considered unreliable, but the trend could be confirmed in 1975 and 1976 with reliable analyses. While the monitoring program WRNET was continued, the question arose, ca 1979, whether anything really had changed, or whether the extreme conditions of a very wet winter (1974-'75), followed by two extremely dry seasons (1975, 1976) had interfered with the 'normal' situation.

First of all, the aquatic macrophyte vegetation in De Weerribben changed considerably. It is not easy to date this change exactly, but, estimating from my own observations and from aerial photographs this must have been after 1971 and before 1975. This may have been an effect of some environmental change, possibly relating to the hydrology. In itself it has diminished the hydraulic resistance in the canals network, and so facilitated the penetration of inlet water. This change seems to have occurred somewhat earlier in De Wieden.

Also the change of the water intake from Beukerssluis, far south from De Weerribben (see Fig.3.3) to the Linthorst-Homan sluices, right north of De Weerribben near Ossenzijl, is not well documented, but it is generally agreed that the Linthorst-Homan sluices gradually became the main intake point in the period 1972-'74. This has been a major change for De Weerribben, as is shown in this chapter. During the 1960-1972 period the water quality at the intake point Beukerssluis had badly worsened, providing a possible explanation for the earlier vegetational effects in De Wieden, which is immediately influenced by water intake at Beukerssluis.

Also in the 1972-'75 period a land reallotment program was executed in the IJsselham polder area, where lower drainage levels were installed, and in the bordering Paaslo morainic area. The effects were not investigated, but it is almost certain that this program has diminished the summer discharge of lithotrophic water in the Steenwijk-Ossenzijl canal. Increased drinking water withdrawals may have contributed effects too.

These changes will inevitably have increased the chance that, during droughts, large amounts of molunotrophic water had to be taken in and could penetrate far into the mire area. So, although such events as shown in the analyses between 1977 and 1987 could have been easily missed by the 1960-'70 water samples, and however extreme the 1975-'76 summers were, the suggested difference probably exists. The deep penetration of molunotrophic water from the *boezem* into the underlying body of groundwater seems to prove this difference.

All this does not prove that the 1960-'70 analyses are representative for a long period. Until 1920 brackish influences occasionally spread over De Weerribben. It is possible that no *kragge* was present at that time in most *petgaten* which are now grown with a vegetation characteristic of a lithotrophic environment, or that intervening periods with fresh water were long enough to determine the nature of the vegetation. As discussed before (Chapters 4 and 5.3-5.5), the installation of the pumping station Stroink and the construction of polders in the 1930-'55 period have strongly changed the hydrology of the area. The Wetering polders may well have discharged a substantial amount of lithotrophic water into the *boezem* during the late 1950s and the 1960s. These polders were reclaimed from a large mire area, most probably comprising a body of supposedly lithotrophic surface water and groundwater. A changed chemical composition of the polder discharge water can be due to the exhaustion of this body of water, the attraction of brackish groundwater from greater depths, and the increased agricultural fertilization.

It must be concluded that much has changed, but that, during the development of the present vegetation, a hydrological steady environment, if any, never was present longer than some ten or twenty years. A comparison between a ‘new’ and an ‘old’ steady state is therefore not realistic. Yet, during the development of the area as it is now, the decreased availability of unpolluted lithotrophic water in the surface water system since about 1970 must be considered a significant change. The hydrology suggests that this change became dramatically evident by the coincidence of the extreme droughts of 1975-'76, the changed water intake point, and the strategy of ‘overshooting’ target values with the water management.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 6

The distribution of *seepage indicators* in De Weerribben

6.1 Introduction

The reputed *seepage indicators* are not especially indicative of groundwater outflow as such, but rather of low-lying, base-rich, yet nutrient-poor sites where fen peat has developed under the continued influence of an external water supply (Chapter 3). In Chapter 5 it appears that groundwater outflow is no characteristic feature of De Weerribben at present. Chemically, the water in the surface system determines most of the variation, both in time and in space. It was shown that inlet and discharge, as related to weather conditions and human decision, resulted in drastic fluctuations of the water quality. Slightly brackish conditions must have obtained in part of the mire area in the beginning of the present century. In the 1960s, a base-rich, lithotrophic type of water became dominant in the area, but this was followed in the 1970s by an increased supply of polluted, molunotrophic (Chapter 5, Appendix D) water originating from the river Rhine. In the late 1970s, and especially in the 1980s, more favourable weather conditions and a more careful operation of discharge and inlet stations led to a return of the lithotrophic character, possibly, however, with a higher nutrient load now prevailing in the reserve than was observed during the 1960s.

Although this information weakens the original theory of groundwater outflow and *seepage indicators*, a further environmental explanation of the distribution of these indicators requires a formal analysis given in this chapter. After an introduction to the overall vegetation cover and to the various factors influencing it, this analysis is carried out by raising some relevant questions. As a *seepage indicator*, the greatest attention is paid to *Scorpidium scorpioides*. Firstly, the basic question: Does the distribution of *seepage* indicators in De Weerribben coincide with the reputed former *seepage* area?, is tackled and this is denied. In the following section it is argued that the distribution of *seepage* indicators is partially restricted to a particular area, for which the geographical evidence suggests a relatively high base state and certain other favourable factors. The species are almost absent from the central part of De Weerribben, *i.e.*, the part of the former bog peat area that was never subject to clay deposition, has reached a far stage of terrestrialization, and missed regular management by cutting or mowing.
In the next section the environment of stands of vegetation with *seepage indicators* is analysed with the help of the indicator table (Appendix C) treated in Chapter 3. It appears that this indication is similar to what was already concluded in Chapter 3 for the *seepage indicators* themselves, though less extreme. It is shown that, even when *seepage indicators* themselves are not counted as ecological indicators, litho-oligotrophic environmental conditions are slightly more important in stands of vegetation with *seepage indicators*, while stands without *seepage indicators* point to a more atmo-oligotrophic milieu.
So far the dynamic behaviour and the possible significance of environmental change was not taken into account. From an analysis of the distributional pattern of *seepage indicators* in different periods, the suggestion emerges that these patterns have altered. A correlation is found with a complex of factors, in which the desalinization of the south-western part of De Weerribben and the progressing succession of the mire vegetation stands candidate for a partial explanation. This is corroborated by an analysis of the distribution of some other plant species. The *seepage indicators* are ranked according to their suggested response to the changes involved, from the relatively fast colonizers *Liparis loeselii* and *Scorpidium scorpioides* to the more ‘prudent’ *Utricularia intermedia* and *Parnassia palustris*, *Menyanthes trifoliata* being intermediate. *Equisetum fluviatile* and *Pedicularis palustris* can possibly be ranked between *Scorpidium* and *Menyanthes*.
The analysis of the dynamic behaviour of *Stratiotes aloides* additionally yields an indication of the role of the molunotrophic type of water invading De Weerribben in the mid-1970s. The recent recurrence of the lithotrophic water features may explain the present resettlement and expansion of *Stratiotes aloides*. The same factor, *viz.*, an increased lithotrophy, may also influence quagfen vegetation, although it remains to be seen whether the nutrient state of the mire water is still low enough for a full development of the *Scorpidio-Caricetum diandrae*.

6.2 *Seepage* indicators in the vegetation of De Weeribben

The vegetation of De Weerribben largely consists of fen vegegation in terrestrializing *petgaten*. Especially stands dominated by *Phragmites australis* and, to a less extent, *Typha angustifolia*, and by *Sphagnum* species are abundant. Carr vegetation and brownmoss reeds, the latter often with species of *Carex* and with *Juncus subnodulosus* co-dominant in the herb layer, are also wide-spread. The local dominance of species is strongly influenced by the management regime. The species composition of the stands of vegetation reflects gradual differences in the local milieus, as produced by the almost unlimited variation in the combinations of hydrological, managerial, historical, and other factors. Accordingly, ordination of more than 900 records of the vegetation cover has not led to the separation of clearly distinct types, but gradients could be derived and the presence of *seepage indicators* appeared to be correlated with the main gradients. In respect of the present problem I have therefore grouped the records in accordance to the presence or absence of *seepage indicators* (see Section 6.5).

Reed cutting in the winter season favours *Phragmites australis*, while mowing in summer, or cutting in early autumn, suppresses the growth of *Phragmites*, in favour of species of *Carex*. Irrigation of reed beds eventually leads to a firm *kragge*, growing up to the flooding water level, and to a substantial increase of *Carex elata*. Irregular mowing and burning of the vegetation cover benefit the growth of *Molinia caerulea*, and further abandonment ultimately leads to carr vegetation. Locally, vegetation with hummocks of *Sphagnum* species and *Polytrichum juniperinum* ssp. *alpestre*, rich in ericaceous shrubs, has developed, but it is still uncertain whether such vegetation is stable or not, and under what conditions it may develop.

'Pure' stands of the *Scorpidio-Caricetum diandrae* are uncommon in the quagfens of De Weerribben, although, with De Wieden and the Vechtplassen mire area, this reserve holds the best and most extensive representatives of the Association left in The Netherlands. Almost certainly De Weerribben is the main area of *Scorpidium scorpioides* in The Netherlands today. Apart from the *seepage* factor, the full development of the *Scorpidio-Caricetum diandrae* depends on a strict regime of mowing in summer. The stage of terrestrialization is also important, but it has been shown that the stands are connected in a quagfen vegetational series. The earlier stages described by Meijer & De Wit (1955) from the Vechtplassen area (Kortenhoefse Plassen) are only rarely met in De Weerribben and De Wieden, since, in these areas, quagfen vegetation develops more or less synchronously in the petgaten. Locally, however, the succession can be observed through the years along the shore of terrestrializing broads. Examples have been given by Segal (1966), by De Wit (1951) and by Kuiper & Kuiper (1958). In time, stands of the *Scorpidio-Caricetum diandrae* may develop into a species-rich type of grassland, reckoned to the *Cirsio-Molinietum* Association, or into a community of *Sphagnum* and ericaceous shrubs. The character species of the *Scorpidio-Caricetum diandrae* also occur in stands where *Phragmites australis* is dominant, but it is uncertain whether this dominance of reed should not be regarded as an aberrant feature due to disturbance. Especially in the northern part of De Wieden and in De Weerribben, *Phragmites australis* and some other helophytes atypical of the *Scorpidio-Caricetum diandrae* proper are often found.

The ups and downs of economic returns from reed culture and changes in nature management often lead to a local alternation of different management regimes: a once abandoned reed bed, overgrown with *Molinia caerulea* and groups of young trees, may be redressed by the cleaning of ditches, by sod cutting, removal of trees, deposition of ditch mud, and by irrigation. Needless to say such measures drastically change the species composition and dominance relations, and they complicate an accurate ecological explanation of the momentary features of any actual stand of vegetation.

Overall vegetation maps of De Weerribben have been made by Van Zon-Van Wagtendonk (1969) together with H.N. Leijs in 1968, and by Staatsbosbeheer (1975). These maps have a physiognomic basis; the types of vegetation recognized are based on the dominance of structural groups and single species, such as *Phragmites australis*, *Juncus subnodulosus*, *Molinea caerulea*, scrub, aquatic macrophytes, etc.. Rare species and bryophytes have not been given any diagnostic importance, or have even not been recorded at all. Such maps are quite indicative of the management situation, and they are useful for the tracing of such processes as the increase of stands of carr in time. They do not yield an accurate picture of, for instance, the occurrence of the types of vegegation with alleged *seepage indicators*. The Staatsbosbeheer report (1988) contains a somewhat more detailed vegetation map, based on field work by H.A.J. Koenders, G.J.R. Allersma, J. Schreurs, R. Veldkamp, and J.H. van Slogteren in 1985-'86; several rare species and mosses were included in the survey. This map refers to the situation about ten years after the investigation reported here, and its further use would require a separate study, especially since the map was reproduced in the form of 13 not easily surveyable leaves. Both Van Zon-Van Wagtendonk and Staatsbosbeheer include distribution maps of selected species, which have been used to improve the interpretation of distributional patterns given below.

A more detailed description of the vegetation in two NO-SW strips across De Weerribben, and in some additional complexes of *petgaten* was made as part of the present study (*e.g.*, Oosterbroek & Post 1977, Verschoor 1978). In contrast to the traditional French-Swiss method of field survey for vegetation mapping, the vegetation was recorded in the form of ‘maximum areas’, rather than minimum areas, in order to let the *kragge*-level of vegetational variation prevail over more fine-scaled levels of species aggregation (Chapter 3). The maximum area method provides a ‘complete’ field discription of every map element. Map elements are predefined on the basis of aerial photo analyses, but they may be subdivided or united if the homogeneity, defined by a recurrence of vegetational patterns within each map element, renders this necessary. Due to time limitations, and to the extremely complex vegetational patterns in the study area, we were unable hierarchically to structure these mapping surveys by primarily defining aggregate types at the finer scales, subsequently to describe the map elements as composites of these aggregate types, as is done, *e.g.*, in the traditional Finnish and Russian mire survey and in the method described by Succow (1988). For this reason, species association in our records of mapping elements may be due to species aggregation at any level described in Chapter 3.

These more detailed surveys have provided a good, but not easily transferable, insight into the vegetational variation. The vegetation records are especially important since they represent a description of the whole statistical population of stands of vegetation in the strips mapped, and, so, can be considered a vegetation sample of De Weerribben as a whole, which is unbiased as regards the sympatric occurrence of *seepage indicators* and other species. This feature will be used in this chapter to find out whether these other species indicate a difference between the milieu of stands with and without *seepage indicators*, respectively.

More direct inferences about the type of environment preferred by the supposed seepage indicators could be made by mapping the vegetation units with and without *seepage* indicators, within single types of vegetation (Verschoor 1978). The *seepage indicators* appear to occur most frequently in a zone of vegetation in the proximity of open surface water, but not in the immediate reach of the water of the larger canals.
This point will be discussed in more detail in the context of a case study in De Stobbenribben (Chapters 7-10), where several, possibly relevant environmental factors have been measured. The mapping surveys, and observations during various terrain visits, raised doubts about the restricted distribution of accepted *seepage indicators* as reported by Kuiper & Kuiper (1958).

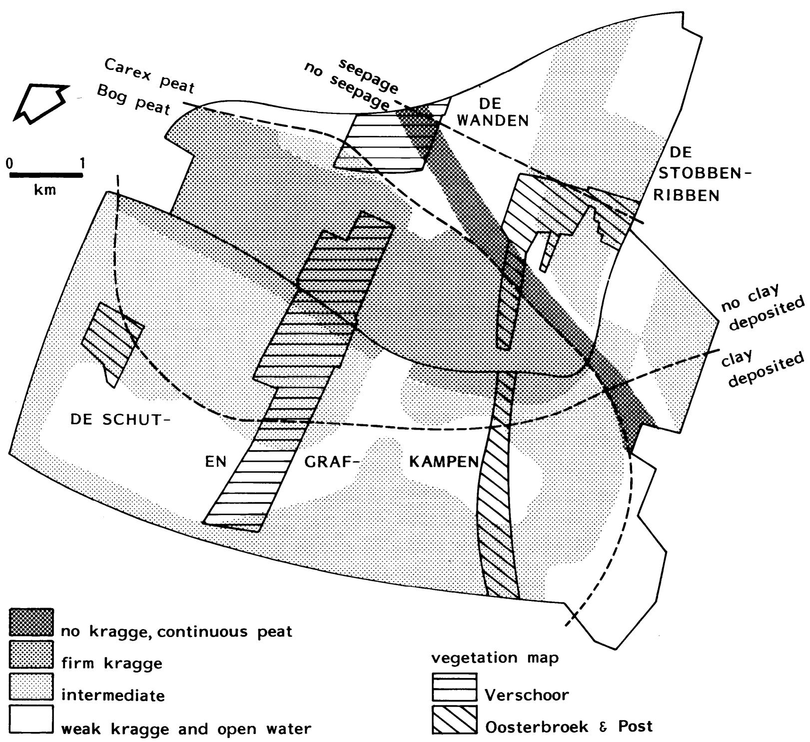


Fig.6.1 Some important physiographic boundaries in De Weerribben, including the *seepage boundary* after Kuiper & Kuiper (1958), and the generalized pattern of the stage of terrestrialization in 1951 (after Haans & Hamming 1962)
The areas traversed for detailed mapping of the vegetation in the present project have been indicated by hatching

Therefore, this distribution is covered in more detail in the next section. It is of course possible that the distributional limit suggested by Kuiper & Kuiper held true in the 1950s, but if it can be proven that the present areal extent of the supposed *seepage indicators* reaches far beyond their '*seepage* area limit', the present information on the hydrology of De Weerribben (Chapter 5) renders a relation with any local groundwater outflow most improbable at least. Below, the distribution of selected *seepage indicators* is reported, first with respect to the groundwater outflow question, and then in order to formulate alternative hypotheses regarding the ecology of these species. Some inferences are made on the basis of a survey of the correspondence between the occurrence of species and the successional stage in 1951 (Haans & Hamming 1962; see Fig.6.1 for the general pattern).

The country-wide distributional pattern of the species involved is not treated here. Distribution maps are available of the vascular plants and the Musci, with the exception of the genus *Sphagnum*. For the Musci, however, the information is incomplete, since it is based on herbarium specimens only. The general pattern is that most of the *seepage indicators* are especially found in the valleys of small rivers in Pleistocene areas, in dune slacks, and in fen areas bordering on the Pleistocene plateaus. While this seems in line with the *seepage hypothesis*, there are at least two weakening points. Firstly, many of the species involved are relatively rare and, so, provide too few data for any statistical treatment, especially not so since the environmental information from the locations is poor. Secondly, there are but few fen areas without brackish influences outside the preferred distributional zones, so that the importance of the *seepage* factor can not be tested there, and several of the *seepage indicators* have been locally observed in the few other freshwater fen mires, *e.g.*, in the Nieuwkoopse Plassen mire area in the Province of South-Holland.

6.3 Is the distribution of *seepage indicators* restricted to an area of groundwater discharge?

Published evidence of seepage in rich-fen quagmires (quagfens, Chapter 2) shows that many authors carried out their research in mire sites in the proximity of more elevated areas, thus suggesting a positive relationship between *seepage indicators* and a possible discharge of groundwater from the mineral subsoil into the overlying mire. One way to shed some light on this question is a mapping of the distribution of these *seepage* indicator species (Chapter 2) over De Weerribben, an area shown (Chapter 4) to comprise large parts without a former groundwater outflow, as well as a roughly indicated area of supposed groundwater discharge (*seepage* area, Kuiper & Kuiper 1958). This *seepage* area includes the De Stobbenribben mire complex, mentioned as a representative example of the influence of groundwater outflow on the vegetation by Segal (1966). Although De Stobbenribben is an area of groundwater recharge at present (Chapters 5 and 7-10), there is no proof that groundwater did not discharge into it formerly. The local vegetation stand could still reflect a former environmental state. The area delimited by the 'borderline of supposed former groundwater outflow phenomena' in Kuiper & Kuiper will be referred to as (supposed former) *seepage* area in the following treatment.

From a comparison with the soil map by Haans & Hamming (1962), it appears that the border of the supposed former *seepage* area is located in the former *Carex* peat area at a distance of some hundreds of metres from the transition to the former *Sphagnum* peat area. In the application of formal statements about the *seepage* hypothesis, I have considered sites of *seepage indicators* in the in-between area as belonging to the supposed former *seepage* area, thus giving the *seepage* hypothesis the benefit of the doubt.

Scorpidium scorpioides

During this survey, *Scorpidium scorpioides* was selected as a guide species for the *seepage* factor, and its distribution was mapped according to:

- The results of a "random test" in 1969: starting at 19 places, more or less evenly distributed over De Weerribben and lying outside the supposed former *seepage* area (Kuiper & Kuiper 1958), a one half-hour search for the species was made. It was eventually recorded at 13 of these sites, several of which only yielded scarce stems;
- All relevés with *Scorpidium* recorded in the vegetation mapping surveys by Oosterbroek & Post in 1973 (1977) and by Verschoor in 1974 (1978). *Scorpidium* was present in a sum total of 67 out of 922 records;

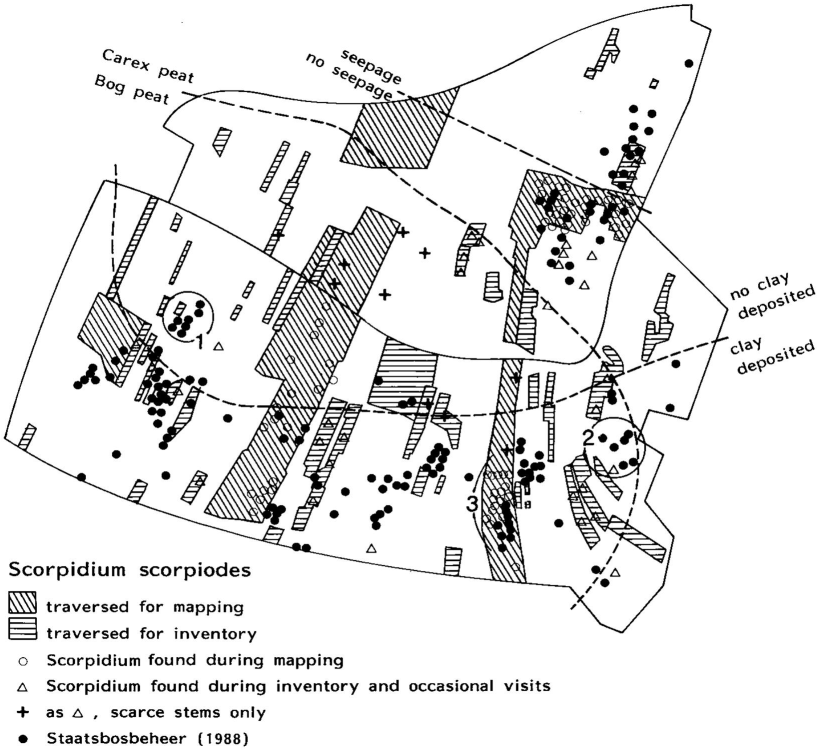


Fig.6.2 Former and present distribution of *Scorpidium scorpioides* in De Weerribben
The observations taken from Staatsbosbeheer (1988) apply to 1984-'85, the others to 1969-'75; Hatching applies to the earlier period

- The results of a bryological inventory in 1972 by members of the KNNV Bryology Working Group (Van Wirdum 1983): *Scorpidium* was found in 9 out of 55 parcel groups visited, partially coinciding with positive scores from the other sources;
- Occasional records up to 1975.

The distribution of *Scorpidium scorpioides* is also shown in a map in Staatsbosbeheer (1988) covering the whole area of the nature reserve. This map gives 153 locations for the species. Fig.6.2 combines the results of both inventories. It is obvious that *Scorpidium scorpioides* is not restricted to any limited *seepage* area. The moss is abundant, or even dominant in several former *petgaten* immediately bordering upon the Blankenham polder area in the South-West, which is known for the incidence of water losses towards the Noordoost-Polder (Veenenbos 1950, see Chapter 5). Much of the area where *Scorpidium* has so far not been recorded consists of open *petgaten* or of carr vegetation (see below).

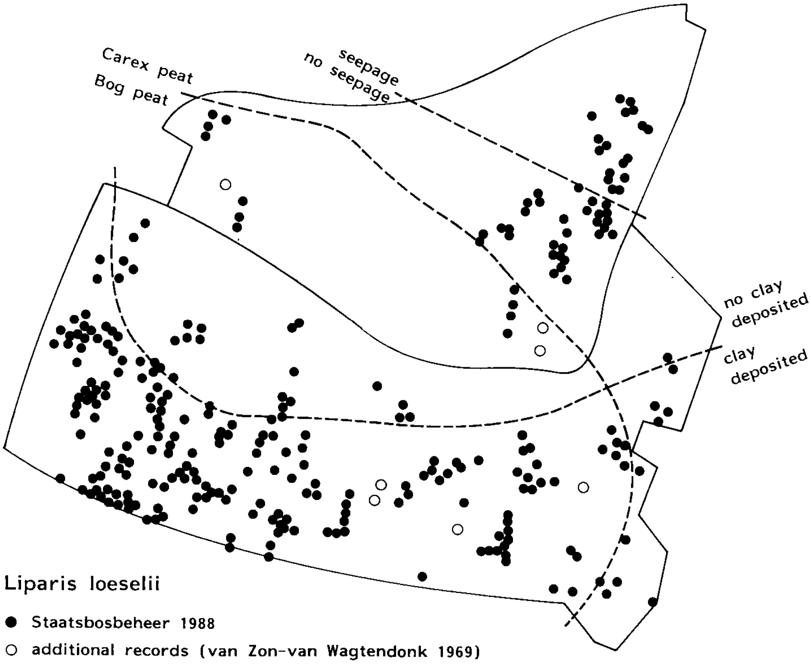


Fig.6.3 Distribution of *Liparis loeselii* in De Weerribben
Records by Van Zon-van Wagtendonk that roughly coincide with those by Staatsbosbeheer have not been separately indicated

Other species

Staatsbosbeheer (1988) also reports the distribution of *Parnassia palustris*, *Menyanthes trifoliata*, *Liparis loeselii*, and *Utricularia intermedia* (Fig.6.3-5), which have been considered *seepage indicators* also (Chapter 3). Among these species, *Parnassia palustris* is the only one restricted to the supposed former *seepage* area.

From the other reputed *seepage indicators*, *Eriophorum gracile* (only reported for De Weerribben by Kuiper & Kuiper 1958), *Philonotis marchica* (not reported for De Weerribben), *Scorpidium cossoni* (= *Drepanocladus revolvens* ssp. *intermedius*, one collection from De Stobbenribben by A.M.Kooijman and H.J.During, at the occasion of a very detailed mapping of the moss cover of that quagfen complex), *Calamagrostis stricta* (mentioned by Kuiper & Kuiper (1958) and observed by the present author in De Stobbenribben; see discussion by Corporaal 1984), *Drepanocladus lycopodioides* (three locations, all outside the supposed *seepage* area), *Sagina nodosa* (observed, with *Linum catharticum*, in De Wobberibben by the present author), *Dactylorhiza incarnata* (distribution in De Weerribben insufficiently known, but occurrence in the supposed *seepage* area certain), and *Carex buxbaumii* (possibly one anonymous observation

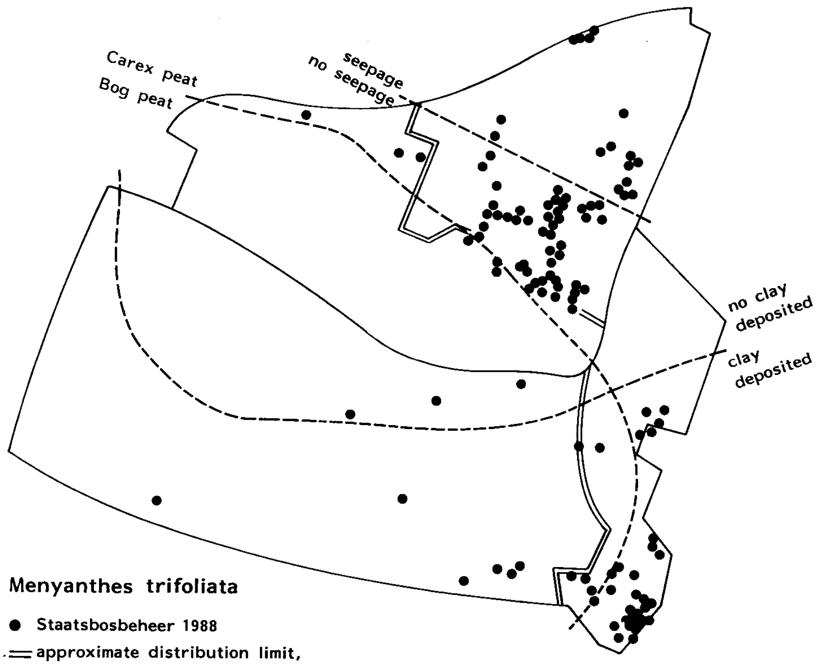


Fig.6.4 Distribution of *Menyanthes trifoliata* in De Weerribben
The distribution roughly coincides with that of *Equisetum fluviatile*

from De Weerribben) are too rare or too difficult to find to draw any valuable information from their distribution in respect to the present question.

Carex lasiocarpa, C.diandra, Aneura pinguis, Riccardia multifida, Bryum pseudotriquetrum, Fissidens adianthoides, Campylium stellatum, and *Campylium elodes* are more common than *Scorpidium scorpioides* in De Weerribben. Their pattern of distribution was not mapped, but from my own observations and from vegetation records, especially those by Oosterbroek & Post (1977) and Verschoor (1978), their distribution supports the conclusion drawn already for *Scorpidium scorpioides.*

Hence, the distribution of *seepage* indicators in De Weerribben is not restricted to an area with groundwater outflow, neither is it restricted to an area which could have been influenced by groundwater outflow in the past, and which has been indicated as such by Kuiper & Kuiper (1958).

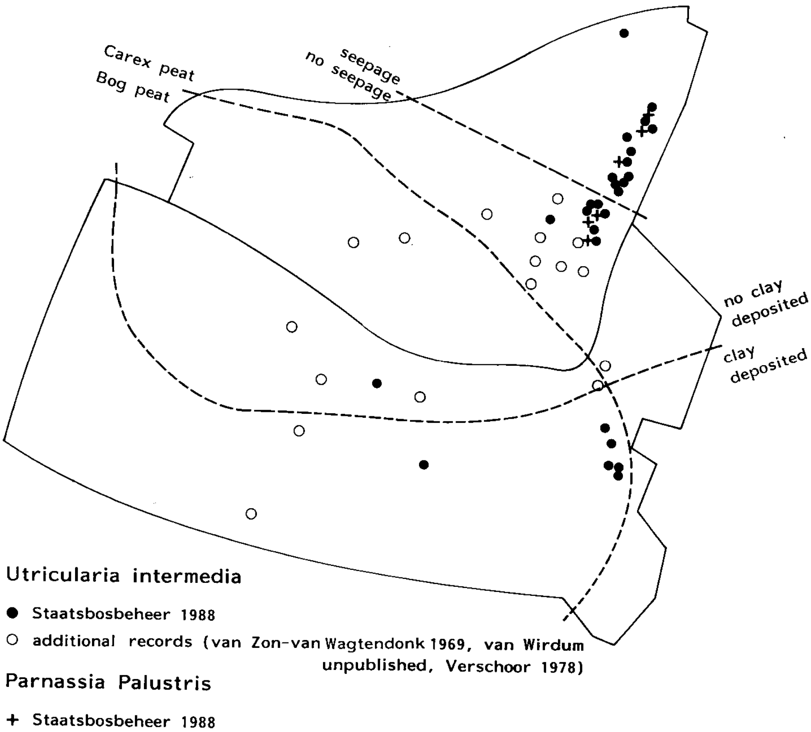


Fig.6.5 Distribution of *Utricularia intermedia* and *Parnassia palustris* in De Weerribben

6.4 Is the distribution of *seepage* indicators restricted to any particular area?

Scorpidium scorpioides and Liparis loeselii

The distribution of *Scorpidium scorpioides* (Fig.6.2) and several other *seepage* indicators (Fig.6.3-5) reveals some general patterns. *Scorpidium scorpioides* and *Liparis loeselii* are almost absent from the central part of the reserve. This is a relatively far terrestrialized area with much carr and scrub, and only few parts are regularly mown in summer. Conceivably, the stage of terrestrialization and the management regime are unfavourable there for these species.

Both species are also absent from the part of the border zone of the Pleistocene sands northeast of De Stobbenribben, called De Wanden. Although this zone is only partially within the supposed *seepage* area indicated by Kuiper & Kuiper (1958), the groundwater outflow is less improbable here than in the Schut- en Grafkampen region, where both species are frequently met with and often abound in the local stands of vegetation. De Wanden consists of many open *petgaten*, interlaced with intensively cultivated reed beds and strips of pasture. The pastures were formerly, and partially still are, used by local farmers and fertilized for agricultural production, and this is reflected on the soil map by Haans & Hamming by the abundance of *kragge*-grassland. Presumably, the early stage of terrestrialization and the absence of relatively nutrient-poor quagfen zones has kept the species away from this area.

Menyanthes trifoliata, Utricularia intermedia, and Parnassia palustris

Menyanthes trifoliata, *Utricularia intermedia*, and *Parnassia palustris* are almost absent from the southeastern part of De Weerribben. In the northwestern part, their distribution shows a gap around the village of Kalenberg. *Parnassia palustris* has not been observed south of this gap. The three species are more or less restricted to the former *Carex* peat area.

It is possible that the distribution of *Utricularia intermedia* is limited by the fact that this species, in The Netherlands, only rarely flowers (flowers only observed ca 1900 in the North of the province of Limburg; Weeda *et al.* 1988). Turions are often abundant in quagfens, however. Most of the known Dutch locations where the species has disappeared have suffered from eutrophication, pollution, reclamation of mires, or a lowering of the groundwater table. The general pattern is one of an obvious retreat from the southern part of The Netherlands during this century. Since the Dutch sites of *Utricularia intermedia* are near its southern distributional limit in North-Western Europe, site quality may be especially critical here.

Menyanthes trifoliata spreads both vegetatively and by means of seeds eaten by birds. The limited distribution in De Weerribben must be due to a limited availability of good settling environments (*i.e.*, borders of shallow bodies of open water with a suitable base and nutrient state). The great majority of *Menyanthes* sites in De Weerribben is in the proximity of the course of an old rivulet, where the peat was not cut or dredged for reasons of a high mineral content, and where the land has since long been used as hayfields and pastures (Chapter 4). The distribution gap near Kalenberg may be explained either by a more intensive agricultural use of the peatland (which also appears from the distribution of *kragge*-grasslands on the soil map by Haans & Hamming), or by the influence of polluted surface water, flowing in from the main canals (see Chapter 5).

Parnassia palustris occurs in two genetically different taxa in The Netherlands, one being abundant in the coastal and dune areas, and the other being a now rare and notoriously ‘demanding’ species of inland mires and wet heathlands, including the North-West Overijssel mires[2]. I have seen the species in some quagfens in the De Wieden area, and it was recorded for De Weerribben ca 1965 by Leijs (pers. comm.) from a site where it was also recorded by Staatsbosbeheer (1988), but where I never found it in the 1969-1975 period. Leijs described a site that was cleared from scrub a few years before his observations, and this also holds for the sites on the distribution map by Staatsbosbeheer (1988; see Fig.6.2). Next to this management factor, it may be noted that several species of more or less calcareous milieus, such as *Parnassia*, were relatively abundant in the mid-1980s, possibly due to an improvement of hydrological factors, including the base state of the water. The present sites are all within or nearby the supposed former seepage area, but, as shown in Chapters 5 and 7-10, they are now part of an area of definite and strong groundwater recharge. Especially the recent increase of the species in this single area does not support the original seepage theory.

---

[2]Gadella, T.W.J. & E. Kliphuis 1968. Parnassia palustris in The Netherlands. Acta Botanica Neerlandica 17, 165-172.

In conclusion, the distribution of some of the *seepage indicators* is mainly restricted to some delimited areas. This areal restriction coincides with various combinations of environmental factors. The stage of succession (not too early or too late), summer mowing, isolation from the main canals, associated with the absence of obvious pollution and eutrophication, and proximity to a former rivulet, associated with both mineral and agricultural influences, seem to determine the distribution of *Scorpidium scorpioides*, *Liparis loeselii*, *Menyanthes trifoliata*, *Utricularia intermedia*, and *Parnassia palustris*. The occurrence of other *seepage* indicators, as far as traced in De Weerribben, especially *Carex diandra*, *Carex lasiocarpa*, and several bryophytes, is probably not restricted to any delimited area.

6.5 Do stands of vegetation with *seepage* indicators indicate a particular type of environment?

The vegetation records in Oosterbroek & Post (1977) and Verschoor (1978) were grouped according to the presence or absence of *seepage indicators*. For each group the frequency distribution of ecological indications, from the list in Appendix C, was calculated on the basis of species presence also. The *seepage indicators* were not taken into account in this calculation, since they would possibly only confirm what was already deduced in Chapter 3, *viz.*, that the *seepage indicators* are associated with base-rich, yet nutrient-poor sites with rich-fen (or neva) peat, and influenced by any sort of seepage or flooding. Indicated ecological differences between the groups were tested with a chi-square test.

Fig.6.6 and Table 6.1 show the ecological spectra for the groups of records with and without *seepage indicators*. The differences are not large, as can be understood from the fact that the records obtain to vegetation stands at the *kragge* level of species aggregation Chapter 3). The *seepage indicators* are characteristic of hydro-environmental zones which may or may not occur within such stands. Moreover, they represent an ecological extremum in the spectrum (Chapter 3, Fig.3.6); the omission of their indication necessarily renders a vaguer picture, still the only independent one that can be drawn on the basis of species indication. The data sets used here are vast (17100 scores of non-*seepage* indicators in 920 records) and they include all stands of vegetation in the areas covered, providing a description of the whole statistical ‘population’ in these areas, not biased by any preselection of supposed *seepage* and definitely non-*seepage* sites, respectively.

The 568 records without *seepage indicators* comprise fewer litho-oligotrophic and more atmo-oligotrophic species than expected on the basis of all-records distribution and the number of species present, whereas the 352 records with seepage indicators have more litho-oligotrophic species. The differences illustrated in Fig.6.6 are all significant at the 0.995 level. The records with *seepage indicators* also comprise significantly more species and more red-list species, whereas the records without *seepage indicators* have less.

More or less similar differences are found for the separate data sets. The Verschoor records cover a strip right through the middle of De Weerribben. A relatively large area of this strip is in a far stage of terrestrialization, including carr and ericaceous vegetation. The number of records with *seepage indicators* is smaller than in the Oosterbroek & Post data set, and the average number of species per record is also smaller. The Oosterbroek & Post data were collected in another strip through De Weerribben, more to the South-East (see Fig.6.1), which is in an earlier stage of terrestrialization. The general characterization of the subsets with and without *seepage indicators* is similar to that in the Verschoor data, but the species frequency indicates a somewhat higher base and nutrient state.

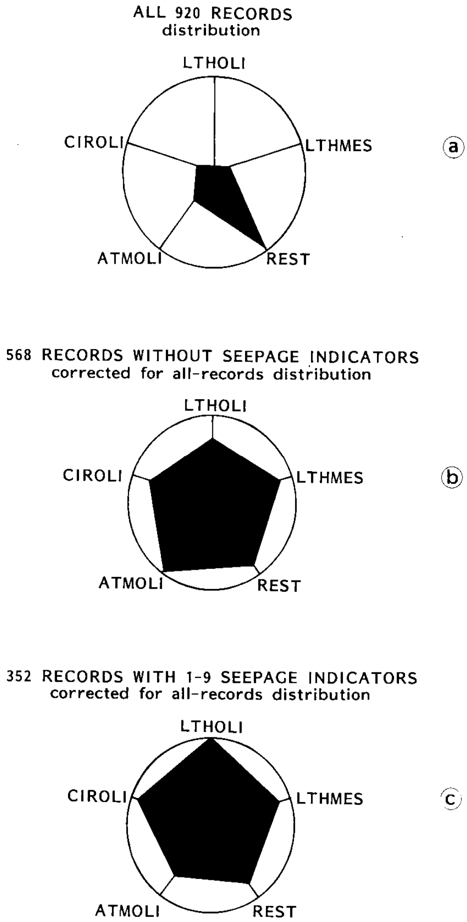


Fig.6.6 Ecological spectra of vegetation without (b) and with (c) *seepage indicators*, corrected for the all-records species distribution (a)

Records from Verschoor (1978) and Oosterbroek & Post (1977); note that the *seepage indicators* themselves were not included in the analyses

6.6 Has the distribution of *seepage* indicators changed in time?

The distribution of several supposed seepage indicators has been mapped, from various points of view, upon more than one occasion in De Weerribben. This allows for some conclusions regarding the dynamic behaviour of the respective distributional patterns.

Table 6.1 Frequency distribution of ecological indicators in de vegetation of De Weerribben

Subset	Absolute scores All	No-sep	Sep	Average per record All	No-sep	Sep
Data set Oosterbroek & Post						
Nr of records	346	161	185			
Sum of species scores	9465	3657	5808	27.4	22.7	31.4
Seepage indicators	444	0	444	1.3	0	2.4
Red-list species	976	166	810	2.8	1.0	4.4
(without *seepage indicators*:)						
Sum of species scores	9021	3657	5364	26.1	22.7	29.0
Litho-oligotrophic species	196	73	123	0.57	0.45	0.66
Litho-mesotrophic species	853	336	517	2.47	2.09	2.79
Circumneutral-oligotrophic species	990	368	622	2.86	2.29	3.36
Atmo-oligotrophic species	1722	795	927	4.98	4.94	5.01
Other species	5260	2085	3175	15.20	12.95	17.16
Red-list species	532	166	366	1.5	1.0	2.0
Data set Verschoor						
Nr of records	574	407	167			
Sum of species scores	7635	4442	3193	13.3	10.9	19.1
Seepage indicators	279	0	279	0.5	0	1.7
Red-list species	931	226	705	1.6	0.6	4.2
(without *seepage indicators*:)						
Sum of species scores	7356	4442	2914	12.8	10.9	17.4
Litho-oligotrophic species	231	99	132	0.40	0.24	0.79
Litho-mesotrophic species	827	468	359	1.44	1.15	2.15
Circumneutral-oligotrophic species	842	429	413	1.47	1.05	2.47
Atmo-oligotrophic species	1683	1088	595	2.93	2.67	3.56
Other species	3773	2358	1415	6.57	5.79	8.47
Red-list species	652	226	426	1.1	0.6	2.6
Data set Verschoor plus Oosterbroek & Post						
Nr of records	920	568	352			
Sum of species scores	17100	8099	9001	18.6	14.3	25.6
Seepage indicators	723	0	723	0.8	0	2.1
Red-list species	1907	392	1515	2.1	0.7	4.3
(without *seepage indicators*:)						
Sum of species scores	16377	8099	8278	17.8	14.3	23.5
Litho-oligotrophic species	427	172	255	0.46	0.30	0.72
Litho-mesotrophic species	1680	804	876	1.83	1.42	2.49
Circumneutral-oligotrophic species	1832	797	1035	1.99	1.40	2.94
Atmo-oligotrophic species	3405	1883	1522	3.70	3.32	4.32
Other species	9033	4443	4590	9.82	7.82	13.04
Red-list species	1184	392	792	1.3	0.7	2.3

No-sep: records without *seepage indicators*; Sep: records with *seepage indicators*

Scorpidium scorpioides

For *Scorpidium scorpioides* a comparison can be made between the 1969-1975 period and the situation reported by Staatsbosbeheer (1988). Although the distribution map for the 1969-1975 period is not at all exhaustive, I have quite frequently visited some of the areas where *Scorpidium* was found ca 1985, but where it was not indicated for 1969-1975. This especially holds true for the areas marked ‘1’ and ‘2’ on the distribution map (Fig.6.2). I am almost certain that *Scorpidium* was absent or almost so from these areas in the earlier period. Also, Kuiper & Kuiper (1958) must have had enough information available to conclude that *Scorpidium* was rare or absent to the south-west of the supposed former seepage area, and all further information I have leads me to believe that the present abundance of *Scorpidium* in the Schut- en Grafkampen is attributable to an expansion in the last decades. The distributional scores in the mapping area ‘3’ (Oosterbroek & Post 1977) are also suggestive of such a shift: the records of isolated stems resulting from the inventory in 1970, the findings from Oosterbroek & Post (1978), and those from Staatsbosbeheer (1988) represent a southwestward movement of *Scorpidium* towards the reserve margin.

In conclusion, there is a trend that the species has disappeared from the central area and adjacent parts of the reserve, while hitherto unknown occurrences are found especially in the more marginal areas. On the whole the species has probably expanded even since 1975, although the recorded data do not provide any conclusive evidence.
The disappearance in De Wobberibben coincides with a substantial increase of *Sphagnum palustre*, *S.papillosum* and *S.flexuosum* ssp. *fallax*, and almost certainly indicates a dramatic acidification (unpublished vegetation map by G.J.M. Ruitenburg 1974, Calis & Van Wetten 1983), most probably due to the observed blocking of a ditch leading into the quagfen complex. In general, the withdrawal of the species from the central part of the area can be attributed to successional progress, including carr formation, abandonment of management, clogging of ditches and the associated acidification or desiccation of quagfens.

The new appearance in area ‘1’ coincides with the clearance of this area from scrub, and the digging of some ditches in order to decrease the influence of rain water and, during droughts, of a possible lowering of the mire water table. I have not revisited area ‘2’ in recent years, but ca 1970 this area comprised a large areal of reed beds with, among other species, *Campylium stellatum*, *C.elodes*, *Carex lasiocarpa*, and *C.diandra*, but without species more characteristically bound to fen vegetation mown in summer or early autumn. It is worth testing whether the management regime has changed here too.

In general, there are two local factors which could explain the expansion of *Scorpidium scorpioides* towards the southwestern border of De Weerribben. Firstly, this area has long been influenced by slightly brackish water. It is uncertain whether this was caused by local seepage from the former Zuyderzee, as reported for the neighbouring polder area (but not very probable at this greater distance from the former Zuyderzee dike), by a discharge of slightly brackish water from these polders, or by resident salt in the local peat and clay deposits. The somewhat brackish strain in the character of this part of De Weerribben is reflected in the occurrence of such species as *Scirpus lacustris* ssp. *tabernaemontani*, *Scirpus maritimus*, *Ophioglossum vulgatum*, and, possibly, *Hippuris vulgaris*. As shown in Chapter 5, the influence of lithotrophic surface water was paramount in this area in the late 1960s, but this was only the case after the construction of the Noordoost-Polder in 1941, and possibly even later, and facilitated by the hydrological impact of reclamations southeast of De Weerribben in the mid 1950s. Clearly it is an area subject to (further) desalinization during the 1940-1970 period, and the expansion of *Scorpidium* could be a lagging response. This could also explain a possible absence of *Scorpidium* and other *seepage indicators*, many of which avoid even slightly brackish water, during the inventory reported by Kuiper & Kuiper (1958).

Secondly, the involved part of the nature reserve comprised the major part of relatively young successional stages, used as productive reed beds, and so cut in winter, ca 1970. In the

Table 6.2 Frequency distribution of the stage of terrestrialization, in 1951, of 1985-'86 sites of *Scorpidium scorpioides* in De Weerribben

Site group:	**A**	**B**	**C**
Open water	5	1	4
Aquatic macrophytes	50	6	44
Very weak and thin *kragge*	37	2	35
Firmer and thicker *kragge*	43	11	32
Firm and thick *kragge*	0	0	0
Not mapped by Haans & Hamming	18	18	18

A: all sites
B: sites north-east of the Kalenbergergracht (decrease area)
C: sites south-west of the Kalenbergergracht (increase area)
Numbers of *Scorpidium* sites; Data from Haans & Hamming 1962 and Staatsbosbeheer 1988

course of the 1970s, the reed culture went through some ups and downs, and nature conservancy took care of the management of several parcels in the Schut- en Grafkampen area, partially advancing the mowing or cutting time, and so favouring some of the supposed seepage indicators prefering the vegetational physiognomy provided by summer-mown stands. For the 153 sites recorded in Staatsbosbeheer (1988), it was possible to quantify the relation with a successional trend on the basis of the corresponding stage indication by Haans & Hamming (1962). The results (Table 6.2) show that the majority of sites south-west of the Kalenbergergracht were open water and very weak *kragge* stages in 1951, whereas the area where *Scorpidium* is now decreasing mainly comprised *kraggen* that were already firmer in 1951. This result compares well with the general picture of the distribution map.

Scorpidium scorpioides is too rare a species in Dutch fen mires to expect its occurrence on the basis of a preferential stage of terrestrialization and the absence of brackish influences alone. There are no indications that the species was ever wide-spread and abundant in the central part of De Weerribben, which was already in a relatively far stage of terrestrialization in 1951. This central part not only differs from the marginal parts by the prevailing stage of terrestrialization and by the absence of brackish influences, but also by the absence of mineral influences such as provided by the former flooding with river water, in the *Carex* peat area in the eastern part of De Weerribben, and by flooding with brackish water from the former Zuyderzee in the Schut- en Grafkampen dredged-out bog peat area. These mineral influences are still traceable by the presence of a local cover of clay, ca 1-4 dm thick, on undisturbed baulks and peat grassland.

A good correlation exists with the dominance of tree species in quagfens in the three relevant areas, as mapped by Van Zon-Van Wagtendonk (1969):

- Expansion area (former bog, marine influences): *Salix*;
- Decrease area (former *Carex* peatland, fluvial influences): *Alnus*;
- Absence area (former bog, no marine or fluvial influences): *Betula*.

Next to these local processes and factors the expansion of *Scorpidium scorpioides* after 1975 was possibly facilitated by a general return towards lithotrophy of the surface water (Chapter 5).

Other species

The distribution of *Liparis loeselii*, *Menyanthes trifoliata*, and *Utricularia intermedia* was also mapped by Van Zon-Van Wagtendonk (1969), and I have added the relevant information to the distribution maps. I also included my own occasional observations during 1969-'72 and information from vegetation records in Verschoor (1978) for *Utricularia intermedia*. Hack (1973) mapped the occurrence of, *inter alia*, *Menyanthes trifoliata* along canals and ditches in De Weerribben in 1969. Although that map is difficult to read the pattern appears to be similar to that reported by Van Zon-Van Wagtendonk.

As regards *Liparis loeselii* (Fig.6.3), the inventory by Staatsbosbeheer (1988) shows much more occurrences than were observed by Van Zon-Van Wagtendonk, although the general area of distribution is similar. Since this species is only readily observable in a limited period and by trained observers, and since Van Zon-Van Wagtendonk and H.N. Leijs, who contributed much to her survey, largely worked on the basis of vegetational physiognomy and quick field inspection, and since they did not visit all parcels, no conclusions can be drawn as to the abundance and distribution of this species.

The distribution of *Menyanthes trifoliata* (Fig.6.4) has remained almost unaltered, although some of the scattered occurrences in the former bog peat area were not noticed by Van Zon-Van Wagtendonk and Hack.

The available data about the distribution of *Utricularia intermedia* have been summarized in Fig.6.5. Although the abundance of this species may vary among years, and the individual data sets may therefore be somewhat biased, the map suggests an outward move of *Utricularia intermedia*, similar to that observed for *Scorpidium scorpioides*. *Utricularia intermedia* is much less common, however, and it is especially rare outside the former *Carex* peat area. It would be interesting to see whether, in due time, this species will or will not expand into the former bog peat area.

A new hypothesis on the local behaviour of Scorpidium scorpioides and associated species

Summarizing, the following hypothesis is raised:

Possibly *Scorpidium scorpioides*, and some associated species, were restricted to the former freshwater *Carex* peat area, roughly the supposed former *seepage* area, until 1940. This situation was reported by Kuiper & Kuiper (1958). The Schut- en Grafkampen area was too brackish for the species (and also too early a stage of terrestrialization), and the central, former bog peat area had too low a base state. After the enclosure of the Zuyderzee and the reclamation of the Noordoost-Polder (1941) and of the polders south-east of De Weerribben (mid 1950s), the brackish water influence strongly decreased and the inflow of freshwater from the bordering Pleistocene, mainly through the surface water system, eventually filled the mire area with a lithotrophic water type, thus facilitating an expansion of the species over all parts of the terrain that were both in a suitable successional stage and endowed with a high base state. Of course it is uncertain whether *Scorpidium* might have settled in any appreciable amount in the central bog peat part if that would have been in an earlier stage of succession. Especially in the 1973-'78 period, however, the expansion was slowed down, or even held up by a general deterioration of the water quality, characterized by an increased similarity to polluted Rhine water and a decreased similarity to lithotrophic groundwater (Chapter 5). In the last decade, the improved water quality and a substantial increase in the area of quagfen mown in summer or early autumn ‘opened’ the Schut- en Grafkampen area for *Scorpidium*.

Simultaneously, successional progress and associated factors, such as the clogging of ditches, leading to an increased similarity of the local mire water to atmotrophic rain water, and the abandonment of management, caused the disappearance of *Scorpidium* from the supposed former seepage region.

Considering the environmental requirements of *Liparis loeselii*, *Scorpidium scorpioides*, *Menyanthes trifoliata*, *Utricularia intermedia*, and *Parnassia palustris* as belonging to a singular class, it appears that these requirements differ in strictness in the order given. Or, in terms of a human analogy, *Liparis* is the first to become conversant with a newly arisen environment, whereas *Utricularia* and *Parnassia* are the most tardy. In a steady-state approach of environmental response, such a difference is often colloquially named a difference in 'site maturity', and it can be interpreted in connexion with the 'inherent nutrient supply' of Finnish authors, defined in Chapter 3. Neither of these terms explain much; they are just names for a notion, which should be specified in order environmentally to test any site on its suitability for the species.

Species-environment response relations are dynamic rather than static relations, however. In the case of quagfens with *seepage indicators*, some sites, such as, in De Weerribben, those in the expansion area of *Scorpidium scorpioides*, are apparently subject to a relatively fast succession, whereas others, such as the older summer-mown quagfens on a firmer *kragge*, do not change much during a certain phase of their existence. In this respect, the species are probably adapted to a particular rate of change by physiological and regenerative capabilities. *Liparis loeselii* and *Scorpidium scorpioides* seem to be more tolerant of relatively high rates of change than *Utricularia* and (the quagfen form of) *Parnassia palustris*. This concept is probably similar to the concept of 'milieu dynamics' introduced by Van Leeuwen (1966, compare Van Wirdum 1982, 1985, 1986). Again, not much is explained, but the domain for further specification is narrowed somewhat, and it has been made clear that the whole process must be studied, rather than single states alone.

By adding the information about *Pedicularis palustris* and *Equisetum fluviatile* presented in the next section, and my own, undocumented, impression with regard to the other *seepage indicators*, the ranking of these species relative to their capability of quickly invading changing environments can be completed as shown in Table 6.3. This capability is more or less related to the withstanding of an increasing rate of change in the sites, such as occurs from disturbances, acidification, or eutrophication.

Drepanocladus lycopodioides has not been included in this table, since I have no good indication whether or not it belongs to the supposed class of *seepage phenomena*. It should be noticed that the various species differ in their preference for various phases of the succession and sometimes for environmental variants of the *seepage* sites, and that some of them may behave differently (and possibly also belong to genetically different taxa) in other types of environment. It is also important that all of the *seepage indicators* are slow invaders as compared to most other species in the Dutch mire flora.

As to the application of this hypothesis in nature management, we could infer from Table 6.3 that, since *Scorpidium scorpioides* has expanded in De Weerribben, the 5 and 6 species groups may possibly follow. If not, we might expect the group-4 species to decrease again, possibly followed by group-3 taxa. Although we do not know in physical terms what happens exactly in reponse to a certain management strategy, this would at least help to ascertain whether or not management is progressing on its way to restore favourable conditions for the

Table 6.3 Ranking of *seepage indicators* and associated species according to their capability of quickly invading changing environments, from strong (1) to weak (9)

1	*Bryum pseudotriquetrum* *Fissidens adianthoides* *Riccardia multifida*	6	*Utricularia intermedia* *Dactylorhiza incarnata*
2	*Aneura pinguis* *Carex diandra* *Campylium stellatum*	7	*Parnassia palustris* *Calamagrostis stricta*
3	*Campylium elodes* *Carex lasiocarpa* *Liparis loeselii*	8	*Eriophorum gracile* *Scorpidium cossoni* *Carex buxbaumii*
4	*Scorpidium scorpioides* *Pedicularis palustris*	9	*Philonotis marchica* *Sagina nodosa*
5	*Equisetum fluviatile* *Menyanthes trifoliata*		

Scorpidio-Caricetum diandrae. With the ecological information presented throughout this study such a diagnosis may be of help in the search for better strategies, if need be.

Although any testing and further environmental specification of the new hypothesis does lie outside the scope of the present study, some corroborative information is given below. The gathering of this information is based on the idea that several points in the hypothesis are not restricted to *Scorpidium* and other *seepage indicators*. Especially the vegetation of aquatic macrophytes is supposed to reflect the hydrological factors in the surface water system more directly than do the quagfen species, since the local peat in the *kraggen* of a quagfen is an additional factor determining the operational milieu of the species and the surface water quality. An analysis of the distribution of other species may, therefore, contribute to the search for ecological factors involved.

6.7 Further corroborative distributional information

The data presented in the above sections do not support the hypothesis that the distribution of *seepage indicators* in De Weerribben is determined by the outflow of groundwater under the influence of larger hydraulic heads in the bordering Pleistocene area. The distributional patterns, and their dynamic behaviour, suggested a relation with (1) desalinization in the formerly slightly brackish southwestern part of the nature reserve, (2) the general succession of the mire vegetation, being in a different phase in the central and marginal parts of the reserve, respectively, (3) management factors, possibly linked with the successional factor, (4) local differences in the nutrient and base states of the fenland, and (5) a general tendency of increasing lithotrophic influences in the whole mire area, both after the reclamation of polders and, in the last decade, after a temporary deterioration of the water quality in the mid 1970s. These relations were summarized in a new hypothesis about the changing distributional patterns of, especially, *Scorpidium scorpioides* and *Utricularia intermedia*. Especially the factors 1, 2, and 5 above

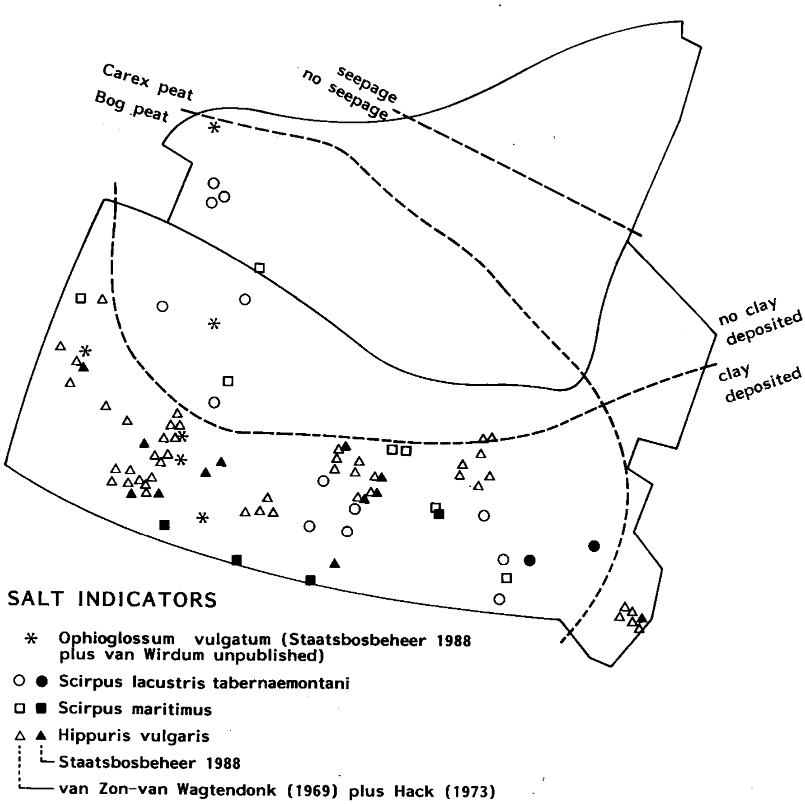


Fig.6.7 Former and present distribution of some salt indicators in De Weerribben

refer to processes rather than states, and I have tried to rank the *seepage indicators* according to the rate of change that they require and tolerate, respectively. The research carried out does not allow any strict testing of this hypothesis and the factors involved, but some further corroborative information will be presented below.

The distribution of salt indicators

The former brackish character of the southwestern marginal area of the De Weerribben nature reserve neatly follows from geological, pedological, historical, and hydrological information, but no water or soil analyses are available to document it. Staatsbosbeheer (1988), Van Zon-Van Wagtendonk (1969) and Hack (1973) mapped the distribution of some salt indicators in De Weerribben (Fig.6.7). *Scirpus maritimus* and *S. lacustris* ssp. *tabernaemontani* are salt indicators beyond doubt. *Hippuris vulgaris* prefers clay soils in The Netherlands, and it is considered a weak salt indicator. These three species occur in or nearby bodies of open surface water, but their root systems may hold contact with a different micro-environment in the soil.

Ophioglossum vulgatum occurs in reeds and litter fen, and in The Netherlands it is less rare in the coastal district with brackish influences, than it is in other parts of the country. The general distribution of these four species together coincides with the present expansion area of *Scorpidium scorpioides*, and also with the area where marine clay was once deposited (Fig.6.1 and 6.7, Haans & Hamming 1962) and disposed of in the *petgaten* in the course of peat dredging.

Although the number of observations is relatively small, both species of *Scirpus* seem to have disappeared from all but the very soutwestern margin of De Weerribben. The distribution of *Ophioglossum vulgatum* was only mapped by Staatsbosbeheer (1988); I just added some occasional observations in order to complete the picture somewhat. *Hippuris vulgaris* has drawn the attention of various researchers through the years. The distribution maps are probably quite reliable and show a substantial decrease in the presence of this species between 1968-'69 and 1985-'86. The finds northeast of the Hamsgracht canal which were not noticed by Hack were not inspected by that author either and most probably do not represent new settlements. *Hippuris* does not show any clear movement; it just gradually disappears.

The distribution of Stratiotes aloides (Fig.6.8)

The ecology of *Stratiotes aloides* has been the subject of other researchers (M.C. Groenhart, largely unpublished, Bloemendaal & Roelofs 1988, Roelofs & Cals 1989), and it is only touched upon here as far as the observations made for the present study provide a link between the surface water system and quagfen vegetation. This is especially so since the aquatic vegetation is expected to react more directly on the surface water quality than does the quagfen vegetation, and *Stratiotes aloides* has shown a dramatically dynamic behaviour in the 1970-'89 period. The species has recently been associated with groundwater outflow phenomena (Roelofs & Cals 1989).

Stratiotes aloides was especially abundant in the northeastern part of De Weerribben from ca 1940 to ca 1970, as can be inferred from maps, aerial photography, and information provided by local inhabitants (Fig.6.8). Some of this information seems to indicate that the species was less abundant before 1940, and that it reached a maximum abundance in the 1950s. Around 1970, it was still so abundant in De Weerribben that several waterways were no longer navigable, and the State Forestry Service purchased a mowing boat in order to remove this vegetation from many places. On aerial photographs and from my own observations it could be noted, however, that ca 1970 a gap existed between the *Stratiotes* zones in many lakes and *petgaten* and a band of nymphoid vegetation, which gap I am now inclined to interpret as a sign of a retreat of the stands of *Stratiotes* vegetation (Van Wirdum 1979). Indeed, in several places where *Stratiotes* has now entirely disappeared, the nymphoid band remained present and only slowly widened in a shoreward direction.

From 1972 onwards, and within 3-5 years *Stratiotes* disappeared from most places in the nature reserves of North-West Overijssel, and ca 1977 it was almost completely absent from De Weerribben. In De Wieden this process started some three years earlier. This has been ascribed to eutrophication and turbulence (compare Segal & Groenhart 1967, for Broadland, U.K.: Moss 1978), to a fungal disease (Zonderwijk, pers. comm.), and to too high concentrations of bicarbonate from the *boezem* system (Bloemendaal & Roelofs 1988, see discussion in Van Wirdum 1989). In Van Wirdum (1979) I related the disappearance of *Stratiotes* to a combination of local nutrient dynamics and the way the relevant processes were governed by the macro-ionic

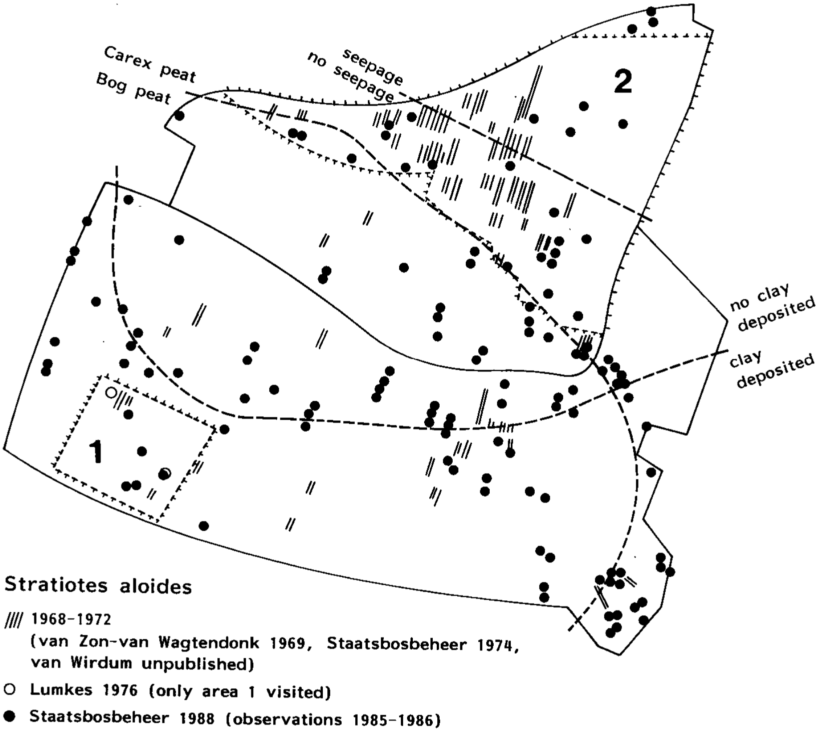


Fig.6.8 Former and present distribution of *Stratiotes aloides* in De Weerribben
The areas '1' and '2' are specifically referred to in the text

composition of the surface water. More or less contrary to Bloemendaal & Roelofs, I hold the decreased lithotrophy, indicated by a decreased Ionic Ratio $[^1/_2Ca^{2+}]/\{[^1/_2Ca^{2+}]+[Cl^-]\}$ (Appendix D) and an increased electrical conductivity, responsible for the occurrence of peaks and lows in the availability of nutrients, which fluctuations I suppose to be unfavourable for *Stratiotes aloides*. Moss' publication provides a description of mechanisms that could be triggered by the nutrient peaks involved. In my hypothesis, *Stratiotes aloides* was related to lithotrophic, yet stable nutrient-rich environments, often in the neighbourhood of farmland. Such a relation is also suggested by the distribution of *Stratiotes* in De Weerribben, where most of the 1968-'72 sites are in the immediate neighbourhood of grassland, and where an interesting aggregation of sites is found near the strip of undredged mineral-rich peat traversing the area.

Through a detailed inventory in 1976 (Lumkes unpublished, Verschuren unpublished) of the areas marked '1' and '2' in Fig.6.8 it was confirmed that the species had almost disappeared from both areas. In area '1' two sites were still present, comprising eight plants and a small but healthy stand, respectively. In area '2' six ditches and six *petgaten* still had *Stratiotes*, four *petgat* sites and one ditch site containing a small number of unhealthy-looking plants only. The sites where the species maintained itself longest were all enclosed in grassland and not easily accessible for *boezem* water, which had changed in character from lithotrophic to molunotrophic, but was not yet hypertrophic (Chapter 5).

During an occasional terrain inspection in 1979 I noticed a few healthy *Stratiotes* plants at two sites from where the species had been absent in the years before. During the 1980s it gradually became clear that *Stratiotes aloides* made its way back in De Weerribben, although Staatsbosbeheer (1988), on the basis of the inventory given in Fig.6.8, did not yet believe this would continue. Healthy *Stratiotes* was, however, in 1985-1989 found scattered all-over the reserve in increasing numbers. From consecutive aerial and field observations, I noticed several small, and at first submerged, flocks expanding to cover whole *petgaten* during this period. Although no causal relation has been demonstrated, this correlates well with the observed stabilization of the lithotrophic strain in the water quality (Chapter 5). It appears from Fig.6.8 that *Stratiotes* now occurs much more scattered throughout De Weerribben than it did in the 1968-'72 period. While lithotrophic conditions were observed all-over the area in the late 1960s, this suggests that the nutrient state was only sufficiently high in the earlier period in the neighbourhood of agricultural land use, and that such a relatively high nutrient state, *i.e.*, a consistently high supply, is now more wide-spread.

A similar recovery as recorded in De Weerribben (and in some other parts of North-West Overijssel) has, until 1988, not been observed in the lakes Venematen and Duinigermeer in the Wieden area. Water quality data are available for lake Venematen, and these data show that the Ionic Ratio has not yet recovered there either.

These data, while not yielding any demonstrative proof of whatever hypothesis, would fit in the hypothesis suggested by the expansion of *Scorpidium scorpioides*: an expansion towards the southwest of De Weerribben by desalinization after the construction of the Noordoost-Polder, and a general recovery by the presently lithotrophic water quality. It remains uncertain whether the higher nutrient state possibly indicated by *Stratiotes* will become a negative factor of any importance to the quagfen vegetation, as suggested by the absence of *Scorpidium* from the main area of the former distribution of *Stratiotes* in De Wanden (compare Fig.6.2 and 6.8).

The distribution of some other species

Among the other species for which the distribution has been mapped in Staatsbosbeheer (1988), Van Zon-Van Wagtendonk (1969), or Hack (1973) and which are relevant to the question of (ground)water flow and vegetation are *Pedicularis palustris* and *Equisetum fluviatile*.

Pedicularis palustris (Fig.6.9) is often associated with quagfen vegetation including *seepage indicators*. On the national scale, *Pedicularis* is considerably less rare than *Scorpidium scorpioides*. Its distribution in De Weerribben is more or less similar to that of *Scorpidium* and *Liparis loeselii*, but it is less common. *Pedicularis palustris* is a half-parasite and it thrives well on graminoid species, such as *Juncus subnodulosus*, in quagfens. If the vegetation is not mown during the growing season, its occurrence is not persistent. There is no evidence of the species showing a strongly dynamic behaviour, and it most probably occurred at most sites in the expansion area of *Scorpidium scorpioides* before the latter species settled there, which indicates that the overlapping part of their requirements, especially the mowing regime and the local base state, was already fulfilled.

Equisetum fluviatile (Fig.6.4) is also often associated with *seepage indicators*, and it has been described as a dominant species in earlier phases of the quagfen succession in supposed

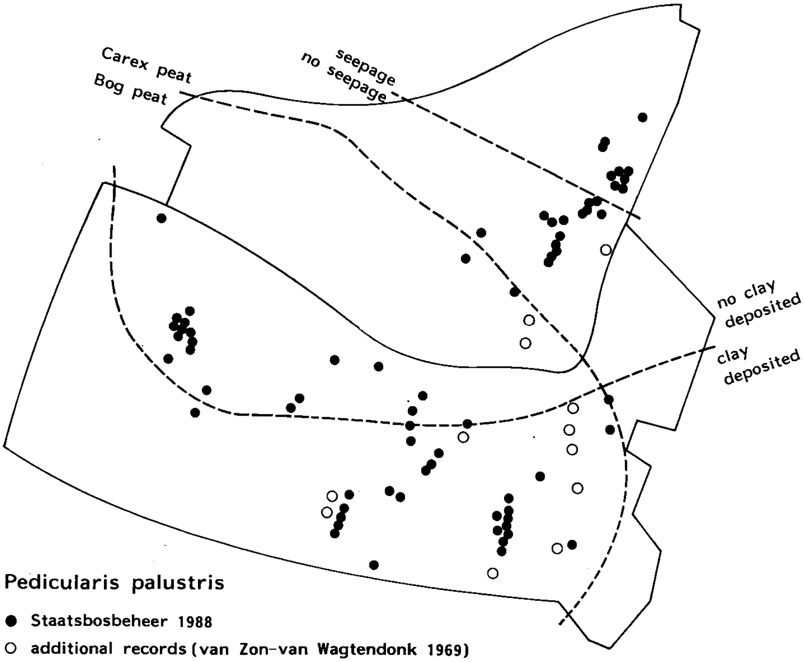


Fig.6.9 Distribution of *Pedicularis palustris* in De Weerriben

groundwater outflow areas (see Kuiper & Kuiper 1958, Segal 1966, Meijer & De Wit 1955). I have observed similar zonations in parts of De Wieden also. In De Weerribben this is far less commonly found, and *Equisetum fluviatile* is restricted to the *Carex* peat area, like *Menyanthes trifoliata*. Its distribution was not studied after 1969, so that no conclusions can be drawn concerning its dynamic behaviour.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 7

The quagfens of De Stobbenribben and their vegetation

7.1 Introduction

De Stobbenribben is a complex of former *petgaten* in the north-eastern part of De Weerribben (Fig.7.1). Kuiper & Kuiper (1958, also Kuiper & Lapré 1956) and Segal (1966) gave particular attention to this complex and mentioned it as a good example of quagfen under the supposed influence of outflowing groundwater. As shown in Chapter 6, De Stobbenribben is well within the area of distribution of various *seepage indicators* in De Weerribben, and it may be considered a *locus classicus* for the *seepage hypothesis* introduced in Chapter 2. From Chapter 5 onward it is clear that, since the reclamation of the nearby polder Wetering-Oost about 1955, the hydraulic head of the groundwater in De Stobbenribben became so much lowered that it is now an area of infiltration, supplied with water from the *boezem* system and the local rainfall.

The vegetation cover of De Stobbenribben, however, did not change considerably since about 1955, and several *seepage indicators* are still present in appreciable quantities. De Stobbenribben was therefore selected for a descriptive case study into the relations between hydrological factors and the occurrence of *seepage indicators*. In this chapter I will provide the relevant information about De Stobbenribben, the local stands of vegetation, and the indicated environmental conditions. Some special methods concerning the eco-hydrology, and the results of their application, will be reported in Chapters 8 and 9. In Chapter 10, I try to combine the various recorded data into a functional hypothesis that can be used as a basis for further research in De Stobbenribben and other mire complexes.

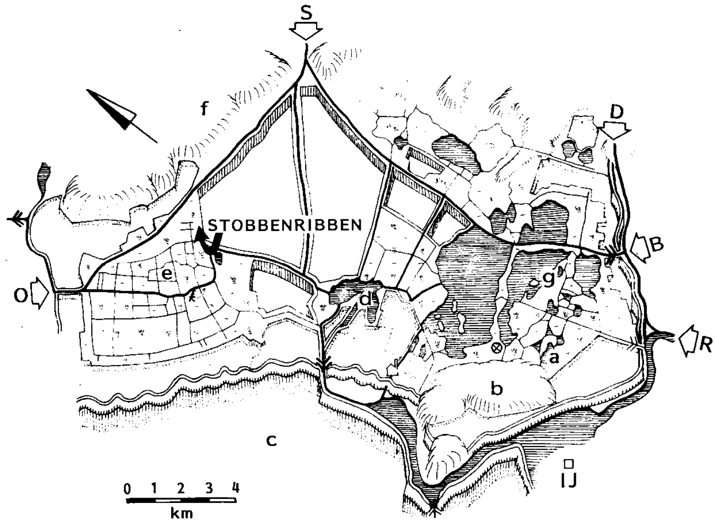


Fig.7.1 Location of De Stobbenribben in North-West Overijssel

See Fig.4.3 for further details

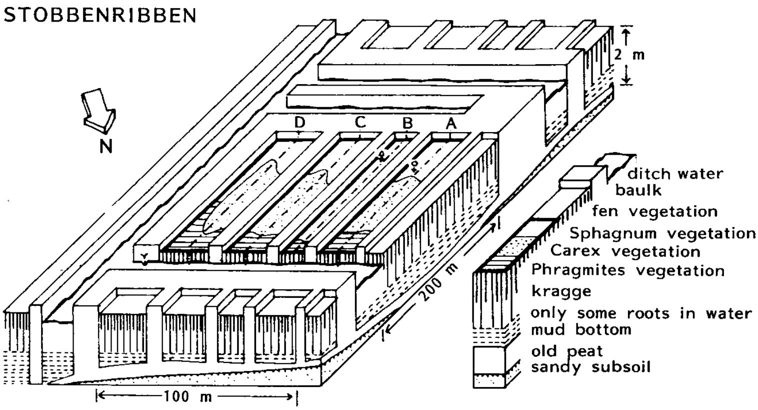


Fig.7.2 Diagrammatic representation of De Stobbenribben

Relative width of baulks and ditches exaggerated; A-D: Parcels and sections referred to in the text of Chapters 7-10

7.2 Topography, *petgaten* and *kraggen*

The four Stobbenribben quagfen parcels studied in this Chapter are about 30 x 200 m each, oriented in a southwest-northeast direction. They will be indicated here as parcel (former *petgat*) A..D from north-west to south-east. (Fig.7.2). The original *Carex* peat was probably dredged away between 1880 and 1920. The depth to the sand bottom varies between 1.6 and 3.6 m (Fig.7.3). The original peat was formed under the influence of a rivulet and it contained many old tree logs; hence the name Stobbenribben (Du. *stobbe*: tree stump). Before the peat was dredged, the area had for some centuries been used as agricultural land, probably primarily as pastures. Due to these factors an inferior quality of fuel peat was produced and tree stumps as well as the grassland sod were partially dumped in the *petgaten*. Some remaining peat was dug away during World-War II. During the terrestrialization, *Typha angustifolia* and *Menyanthes trifoliata* probably were the pioneering helophytes, growing partially on sods and old peat materials floating up from the bottom of the *petgaten* (Havinga 1957). The *kragge* thus became an admixture of newly formed rhizomes and peat, and older materials. Where old peat was raised partially above the water level, it may have given rise to a fast acidification and the formation of irregular patches of *Sphagnum* and *Molinia* vegetation which can still be recognized.

Most probably the 1.5-3 m wide baulks in-between the terrestrialized *petgaten* were formed by the disposal of sods in old ditches during peat dredging. The *kraggen* are fixed to these baulks about 0.5 m below the baulk top. Away from the baulks they float up and down with the movement of the water table almost freely. During the present survey the baulks were partially grown with *Myrica*, *Salix* and *Alnus* scrub and *Molinia* tussocks, but they have recently been cleared to provide acess for tractors used for the transportation of hay and reed. The wider strips of peat bordering De Stobbenribben to the south-east and south-west partially consist of the original peat. The thickness of the *kragge* roughly varies between 0.4 and 0.7 m, but at some places the removal of scrub has produced scars providing a window to the underlying body of mire water. Similar windows (called pulk-holes in Norfolk) have in the past been interpreted as *seepage* windows, but there is no evidence of the correctness of this interpretation. *Phragmites* rhizomes form the main network in the *kragge,* and vertical stems extend far below it into a body of relatively clear water. The upper part of the *kragge* is mostly composed of *Carex* rhizomes, covered with bryophyte material, but locally other species may have contributed substantially to *kragge* formation. The peat in De Stobbenribben has been dredged to an average depth of 2.5 m. The remaining peat is covered with a ca 1 m thick layer of sapropelic broth, leaving a "sheet" of relatively clear water between 0.7 and 1.2-1.5 m below the kragge surface. Between the remaining peat and the underlying sand bottom a 3-15 cm thin so-called *gliede* layer is often observed. This layer consists of an amorphous, strongly humified organic matter inclusive of illuvial humic substances, which may contain clay minerals and sand grains, and it has a low permeability to water.

Nature management in De Stobbenribben started about 1959 and some scrub of *Myrica* and *Alnus* was removed from the *kraggen* shortly after 1965, as can be inferred from a comparison of vegetation maps. During a preliminary survey in 1969-'70 I raised strong doubts about the presence of groundwater outflow (see Chapters 8 and 9), and the alternative hypothesis emanated from studies of a quagfen complex loosing substantial amounts of water towards the body of groundwater, especially under the influence of the low-lying polder Wetering-Oost at a distance of only 250 m. De Stobbenribben was chosen for a case study for this reason and also since (1) it is a *locus classicus* in the original seepage theory and (2) the entrance of surface

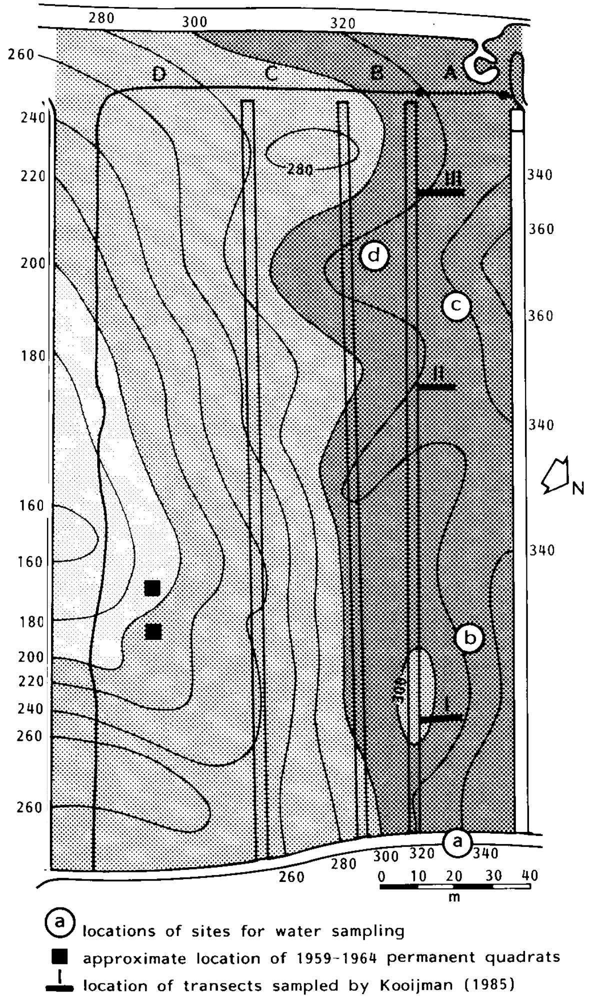


Fig.7.3 Sand depth (cm) in De Stobbenribben; location of some research sites mentioned in Chapters 7-10

water into the *petgaten* is almost entirely forced through the open connexion with a ditch at one short end of each *petgat*. The study was directed towards the detection, description, and analysis of a conceivably resulting length gradient in the *petgaten*.

7.3 The vegetation cover

Available data

The vegetation cover of De Stobbenribben has repeatedly been recorded. A general description was given by Kuiper & Lapré (1956). The stands of two ‘permanent quadrats’ were reported by E.H. Krijger, H. Gaasenbeek, S. Segal, A.C. Adam, W.N. Ellis, and M.C. Groenhart, in various combinations, in 1959, '60, '61, and '64 (unpublished records in State Forestry Archives, Zwolle). These permanent quadrats were abandoned after 1964 and their exact location was not recorded. From a sketch map and additional data on the data sheets it is certain that they were situated in quagfen parcel D, in a wet hollow with a weak *kragge* (Fig.7.3). More detailed investigations were carried out from about 1964 to 1970 under the supervision of S. Segal (University of Amsterdam). The present author was also introduced to the area and the *seepage* problem as a student of Segal in 1969. From 1973 onwards various students took part in the study reported here under his supervision.

The first vegetation map was produced by Van Zon-Van Wagtendonk (1965). The moss layer was not analysed in detail during that study, and the boundaries between different types of vegetation were sketched in, rather than accurately determined. Stegeman (1968) made a detailed survey of the micro-zonation of bryophytes, especially in De Stobbenribben, but her report does not provide a synopsis of the stands of bryophyte vegetation, and she obviously wrongly identified some species. Van Zon-Van Wagtendonk and Stegeman also report relevés of representative vegetation stands.

During the present survey, a new map of the vegetation cover was prepared in 1973 by Bergmans (1975). Although some species may have been overlooked by him, this map provides a rather precise and well-documented picture of the vegetation cover, based both on the higher plants and the bryophytes. A simplified version of this vegetation map is discussed below and presented as Fig.7.4.

Bredenbeek, Gerrits & Van Loon (1979), under the supervision of H.N. Leijs (RIN) published another vegetation map, according to the legend developed by Van Zon-Van Wagtendonk. The drawback of this legend, which is strongly based on the abundance of some higher plant species with a rapid vegetative spread, is that the resulting maps probably reflect the effects of drier and wetter years and of the time of mowing at least as strongly as the basic pattern of water relations (*cf* Chapter 6). Boeye (1983) compared the various vegetation maps and made an additional, though short, survey as part of the present study. Kooijman (1985) studied some important factors of nutrient dynamics in De Stobbenribben at three locations in one of the parcels and she recorded the vegetation stands at these locations various times according to a detailed sampling in 20 x 20 cm plots. Her study was supervised by J.T.A.Verhoeven (University of Utrecht) and by the present author.

Aerial photography and multispectral scanning were applied to De Stobbenribben as part of a survey into the application of remote sensing techniques to the mapping of vegetation (Van Wirdum 1977, Jalink 1990, and various unpublished results). Although these remote sensing studies are not reported here, the results have provided additional information concerning the vegetational pattern through the years (see also Chapter 10), and one aerial photo is reproduced in Fig.7.5 in order to provide a picture of De Stobbenribben intermediate between the real situation and the abstract vegetation map.

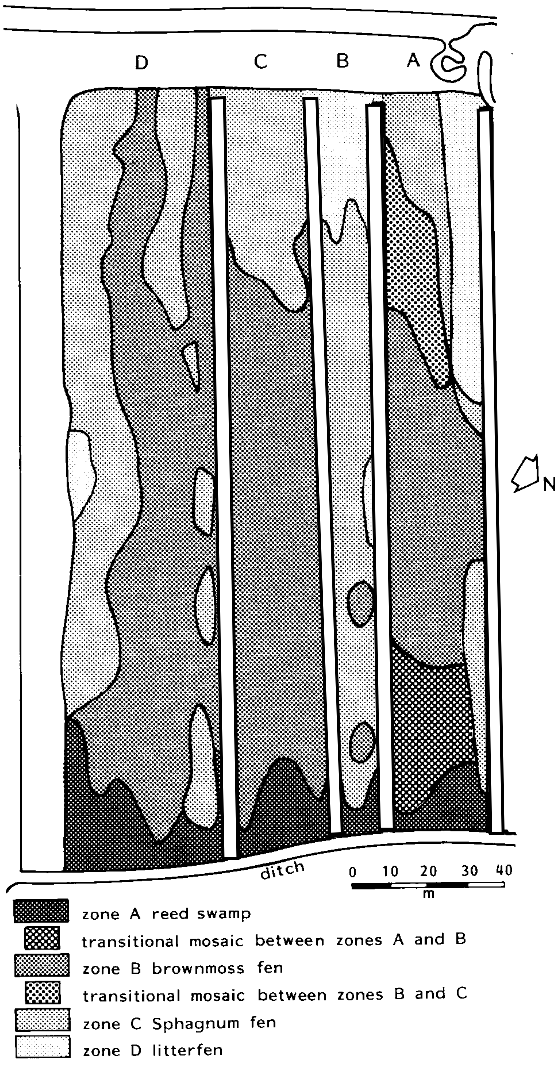


Fig.7.4 Vegetation map of De Stobbenribben (generalized after Bergmans 1974)

The vegetation map (1973)

In order to render the vegetational pattern of 1973, reported by Bergmans (1975), in a surveyable diagram, several types were combined into four that especially emphasize the composition of the moss layer and the presence of differential species. By doing so, the abundance coding of species had to be adapted and was scaled down to four classes with a numerical value used for quantitative interpretation:

5 Dominant, and alone determining the visual impression of either the herb layer or the moss layer in substantial parts of the mapped area;
3 Frequent, *i.e.*, found without much searching, and often locally abundant or even patchwise dominant;
1 Infrequent, *i.e.*, either rare, or in fact not rare but easily overlooked when the actual sites of occurrence are not specially searched for;
0 Not observed.

The estimates given in Table 7.1 at the end of this chapter apply to the whole area mapped under the relevant type, rather than to any arbitrary number of vegetation samples. The description is, therefore, equivalent to that given for the map elements in the maximum-areas method introduced in Chapter 5, although the reliability and accuracy of the descriptions for De Stobbenribben are much greater, due to the more elaborate method of field recording. Still some species must have been overlooked or misidentified.

Since the main types of the vegetation cover are different in their spectral reflection also, the pattern can be recognized from the air, as shown in the remote sensing image of Fig.7.5. The vegetation cover obviously exhibits a length gradient, both in its floristic composition and in its spectral reflection.

Table 7.1 includes a summary of the vegetation records of the permanent quadrats, re-scaled to the new scale, although strictly not applicable to single relevés. The records by S.Segal and H.Gaasenbeek, dated 1961 (July, 25th, and August, 3rd) were taken as the main reference, since these records appear most reliable. Additional species mentioned for any of the years 1959-'64, in these permanent quadrats have been marked with a plus-sign in the appropriate column. All relevés, especially of the moss layer, are biased by the experience and feeling for less conspicious species of the various investigators, and the differences should not be over-emphasized.

Some species were not mentioned by Bergmans (1975). Most of these species are still rather abundant in De Stobbenribben, and must have been overlooked. The abundance of *Drepanocladus lycopodioides* mentioned by Segal is almost certainly a mistake. The species may have been present, but forms of *Scorpidium scorpioides* may have been taken for it in the abundance coding. Collections I saw invariably contained only *Scorpidium scorpioides*. *Calliergon giganteum* is difficult to distinguish from *C.cordifolium*. Plants usually considered to belong to *C.giganteum* certainly occur (or occurred) in De Stobbenribben, but unquestionable *C.cordifolium* is as abundant locally. *Sparganium minimum* is a very rare species in De Weerribben anyway.

The permanent quadrats were situated in a very wet part of zone B in quagfen parcel D (Fig.7.3). A comparison of the records made ca 1960 with the 1973 zone B description (Table 7.1) does not reveal any striking differences, the less so since the exact location is not known.

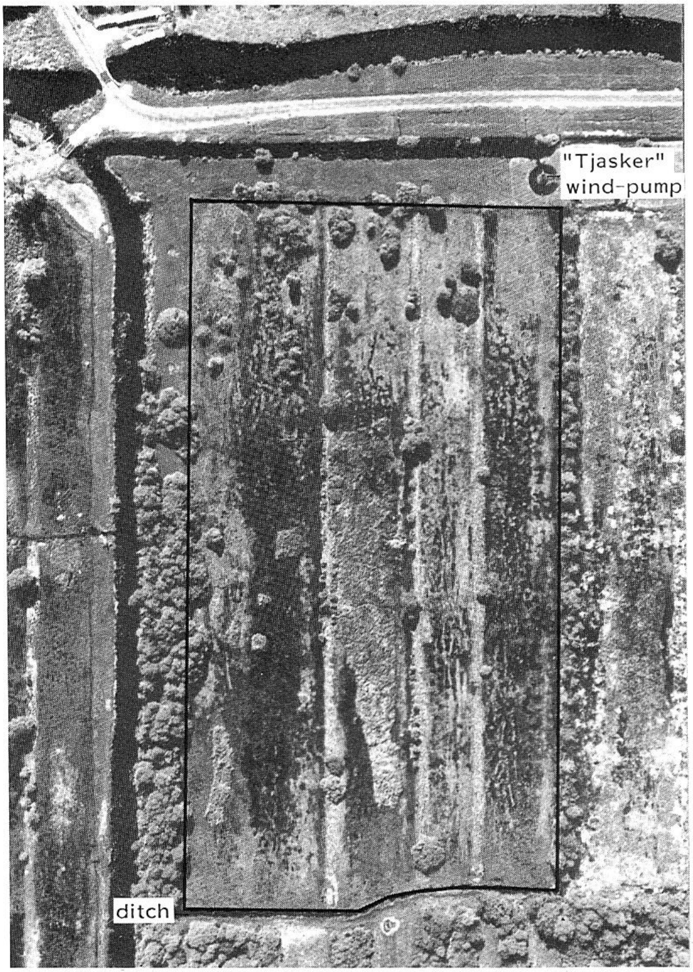


Fig.7.5 Aerial photograph (near-infrared) of De Stobbenribben (1975, May, 30th)
Photography: CNES/NIWARS; the deviating field in parcel C (Fig.7.4) represents a *Cladium mariscus* stand

On the stability of the vegetational gradient

A comparison of the various vegetation maps (Bergmans 1975, Boeye 1983) proves that the general length gradient observed in 1973 was also present in 1965, 1979 and 1983. There are certain striking differences, however, within the main vegetational zones. These differences are largely due to management factors, as dicussed below for the three major points.

In parcel A, zone B, a stand dominated by *Typha angustifolia* was mapped by Bergmans (1975). This stand was also observed by Van Zon-Van Wagtendonk (1965), but it had disappeared in 1979 (Bredenbeek *et al.* 1979). It was replaced by quagfen vegetation dominated by *Juncus subnodulosus* and, on hummocks, by *Sphagnum* species. This may be due to the continued mowing in late summer. Mowing in summer not only reduces the growth of large helophytes but also exerts an influence on the terrain conditions: the weak upper part of the *kragge*, with hollows and hummocks, is re-modelled by the machine tracks, and some of the weakest spots become filled with plant remains. Possibly, the obstruction of the ditch, discussed in Chapters 8 and 9, contributed to a changing water quality underneath the *kragge*, thus also worsening the milieu for *Typha angustifolia*.

In parcel C, zone B, Bergmans (1975) found an extensive stand of *Cladium mariscus*. This stand was formed by the extension of *Cladium* vegetation from smaller patches indicated by Van Zon-Van Wagtendonk (1965). This was almost certainly caused by a less intensive mowing due to the local inaccessibility of the weak *kragge*. After 1983 the stand of *Cladium mariscus* was cleared and it is now replaced by another zone B ,and partially zone C, vegetation.

In parcel D, zone B, vegetation dominated by *Juncus subnodulosus* and *Sphagnum* species in 1965-'79 was partially replaced by a type dominated by *Carex elata* and *Scorpidium scorpioides* in 1983. This seeming regression may well be due to the combined influences of ditch cleaning and mowing with machines. It was also noticed in other parcels. It is possible that this particular effect is rather due to weather and wetness conditions in specific years than representing an ongoing trend, however. I have seen relatively strong fluctuations in the dominance of various plant species through the years anyway.

As regards the present survey, the following conclusions can be drawn from the comparison of vegetation maps:

The length gradient in the vegetation of De Stobbenribben was stable between ca 1965 and ca 1983. Additional reference to aerial photography (1949, 1959), and own observations suggests that this stability holds true for the whole period 1950-'90.

In spite of possible changes in hydrological conditions, the local environment was still suitable for an expansion of *Scorpidium scorpioides* and other associated supposed seepage indicators at the end of the period mentioned. Any significant expansion of zone A vegetation can not be proved on the basis of the vegetation maps.

7.4 The vegetational zones

In order to quantify the similarities between the vegetational zones in 1973, the similarity coefficient of Sørensen (**S**) is evaluated in Table 7.2:

(**Sørensen Formula**) $\mathbf{S} = 2\mathbf{c} / (\mathbf{a}+\mathbf{b})$

where
a,**b**: sum total of species in zones a and b, respectively;
c: species common to both zones compared;
a+**b**-**c**: species unique to either of the zones compared.

Table 7.2 Evaluation of the Sørensen similarity coefficient for the vegetational zones in De Stobbenribben (left-hand table, **S** given as %).

	Sørensen				**unique**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
A	100	53	55	55	70	63	76	72
B		100	65	68	36	65	57	49
C			100	78	47	54	100	42
D				100	44	53	74	90
					common			

The right-hand table shows the number of species common to both zones compared (below diagonal), and the number of unique species (above the diagonal). The diagonal has the sum total of species in each zone.

Table 7.3 Ecological indicators in the vegetational zones A-D in De Stobbenribben.

	N	**A**	**B**	**C**	**D**	**TOT**
ALL	133	150	149	228	170	697
Two-factor indications:						
LTHOLI	8	4	20	10	3	37
LTHMES	6	9	13	10	8	40
REST	79	106	75	116	90	387
ATMOLI	24	13	22	66	44	145
CIROLI	16	18	19	26	25	88
Seepage, Red-List species:						
SEP	10	11	27	21	4	63
RED	27	22	37	63	25	147
Water Type:						
WT?	21	21	22	40	31	114
LTH	25	30	42	29	17	118
ATM	32	17	25	83	54	179
CIR	55	82	60	76	68	286
Nutrient State:						ANY
NU?	10	11	13	16	14	54
EUT	23	40	12	16	14	82
MES	47	60	54	81	60	255
OLI	53	39	70	115	82	306
Phytosociological Type:						
BOG	8	0	1	16	7	24
DAV	4	5	7	10	3	25
FEN	30	28	41	72	52	193
LAS	10	9	19	22	8	58
LIT	30	33	27	47	45	152
MOL	22	20	16	39	33	108
SMP	29	55	38	22	22	137

	N	**A**	**B**	**C**	**D**	**TOT**
Finnish System:						
FN?	52	54	33	63	53	203
FIN	81	96	116	165	117	494
Base State:						
OMB	7	1	4	21	10	36
POR	6	4	7	16	9	36
TRL	32	40	51	62	57	210
WMS	30	44	39	48	37	168
XRC	6	7	15	18	4	44
Mire Level:						
FLK	41	71	81	70	45	267
HUM	18	7	13	44	29	93
INT	22	18	22	51	43	134
Supplementary Nutrient Effect:						
NO	8	1	8	28	14	51
16	23	21	40	24	108	
FLD	39	50	67	66	62	245
SEP	18	22	20	31	17	90
Inherent Nutrient Effect:						
NO	51	68	69	90	76	303
MOS	6	1	4	16	10	31
NVA	10	11	18	21	11	61
RFN	14	16	25	38	20	99

N Number of species involved; A..D Frequency scores per zone; TOT Sum total of scores
(Phytosociological type SMP includes type AQU)
Explanation of terms: Appendix C, Chapter 3.

The greatest floristic similarity exists between zones C and D, B and D, and B and C, respectively. The zones are considered more or less arbitrarily defined in a continuous gradient. The transition from zone A to B is somewhat more abrupt.

An ecological characterization of the zones is made on the basis of species indication, as treated in Chapter 3 (see Table 7.1 also) in order to obtain an independent reference for conclusions on the basis of ecological investigations. Several avenues are open for such a characterization. The one treated below is based on the frequency of indicators in the various vegetational zones, evaluating dominant, frequent, and infrequent species by counts of 5, 3, and 1, repectively. The result of this counting is shown in Table 7.3 and will be referred to as a spectrum. The distribution of frequencies in De Stobbenribben as a whole results from the sum total of the values found for the separate zones and this all-zones spectrum is diagrammatically represented in Fig.7.6. The spectra for the separate zones have been corrected for the all-zones distribution in order to obtain the ‘corrected’ spectra given in Fig.7.6. Note that, as in Chapters 3 and 6, only species indicative of a co-occurrence of litho- and oligotrophic, litho- and mesotrophic, atmo- and oligotrophic, and circumneutral and oligotrophic conditions, respectively, were separately counted in these diagrams. The differences between the zones are significant at the 0.995 level (chi-square test).

Seepage indicators and red-list species are especially found in zones B and C. The phytosociological spectra in Fig.7.6 show that zone A especially differs from the other zones in the abundant representation of SMP indicators. Zones B and C are somewhat different from the others in their slightly higher presence of LAS and DAV indicators, the transition from B to C being marked by a shift from SMP to BOG species. Although the frequency of BOG species is also higher in zone D than in De Stobbenribben as a whole, this zone is especially characterized by FEN, MOL, and LIT species. Ecologically, zone A is characterized by a strong dominance of indicators for the CIR water type plus a wide range of trophic state indicators (Table 7.3). The spectrum in Fig.7.6 draws the attention to the relatively poor representation of litho-oligotrophic and atmo-oligotrophic conditions. In zones B..D the oligotrophic nutrient state is dominant and eutrophic conditions (in the REST group) are indicated as unimportant. As regards the water type, the circumneutral indications prevail, but not as strongly as in zone A. The spectra for the zones B and C in Fig.7.6 suggest a relatively great importance of litho-oligotrophic and atmo-oligotrophic conditions, respectively.

The results of the application of the Finnish system of indicators have been included in Table 7.3. These results, while generally in line with the above discussion, are suggestive of some further points. Flark level species indicative of an external nutrient supply by flooding are about equally distributed over the zones A..C, such species being less abundant in zone D. Zone C shows a peak in the presence of indicators of an inherent nutrient supply typical for bog (group MOS) and rich fen (RFN). Hummock-level species are especially more abundant in this zone suggesting a possible successional relationship between zones B and C, facilitated by local factors. The importance of such local factors as the access of ditch water, the depth of peat removal, and the proximity to baulks, is strongly suggested by the deviating pattern for zones B..D in the narrow parcel B (Fig.7.4). The transition of zone A to zone B is not marked by a reduced abundance of flark level indicators, and so does not yield evidence for the suggestion that zone B follows upon zone A in the vegetational succession; the pattern is probably based on spatial relations.

In conclusion, *seepage indicators* are especially abundant, in De Stobbenribben, in an extended vegetational zone between the more swampy and eutrophic ditch side and the litterfen at the opposite side of the quagfen parcels. This extended zone can be roughly divided into a part

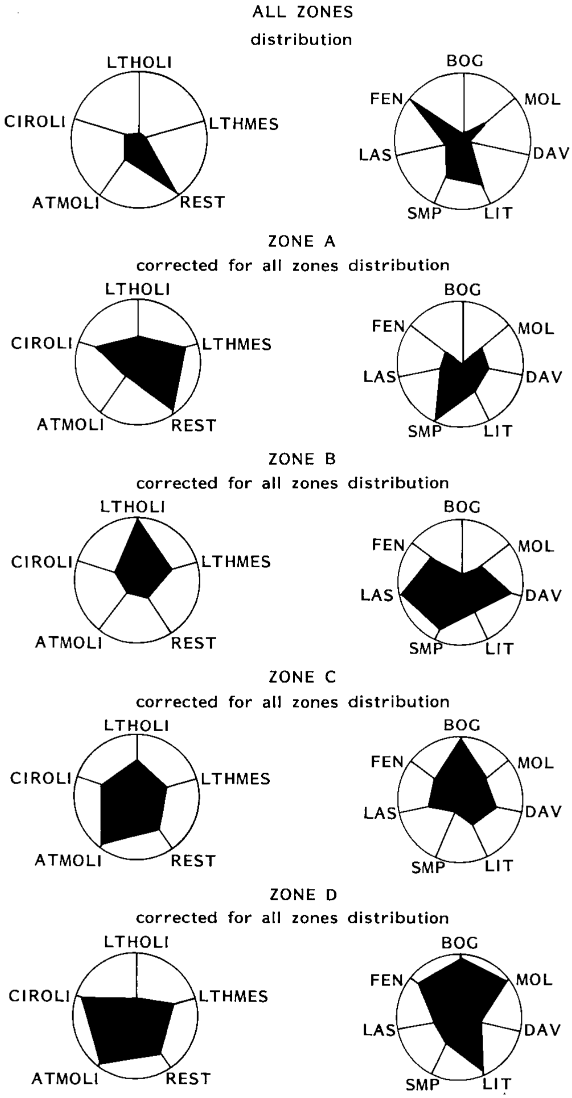


Fig.7.6 Ecological and phytosociological spectra of the vegetation stands in zones A-D in De Stobbenribben, corrected for the all-zones distribution given in the first radar diagrams

Radar diagrams have been explained in Chapter 3 dominated by amblystegiaceous mosses and a part dominated by *Sphagnum* species, which may be considered a successional phase due to the increased influence of peat accumulation, rain water and acidification. The micro-sites unique to zones B and C are indicated as litho- and atmotrophic, repectively, and oligotrophic in both.

7.5 Description of the vegetational zones

In this section a primarily floristic description of the vegetational zones A..D is given along with references to mapping units used by various authors and to phytosociological units according to Westhoff & Den Held (1969). A more elaborate discussion of phytosociological schemes of classification is given in Appendix B, and further ecological data are presented in Chapter 10.

Zone A - Referred to as: Eu-mesotrophic reed swamp, reed, swamp, eutrophic zone, *Calliergonella-Phragmites* reed

Bergmans 1975:	Type 6;
Van Zon-Van Wagtendonk 1965:	Type 30;
Bredenbeek *et al*. 1979:	Types 35 and R31

Occurring along the place where ditch water enters the quagfen parcels in the north-east.

Phragmites australis reaches a height of ca 1.8 m. Near the ditch and the baulks the stems are even taller. It is usually cut in late autumn, but cutting in winter and mowing in summer have occurred in certain years. *Carex elata* and *C.paniculata* form tussocks, *C.paniculata* being the more abundant of the two. *Phalaris arundinacea*, *Alisma plantago-aquatica*, *Ranunculus lingua*, and *Brachythecium rutabulum* may have been overlooked. These species, and those listed in the appropriate groups in Table 7.1, are quite characteristic of the zone. At the ditch side *Glyceria maxima* and *Sparganium erectum* are also found. Most species that are frequent in this type are more vigorous here than elsewhere in De Stobbenribben. The difference in types 35 and R31, both also different from 30, is not considered significant in respect of the overall heterogeneity of the type and of the influence of the varying mowing season.

Classification: Class *Phragmitetea*, Order *Nasturtio-Glycerietalia*, Alliance *Cicution virosae*; several species of the Orders *Phragmitetalia* and *Magnocaricetalia* of the same Class and species of the Alliances *Calthion* and *Filipendulion* (Order *Molinietalia*, Class *Molinio-Arrhenateretea*) are also present. In view of the small areal extent, at a meeting place of ditches, baulks, and *kraggen*, and their associated influences and border effects, the heterogeneity of the stands can easily be explained.

Zone B - Referred to as: Litho-oligotrophic swampy brownmoss fen, brownmoss (quag)fen phase, *Scorpidium-Carex* fen

Bergmans 1975:	Types 7, 2, 3, 4, (1);
Van Zon-Van Wagtendonk 1965:	Types 52, 53, 32, 37;
Bredenbeek *et al*. 1979:	Types 53, 55, 37, 52, (51)

Occurring in the large central parts of the parcels, in parcel A forming a fine-scaled mosaic with types A and C, respectively.

Types 52, 53, and 55 represent quagfen vegetation characterized by *Juncus subnodulosus* with *Scorpidium scorpioides* (52) and local hummocks of *Sphagnum subnitens* (53), and *Carex elata*-dominated quagfen (55). Most of the areal extent of these types is covered by Bergmans' type 7: a quagfen vegetation with *Scorpidium scorpioides* and *Campylium stellatum* dominant in the moss layer and with *Carex elata* and various other species in the herb layer. *Campylium elodes* and *Bryum pseudotriquetrum* should be mentioned for this zone also, although missing from Bergmans' table. The growth form of *Carex elata* is similar to that discribed as *forma dissoluta* by Braun (1968), but this is most probably a modification stimulated by the mowing regime.

Type 51 (Bergmans: 1) above refers to a narrow strip of vegetation dominated by *Menyanthes trifoliata* and *Carex lasiocarpa* near the baulks of parcel A. Type 50 (Bergmans: 2), a very weak part of the *kragge* in parcel D, where the vegetational aspect is determined by *Carex lasiocarpa*, is a large hollow, with ca 0.2 m standing water over a mud bottom in the central part, grading into a *Scorpidium* moss layer with, locally, *Drepanocladus sendtneri* towards the margins. Types 32 (Bergmans: 4) and 37 (Bergmans: 3) refer to dense stands of *Typha angustifolia* and *Cladium mariscus*, respectively.

Classification: Class *Parvocaricetea*, Order *Tofieldietalia*, Associations *Scorpidio-Caricetum diandrae* and *Scorpidio-Utricularietum*, mixed with elements of the Order *Caricetalia nigrae*, Alliance *Caricion curto-nigrae*, Association *Sphagno-Caricetum lasiocarpae*. The overall composition of the stands also reflects a relationship to the *Magnocaricion* Alliance (Order *Magnocaricetalia*, Class *Phragmitetea*; see also Appendix B), which seems to apply especially to the *kragge* synusia (Chapter 3). The hydro-environmental zone of the *Scorpidio-Caricetum diandrae* with *Scorpidio-Utricularietum* hollow communities seems to be superimposed on the *Magnocaricionkragge* character.

Zone C: Referred to as: Atmo-oligotrophic (*Sphagnum*) fen, *Sphagnum* (quag)fen phase, *Sphagnum-Carex* fen

Bergmans 1975:	Types 9 and 11;
Van Zon-Van Wagtendonk 1965:	Types 53, 54, 56, 57;
Bredenbeek *et al*. 1979:	Types 54, 55, 57

Occurring at a distance of some 100 m from the ditch towards the dead ends of the *petgaten*.

A closed *Sphagnum* cover, typically consisting of *S.subnitens* and *S.flexuosum*, and, locally, *S.papillosum* and *S.palustre*, is characteristic of this zone. *Juncus subnodulosus*, *Carex elata*, and *Phragmites australis* are the most abundant helophytes, although their stand is usually more open than in zone B. *Carex panicea*, *Carex curta*, *Cirsium dissectum*, and *Succisa pratensis*, along with several species extending further into zone D are locally abundant. *Carex tumidicarpa*, which is also abundant in zone B, has shown a substantial increase in numbers in De Stobenribben since the late 1970s. Dwarfshrubs and *Molinea coerulea* invade the hummocks in zone C.

Classification: This zone includes elements of a range of phytosociological units. Although these elements are probably linked by successional relationships, the pattern is often fine-scaled and expressed as a hummock-hollow pattern. The phytosociological units include:

Class *Parvocaricetea*, Order *Caricetalia nigrae*, Alliance *Caricion curto-nigrae*, Associations *Caricetum curto-nigrae* (weakly represented), *Sphagno-Caricetum lasiocarpae*, *Pallavicinio-Sphagnetum* (weakly represented);

Class *Oxycocco-Sphagnetea*, Order *Sphagnetalia magellanici*, Alliance *Erico-Sphagnion*, Association *Sphagnetum palustri-papillosi*.

Zone D: Referred to as: Litterfen

Bergmans 1975:	Types 10, 12, 13;
Van Zon-Van Wagtendonk 1965:	?;
Bredenbeek *et al*. 1979:	57, 58, 59

This zone typically consists of zone C stands with various species indicating the effects of more frequent access by people walking in from the baulks, and of disruptions of the moss cover due to machine damage. The zone is liable to such damage since it is located where the machines turn around during mowing and since especially *Molinea* and certain other phanerogam species provide hummocks of a firm peat not very resilient under machine attacks. It is possible that this zone also suffers from slightly greater fluctuations of the water level and an associated superficial drying in summer. *Calamagrostos canescens*, *Rubus fruticosus* and *Lysimachia vulgaris* are more abundant in this zone than elsewhere in De Stobbenribben.

Classification: Any accurate classification seems difficult, but elements of the Class *Molinio-Arrhenateretea*, Order *Molinietalia*, Alliance *Filipendulion* are weakly characteristic of this zone.

Zones B and C together will sometimes be referred to as the (spatially) intermediate quagfen zone.

Table 7.1 The distribution of species over zones A-D in the vegetation of De Stobbenribben (De Weerribben)

species	xy	ABCD	321	wat	nut	typ	r
EQUALLY FREQUENT IN ALL ZONES (COM)							
Agrostis canina		3333	112	ATM	OLI	LIT	
Cirsium palustre	+1	3333	000		OLI	MOL	
Galium palustre	11	3333	201	CIR		SMP	
Juncus subnodulosus	55	3333	455	LTH		LIT	
Lysimachia thyrsiflora	33	3333	100	CIR	OLI	SMP	
Potentilla palustris	13	3333	112	ATM	OLI	FEN	
Thelypteris palustris	11	3333	200	CIR	MES	FEN	
Viola palustris	++	3333	101	ATM	MES	FEN	
Angelica sylvestris	+	1111		LTH	OLI	LIT	
Plagiothecium denticulatum var. undulatum	+	1111		CIR	EUT	LIT	
ESPECIALLY IN ZONE A (A)							
Carex elata	55	5333	522	CIR	MES	FEN	
Phragmites australis	33	5333	544	LTH	MES	SMP	
Calliergonella cuspidata	13	5331	422		MES	LIT	
Caltha palustris	1	3101	000	CIR	MES	MOL	
Eupatorium cannabinum	13	3111		LTH	EUT	LIT	
Hypericum tetrapterum		3010		CIR	OLI	MOL	
Rhizomnium pseudopunctatum	1	3010		CIR	MES	DAV	!
Berula erecta	+1	3001		CIR	EUT	SMP	
Iris pseudacorus	11	3001		CIR	EUT	SMP	
Rorippa amphibia		3001		CIR	EUT	SMP	
Acorus calamus		3000		CIR	EUT	SMP	
Lemna gibba + L. minor	+	3000	200			AQU	
Lemna trisulca		3000	000	LTH	EUT	AQU	
Nasturtium microphyllum		3000	000	CIR	EUT	SMP	
Poa trivialis		3000		LTH	EUT	SMP	
Rumex hydrolapathum		3000		CIR	EUT	SMP	
Drepanocladus aduncus		1000		LTH	EUT	SMP	
Epilobium hirsutum		1000		LTH	EUT	LIT	
Eurhynchium praelongum		1000			EUT	SMP	
Hydrocharis morsus-ranae	1	1000		CIR	EUT	AQU	
Lophocolea heterophylla		1000		CIR	MES	LIT	
Myosotis palustris		1000	100	ATM	MES	MOL	
Oenanthe aquatica		1000		LTH	MES	SMP	
Rhytidiadelphus squarrosus		1000			MES	MOL	
Chiloscyphus pallescens	1	3030		CIR	MES	LIT	
Funaria hygrometrica		1010		CIR	EUT	LIT	
Lycopus europaeus	+1	1010		LTH	MES	SMP	
ESPECIALLY IN ZONE B (B)							
Scorpidium scorpioides	53	1531	422	LTH	OLI	LAS	#
Lythrum salicaria	11	1311		CIR	MES	LIT	
Peucedanum palustre	13	1311	100	CIR	OLI	FEN	
Utricularia intermedia	11	1310	010	LTH	OLI	LAS	#
Valeriana officinalis		1301		LTH	MES	LIT	
Chara spec.	33	1300	100				
Calystegia sepium		0100		CIR	EUT	LIT	
Liparis loeselii	11	0100		LTH	OLI	LAS	#
Nymphaea alba		0311		CIR	EUT	AQU	
Typha angustifolia	11	0311		LTH	MES	SMP	
Utricularia vulgaris		0311		CIR	MES	SMP	
Aneura pinguis	1	0310	100	LTH	OLI	LAS	#
Cladium mariscus	15	0310		LTH	OLI	SMP	!
Dactylorhiza majalis	11	0301	000	CIR	OLI	MOL	
ESPECIALLY IN ZONE C (C)							
Sphagnum contortum		1031	011	CIR	MES	LAS	!
Sphagnum subnitens	+	0353	050	CIR	MES	LAS	!
Alnus glutinosa	1	0131	000	CIR	EUT	LIT	
Carex panicea		0131	000	ATM	OLI	MOL	

species	xy	ABCD	321	wat	nut	typ	r
Sphagnum papillosum		0050	004	ATM	OLI	BOG	!
Agrostis stolonifera		0030	333		MES	LIT	
Carex rostrata	33	0030		ATM	OLI	FEN	
Cirsium dissectum		0030		ATM	OLI	MOL	!
Riccardia multifida	+	0030		CIR	OLI	LAS	#
Pinus sylvestris		0010		ATM		BOG	
Atrichum undulatum	+	0010		ATM	EUT	FEN	
Filipendula ulmaria		0010		LTH	MES	LIT	
Prunella vulgaris		0010			OLI	MOL	
Quercus robur		0010				BOG	
Sphagnum russowii		0010		ATM	MES	BOG	!
Sphagnum teres		0010		CIR	OLI	FEN	!
Sphagnum flexuosum		0053	024	ATM	MES	FEN	
Aulacomnium palustre		0031	002	ATM	MES	FEN	
Carex curta		0031	000	ATM	OLI	FEN	
Cephalozia connivens		0031		ATM	OLI	FEN	!
Succisa pratensis		0031		ATM	OLI	MOL	!
ESPECIALLY IN ZONE D (D)							
Rubus fruticosus		1013			EUT	LIT	
Calamagrostis canescens	+1	0113	000	ATM	OLI	LIT	
Lysimachia vulgaris	11	0113		CIR	OLI	LIT	
Carex disticha		0001		CIR	MES	LIT	
Lotus uliginosus		0001	000	CIR	MES	MOL	
Ranunculus flammula		0001		CIR	OLI	LIT	
Rumex acetosa		0001		CIR	MES	MOL	
Lathyrus palustris	11	0101	000	LTH	OLI	LIT	
Pedicularis palustris		0101	100	CIR	OLI	LAS	!
Scutellaria galericulata	1	0101		CIR	MES	SMP	
ESPECIALLY IN ZONES A AND B (AB)							
Carex lasiocarpa	33	3311	000	CIR	OLI	FEN	#
Mentha aquatica	1	3311	100	CIR	MES	SMP	
Utricularia minor	33	3311	331	CIR	MES	FEN	
Carex acutiformis	1	3300		CIR	MES	SMP	
ESPECIALLY IN ZONES B AND C (BC)							
Campylium stellatum	33	1330		LTH	OLI	DAV	#
Fissidens adianthoides	1	1330	200		MES	DAV	#
Menyanthes trifoliata	33	1331	000		OLI	FEN	#
Hypnum jutlandicum		0110		ATM	OLI	BOG	
Carex pseudocyperus		0110		LTH	EUT	SMP	
Carex echinata		0331		ATM	OLI	FEN	
ESPECIALLY IN ZONES C AND D (CD)							
Calypogeia fissa		1133	010		MES	FEN	
Holcus lanatus		1033	000	CIR	MES	MOL	
Mnium hornum		1033	313	ATM	OLI	LIT	
Sphagnum fimbriatum	+	1033	010		MES	FEN	
Thalictrum flavum		1033		CIR	OLI	LIT	
Betula pubescens		0133	012	ATM	OLI	DAV	
Luzula multiflora multiflora		0133	000	CIR	OLI	MOL	
Anthoxanthum odoratum		0033	002		OLI	BOG	
Cephalozia bicuspidata var. lammersiana	+	0033		CIR	MES	FEN	!
Dicranum bonjeanii		0033		ATM	MES	FEN	
Erica tetralix		0033		ATM	OLI	BOG	!
Molinia caerulea		0033	001	ATM	OLI	MOL	
Polytrichum commune		0033		ATM	OLI	FEN	
Polytrichum longisetum		0033	024		MES	LIT	
Potentilla erecta		0033		ATM	OLI	MOL	
Salix repens		0033	000	CIR	OLI	MOL	
Sphagnum palustre		0033				FEN	
Luzula campestris		0011		ATM	OLI	BOG	
Campylopus fragilis		0011		ATM	OLI	LIT	
Sorbus aucuparia		0011				LIT	
Stellaria palustris	1+	0011	000	CIR	MES	FEN	
LESS FREQUENT IN ZONE D (-D)							
Cardamine pratensis	33	3331	301	CIR	MES	MOL	

species	xy	ABCD	321	wat	nut	typ	r
Carex diandra	33	3331	002	CIR	OLI	LAS	#
Carex paniculata	11	3331	401	LTH	EUT	SMP	
Dryopteris carthusiana	1	3331		ATM	OLI	FEN	
Epilobium palustre	1+	1110	000	LTH	MES	FEN	
LESS FREQUENT IN ZONE C (-C)							
Vicia cracca		1101		CIR	OLI	MOL	
LESS FREQUENT IN ZONES B AND C (-BC)							
Carex riparia		1001			MES	SMP	
LESS FREQUENT IN ZONE B (-B)							
Juncus conglomeratus		3033		ATM	OLI	LIT	
Valeriana dioica	+	3033	000	CIR	OLI	MOL	!
Pellia neesiana	1	3031		CIR	MES	LAS	!
Sphagnum squarrosum		3133	021	CIR	EUT	LIT	
Lychnis flos-cuculi		1011		CIR	MES	MOL	!
LESS FREQUENT IN ZONE A (-A)							
Salix aurita + cinerea	1	1333				SMP	
Carex tumidicarpa		0333		LTH	MES	MOL	
Drosera rotundifolia	++	0333	045	ATM	OLI	FEN	!
Dryopteris cristata	+1	0333			OLI	FEN	
Hydrocotyle vulgaris		0333	212	ATM	OLI	LIT	
Equisetum fluviatile		0111		CIR	MES	FEN	
Frangula alnus		0111		LTH		FEN	
Myrica gale	1	0111	000	CIR	MES	FEN	
NOT MENTIONED BY BERGMANS (?)							
Alisma plantago-aquatica	++		100	CIR	EUT	SMP	
Brachythecium rutabulum	11				EUT	LIT	
Bryum pseudotriquetrum	33		000	LTH	MES	LAS	#
Calliergon giganteum	33			LTH	MES	LAS	!
Calliergon stramineum	1			ATM	OLI	FEN	
Campylium elodes	31				MES	MOL	#
Campylium polygamum	11			CIR	MES	LIT	
Cicuta virosa	11			LTH	EUT	SMP	
Cladophora fracta	11						
Drepanocladus lycopodioides	31			LTH	MES	LAS	#
Dactylorhiza incarnata	11			CIR	OLI	DAV	#
Pellia epiphylla	3			ATM	EUT	LIT	
Plagiomnium affine	3			CIR	EUT	LIT	
Ranunculus lingua	33			LTH	MES	SMP	!
Sium latifolium	++			LTH	EUT	SMP	
Sparganium minimum	+			CIR	OLI	SMP	!
Eriophorum angustifolium			001	ATM	OLI	FEN	!
Hierochloë odorata			000	CIR	OLI	LIT	
Taraxacum cf. T. palustre			000				
Calliergon cordifolium			000	CIR	EUT	SMP	
Sparganium erectum			000	CIR	MES	SMP	
Galium uliginosum			000	CIR	OLI	MOL	
Riccia fluitans			001	CIR	MES	SMP	!

At the right-hand side indicator values have been listed as treated in chapter 3; the species have been grouped according to their preference for specific zones. The occurrence of the species in permanent quadrats 1 and 2 ca 1960 (columns x, y) and in samples reported by Kooijman (1985, observations 1984) has been indicated also (1-3, where 3 is closest to the ditch).
wat water type; nut nutrient state; typ phytosociological group; r red-list (! red-list species; # red-list species and seepage indicator)

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 8

Peat temperature and the estimation of vertical water flow

8.1 Introduction

Conventional hydrological survey methods are especially useful for the assessment of the average characteristics of a whole area. In order to explain the vegetational pattern within single *petgaten*, an additional, more detailed assessment of water flow was deemed desirable. One appropriate method uses a heat transport model for the estimation of seepage, the use of which was inspired by the frequent mentioning of reduced temperature fluctuations as a result of upward seepage in quagfens in North-West Overijssel. S.Segal (pers. comm.) carried out temperature recordings in various shallow pools and he thought that the results demonstrated differences in seepage intensity. While I was unable to reproduce such measurements with enough accuracy to allow for any positive conclusion (Van Wirdum 1972), the quantitative treatment of the problem suggested a different approach. Instead of measuring in the immediate environment of plants, the temperature sensors were moved deeper into the peat, where the effect of seepage would be measurable in the characteristics of the sinusoidal annual temperature wave. Although many complicating factors were discovered, the results contributed to the understanding of the water flow through De Stobbenribben and other terrestrialized *petgaten*.

Daily and annual fluctuations of the temperature at the soil surface cause a flow of heat between this surface and deeper strata, where the temperature is more constant. Any vertical flow of water contributes to this heat transportation, so that accurate measurements of temperature profiles in the soil enable an estimation of the vertical component of water flow. Such estimations were made with an increasing accuracy and reliability from 1969 onward. Van Wirdum (1984) provides a summary of the development of gauges, physical models, and methods of computation regarding the heat transportation method for the estimation of seepage.

In the first section of this chapter a tentative theory is presented, including studies of physical models, a survey of thermal properties of wet peat soils, and an investigation of the periodicity of temperature fluctuations slightly above the soil surface. The main questions to be answered in the next sections are:

Can seepage in De Stobbenribben and similar quagfens be assessed with thermal methods?

If so, are there appreciable local differences, and can these differences have an ecologically significant influence on the temperature regime at the soil surface and in shallow pools?

I focus on the vertical component of water flow in this chapter. The lateral flow of water will be considered in some detail in Chapter 9.

Table 8.1 List of symbols, dimensions and units

Symbol	Dimension	Units used	Comment
A	**θ**	K or ^{0}C	temperature amplitude
a	$\mathbf{L^{-1}}$	m^{-1}	damping coefficient
b	$\mathbf{L^{-1}}$	m^{-1}	phase-shift coefficient
c	$\mathbf{L^2\,T^{-2}\,\theta^{-1}}$	$J\ kg^{-1}\ K^{-1}$	specific heat
k	$\mathbf{L\,M\,T^{-3}\,\theta^{-1}}$	$W\ m^{-1}\ K^{-1}$	thermal conductance
T	**θ**	^{0}C	temperature
t	**T**	s	phase, relative to the wave minimum
v	$\mathbf{L\,T^{-1}}$	$m\ s^{-1}$	gross velocity of water
z	**L**	m	depth
κ	$\mathbf{L^2\,T^{-1}}$	$m^2\ s^{-1}$	thermal diffusivity
ρ	$\mathbf{L^{-3}\,M}$	$kg\ m^{-3}$	density
τ	**T**	s	period of the wave
φ	-	rad	phase, relative to the wave minimum
ω	$\mathbf{T^{-1}}$	$rad\ s^{-1}$	angular velocity of wave

A list of symbols, dimensions and units used in this chapter is provided in Table 8.1. In the text, **v** is given in mm/d for convenience. A positive sign indicates a downward flow. Also for convenience, **t** is mostly given in days. The product **ρc** is known as the heat capacity. The attribute ‘0’ refers to water in the case of thermal properties. Elsewhere, '0' refers to the soil surface; '∞' is used to indicate an infinite depth. The temperature gradient at great depth has not been considered, however, and the geothermal heat flux is disregarded. The values presented for the thermal properties of soil constituents in this chapter hold for an ambient temperature of 10 ^{0}C, which is close to the mean annual air and groundwater temperatures in The Netherlands.

8.2 Theory of soil temperature as a function of seepage

In this section, a general model of temperature fluctuations in wet peat soils is described. Two extensions of the model are presented for the assessment of the flux density of water along the vertical axis. The first uses an analogue of the Doppler effect and was developed during this investigation. Although it appears to be in conflict with the continuity principle, experience suggests that this model is less sensitive to some errors which result from the 'non-ideality' of actual situations. The simplest implementations of the model, however, are probably very sensitive to a lateral flow of water and to the occurrence of extremely warm or cold periods. At the lowest level of accuracy, the Doppler analogy can be applied already to a single temperature profile comprising three measured temperatures.
The alternative extension of the model, borrowed from Stallman (1965), is consistent with the physics of heat transfer. The procedure used for the derivation of values for the damping and phase-shift coefficients, and the computational solution of the thermal diffusivity of the peat, respectively, were newly developed.

The general model

Under the influence of a varying soil-surface temperature and a constant soil temperature at infinite depth ($\mathbf{z}_\infty$), the temperature of the soil at some intermediate depth $\mathbf{z}$ will reflect the fluctuations at the surface ($\mathbf{z_0}$) with a decreased amplitude and a phase lag. The theory of the attenuation and phase shift with depth of the annual and daily temperature waves at the soil surface by heat conduction alone has been dealt with by several authors (see Rose 1969), resulting in

(**Formula 8.1**) $$\mathbf{T_{t,z}} = \mathbf{T_m} - \mathbf{A_0}\, e^{-\mathbf{bz}} \cos(\boldsymbol{\varphi} - \mathbf{bz}), \text{ with } \mathbf{b} = (\pi/(\boldsymbol{\tau\kappa}))^{1/2} \text{ (and } \boldsymbol{\varphi} = \boldsymbol{\omega}\mathbf{t} = 2\pi\, \mathbf{t}/\boldsymbol{\tau}),$$

where $\mathbf{T_m}$ is the mean annual temperature, which is almost constant for the depths studied. Rose (1969) mentioned the influence of convective heat transport and proposed the determination of an effective value of $\boldsymbol{\kappa}$, which should then be regarded an 'apparent' diffusivity only. When the thermal parameters of the soil medium are known and when they are nearly equal to those of water, the gross velocity of the vertical flow of water can be estimated from the difference between the 'apparent' and 'real' thermal diffusivities. Van Wirdum (1972) used the analogy with the Doppler effect in this connection, by considering the penetration of the temperature wave in a moving, semi-infinite body of water, yielding:

(**Formula 8.2**) $$\mathbf{v} = (1/\mathbf{b'} - 1/\mathbf{b})\, 2\pi/\boldsymbol{\tau},$$

where $\mathbf{b'}$ results from an 'apparent' $\boldsymbol{\kappa}$. In this formula, $\mathbf{v}$ is the gross velocity of the medium as a

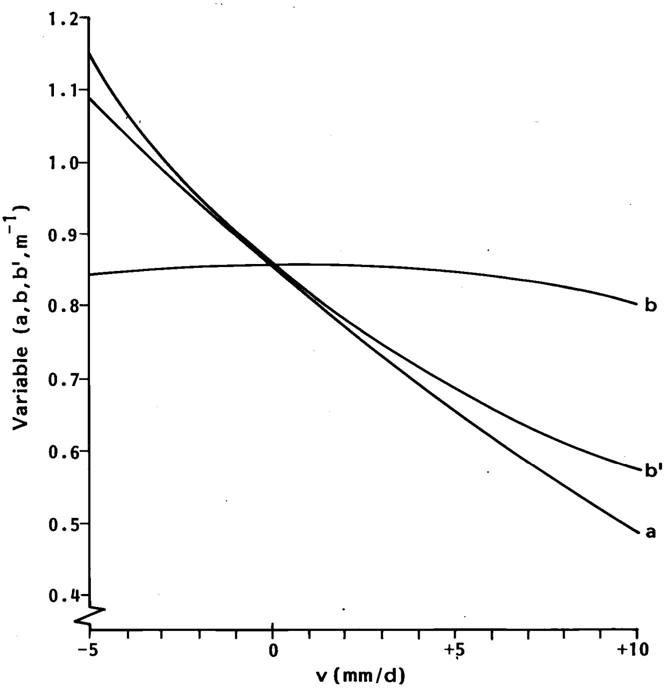


Fig. 8.1 The relation between v and a, b, and b', respectively, in very wet peats (κ = 1.35 10^{-7} m^2 s^{-1})

whole, which, in the case of the very wet peat soils investigated here, contains more than 95% by volume of water. The remaining part of the medium is the organic matrix, which may hold a large volume of water in place by physical bounds or in closed ('dead') pores. The actual velocity of the moving 'fingers' of water in preferential flow channels may well be much larger than the calculated **v**. The gross velocity calculated here should be nearly equal to the flux density or 'Darcy velocity' as used in hydrological models. Note that the Doppler method is based on the observed wave characteristics, rather than on the laws of conservation of mass and energy and the relevant principles of continuity. The relation between **v** and **b'** in very wet peat soils has been depicted in Fig.8.1.

A report by De Crook (1979) directed my attention to work by Stallman (1965) and Suzuki (1960), who showed that, in order to satisfy continuity requirements, equation 8.1 should be adapted to the case of combined conduction and convection of heat:

(**Formula 8.3**) $$\mathbf{T_{t,z}} = \mathbf{T_m} - \mathbf{A_0}\, e^{-\mathbf{az}} \cos(\varphi - \mathbf{bz}),$$

where **a**=**b** only if there is no convective heat transport. This means that the respective effects of moving water on the amplitude and the phase of the temperature wave are different. The following relations were derived by Stallman:

(**Formula 8.4**) $\mathbf{a} = ((\mathbf{K}^2 + \mathbf{V}^4/4)^{1/2} + \mathbf{V}^2/2)^{1/2} - \mathbf{V}$,

and (**Formula 8.5**) $\mathbf{b} = ((\mathbf{K}^2 + \mathbf{V}^4/4)^{1/2} - \mathbf{V}^2/2)^{1/2}$,

where $\mathbf{K} = \pi/(\boldsymbol{\tau\kappa})$ $(= \boldsymbol{\omega}/(2\boldsymbol{\kappa}))$, and $\mathbf{V} = (\mathbf{v}\ \boldsymbol{\rho_0}\mathbf{c_0}) / (2\boldsymbol{\kappa}\ \boldsymbol{\rho}\mathbf{c})$.

This physical model holds true under the following conditions:
1) The flow of water in the soil layer considered is steady and uniform along the **z** axis;
2) The thermal properties of the water and the medium are constant in space and time;
3) All components of heat and fluid flow occur only along the **z** axis;
4) The temperature of the water at every point in the interstices equals the temperature of the adjoining soil particles at all times.

Stallman suggests a graphical representation of measured temperatures to find the pertaining values of **a** and **b**. Note that **b** is not sensitive to the sign of **v**, *i.e.*, to the direction of the vertical flow component. Stallman provides a table and graphs for the solution of $2\mathbf{V}(\mathbf{K}^{-1/2})$ as a function of **a**/**b**, followed by the substitution of the value of $(\mathbf{b}^2-\mathbf{a}^2)/\mathbf{a}$ for 2**V** in order to find **K** and, accordingly, **κ**. **V** is then solved from the formula defining **V** (see under Formula 8.5), where **ρc** should be known. The relation between **v** and **a** and **b**, respectively, in very wet peat soils has been depicted in Fig.8.1. An alternative, computational method to solve **κ** is derived below. Equation 8.4 can be rewritten, using $2\mathbf{V} = (\mathbf{b}^2-\mathbf{a}^2)/\mathbf{a}$, in the following form:

(**Formula 8.6**) $\mathbf{a} + (\mathbf{b}^2 - \mathbf{a}^2)/2\mathbf{a} = ((\mathbf{K}^2 + \mathbf{V}^4/4)^{1/2} + \mathbf{V}^2/2)^{1/2}$.

Multiplication of (8.5) by (8.6), using the reverse of the well-known expansion formula
$(p^2-q^2)^{1/2} = (p+q)^{1/2}\ (p-q)^{1/2}$, yields

$$\mathbf{K} = (1/2)\ \mathbf{ab}\ (1 + \mathbf{b}^2/\mathbf{a}^2).$$

This enables the solution of **κ** from the defining formula for **K** (see under Formula 8.5). In the working scheme proposed here, **a** and **b** are determined by means of exponential and linear regression, respectively, for

$$\mathbf{A_z} = \mathbf{A_0}\ e^{-\mathbf{az}}, \text{ and } \boldsymbol{\varphi}_\mathbf{z} = \boldsymbol{\varphi}_\mathbf{0} - \mathbf{bz}$$

with $\mathbf{A_z}$ and $\boldsymbol{\varphi}_\mathbf{z}$ data regarding the fundamental wave as obtained by Fourier analysis of $\mathbf{T_{t,z}}$ field data. Now **v** may be found if **ρc** is known. A fixed value $\boldsymbol{\rho}\mathbf{c} = 4\ 10^6$ J m^{-3} K^{-1} was used here. Values of **κ** and **ρc** for wet peat soils are derived in the next subsection.

In summary, **κ** may be determined if
1) Sufficient $\mathbf{T_{t,z}}$ data are available reliably to determine the phase and amplitude of the fundamental component of the annual temperature wave at depth **z**, for instance by graphical or Fourier analysis;
2) Such data are available for at least two different depths whose distance Δ**z** is known,

and **v** may be determined if
1) **ρc** is known or may be estimated with sufficient accuracy from the volumetric composition of the soil.

Problems may arise when, among others,
1) A considerable convective heat transport is present in directions other than vertical;
2) Variation of the moisture content with depth causes variation of **κ**;
3) Sources or sinks of heat within the soil profile may not be disregarded;
4) Higher harmonics of the temperature wave may not be disregarded.

The conditions 1, 2, and 3 are considered the main drawbacks for the application of this physical model. In certain cases the actual flow may be so much restricted to singular preferential channels that the temperature of the flowing water does not equal that of the surrounding soil matrix. Such cases have probably not been very important in the present investigation, but have been suggested as a cause of error when the same method was applied to more consolidated bog peat soils elsewhere in The Netherlands, where the results obtained with the Doppler analogy method seemed to make more sense.

The first source of error is investigated from a theoretical point of view in Section 8.4. The calculations indicate a considerable downward flow of water in De Stobbenribben, so that a lateral inflow must be large enough to evoke serious errors in the quantitative interpretation at the depth where this flow occurs. The presence of a lateral flow in the expected order of magnitude is obvious from the independent data presented in Chapter 9. The use of time series, as in this investigation, reduces the chance that large errors result. As shown in the next section, the second source of error may be disregarded in the very wet peat soils considered here. Error type 3 may also be left unconsidered as far as it is not caused by the first-mentioned type of problem. A discussion of error source 4 is given later in the present section. The results provided an argument for the application of Fourier analysis to the measured time series.

In places where the hydraulic conductivity of the porous medium is very large, density currents can be generated during winter. This problem was investigated in connection with the study of longitudinal transects as described in Chapter 9. It does probably not constitute a serious problem in De Stobbenribben.

Heat capacity and thermal diffusivity of very wet peat soils

The rate of thermal diffusion (thermal diffusivity) through wet peat soils is considered a known parameter in the Doppler analogy model discussed before. In the Stallman model, the thermal diffusivity is resolved with temperature data and a heat capacity value as inputs, and it would be desirable to have at one's disposal any reference value for the thermal diffusivity in order to detect anomalous results. Such values are provided here. In order to avoid confusion, a concise summary of the thermal characteristics of the porous medium and of what they depend on is given in Table 8.2. The values of the various parameters also depend on the ambient temperature. The values selected here are approximately correct at 10 ^{0}C. Many values found in the literature appear to apply to ambient temperatures well above those normally found in soils in The Netherlands. Especially in the case of thermal conductance this may cause serious errors.

Table 8.2 Thermal characteristics of porous media

specific heat (**c**)	depends on medium composition
density (**ρ**)	depends on medium composition
heat capacity (**ρc**)	product of specific heat and density
thermal conductance (**k**)	a property of the various soil components
thermal diffusivity (**κ**)	depends on thermal conductance and heat capacity
damping coefficient (**a**)	depends on thermal diffusivity and wave period; in case of mass flow also on heat capacity of flowing material and on flow velocity
phase shift coefficient (**b**)	as damping coefficient

For dimensions and units: see Table 8.1

The thermal diffusivity of a medium of heat transport can be calculated from

(**Formula 8.7**) $$\kappa = k/(\rho c).$$

Since the type of medium under discussion (soil) is composed of solids of different kinds, and of interstitial water and, possibly, air, **ρc** is a weighted sum:

(**Formula 8.8**) $$\rho c = 1/V\ \Sigma(V_i\ \rho_i c_i),$$

where **V** is the volume considered and where the specifier $_i$ denotes the different materials of which the soil is composed: sand, clay, organic matter, water, and air. Taking sand and clay together as 'minerals', and substituting the accurately known values for **ρ** and **c** this formula reduces to (De Vries 1963):

$$\rho c = 1/V\ (1.93\ V_1 + 2.5\ V_2 + 4.19\ V_3 + 0.0013\ V_4)\ 10^6,$$

where the specifiers $_1$, $_2$, $_3$, $_4$ denote minerals, organic matter, water, and air, respectively. The term with V_4 may be deleted due to its very small value. De Vries (*l.c.*) provides the following formula for the calculation of the thermal conductance **k**:

(**Formula 8.9**) $$k = \Sigma(\alpha_i\ V_i\ k_i) / \Sigma(\alpha_i\ V_i),$$

where the specifier $_i$ denotes each particular combination of form and material (each 'type of granule') present, and where **α** is a parameter which depends on the type of granules and on the medium in which they are embedded. According to De Vries the value of **α** can be reliably estimated by

(**Formula 8.10**) $$\alpha_i = 1/3\ \Sigma(1 / (1 + g_k\ (k_i / k_0 - 1)),$$

where $_0$ specifies the embedding medium (the volumetrically dominant component), and the summation is over three components specified by $_k$, the soil particles being conceived as ellipsoidal bodies with a so-called 'factor of depolarization' g_k associated with each of the three axes. The factors of depolarization have the following characteristic values:

spherical grains $\mathbf{g_1} = \mathbf{g_2} = \mathbf{g_3} = 1/3$
laminae $\mathbf{g_1} = 1$, $\mathbf{g_2} = \mathbf{g_3} = 0$
terete fibres $\mathbf{g_1} = \mathbf{g_2} = 1/2$, $\mathbf{g_3} = 0$.

The thermal conductance of various composite soils can now be calculated by means of the material properties and resulting values for $\boldsymbol{\alpha}$ listed in Table 8.3.

It is apparent from this table that an average value, $\boldsymbol{\alpha} = 1.31$, will do for very wet peats. Fig.8.2 shows the variation of $\boldsymbol{\kappa}$ and $\boldsymbol{\rho c}$ for such soils, depending on the volumetric composition. Since sand and clay have not been found in any appreciable amount in the peat in De Stobbenribben, and the peat is of a very soft and water-saturated type, $\boldsymbol{\kappa} = 1.35\ 10^{-7}\ m^2\ s^{-1}$ ±7.5%. The value $\boldsymbol{\rho c} = 4\ 10^6\ J\ m^{-3}\ K^{-1}$ is also quite reliable.

Table 8.3 Thermal conductance of single soil components and values of $\boldsymbol{\alpha}$ associated with various types of granules

Type of granules	Thermal conductance	$\boldsymbol{\alpha}$
'grains' of air	0.025 $W\ m^{-1}\ K^{-1}$	1.47
laminae of peat	0.251 $W\ m^{-1}\ K^{-1}$	1.43
fibres of peat	0.251 $W\ m^{-1}\ K^{-1}$	1.26
grains of peat	0.251 $W\ m^{-1}\ K^{-1}$	1.23
grains of clay	2.9 $W\ m^{-1}\ K^{-1}$	0.42
grains of sand	8.7 $W\ m^{-1}\ K^{-1}$	0.17

embedding medium: water, $\mathbf{k} = 0.574\ W\ m^{-1}\ K^{-1}$

A wave analysis of annual temperature fluctuations

The driving force of the variation in soil temperature is the temperature fluctuation at the soil surface, which can be described as a complex wave. Of all components of this wave the annual and daily ones have the largest amplitudes. In order to simplify matters, only one component was included in the formulas presented before. In this section it is investigated which component is most useful for the present purpose, and whether problems may arise from the exclusion of other components.

As follows from formula 8.3, the amplitude of the temperature wave is damped according to

$$\mathbf{A_z} = \mathbf{A_0}\ e^{\mathbf{-az}},$$

which enables a calculation of the attenuation. Results of such calculations have been collected in Fig.8.3 for very wet peat soils. It is obvious from this figure that the annual fluctuations penetrate to a much greater depth than the daily ones. Assuming an amplitude of 10 K around

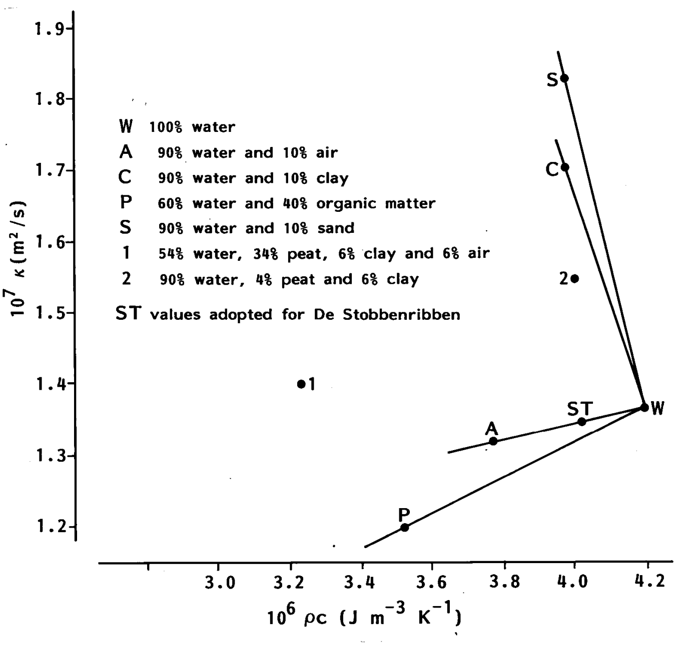


Fig. 8.2 Representative values of **ρc** and **κ** in wet peats, depending on the volumetric composition of the soil

the mean at the surface, $\mathbf{A_z}$ is <0.01 K for the daily wave component at **z**=0.6 m and 5.97 K for the annual one. The daily component can thus not be assessed on the basis of soil temperature measurements in very wet peat soils, unless these measurements are performed close to the soil surface, but such measurements would require an undue precision. Alternatively, when the annual wave component is used, fluctuations with a short period will not cause any appreciable 'noise' if the measurements are not taken too close to the surface. Taking 0.6 m as a representative depth, and considering an amplitude of 0.5 K critical, any wave component with a period shorter than 20 days may be disregarded unless, for such wave components, $\mathbf{A_0}$ is >5 K.

The daily and annual amplitudes are rather constant between years, but the other components vary largely, since they result from relatively warm or cold periods lasting only for several days or weeks, *i.e.*, from the irregularities of the weather. In order to get an idea of the occurrence of such irregularities and their possible effects on the soil temperature below 0.6 m, a Fourier analysis was made of the decade temperatures measured at De Bilt and Eelde by the Royal Meteorological Service (KNMI). These temperatures are measured with standard equipment in meteorological boxes at 1.5 m above the soil surface. According to the KNMI (1972) records the temperature in North-West Overijssel is about the mean of the values for Eelde and De Bilt. The mean and amplitude of the wave components with periods longer than a few days, measured at the soil surface and in a meteorological box, respectively, probably do not differ very much, as

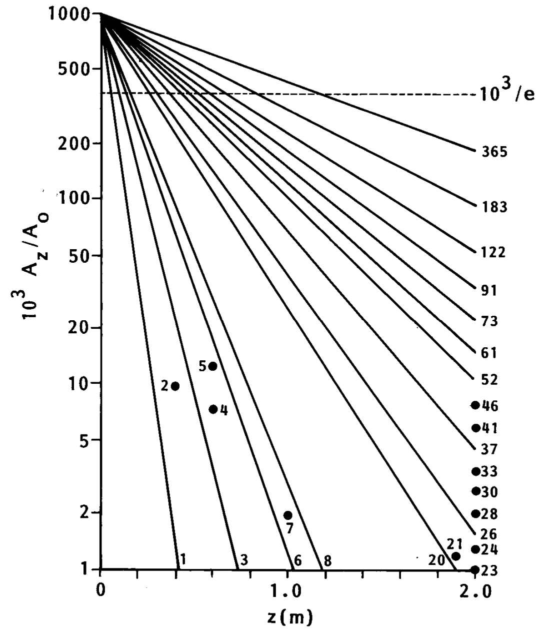


Fig. 8.3 Damping of temperature oscillations with depth in wet peats (κ=1.35 10^{-7} m^2 s^{-1})

Numbers denote the period (τ) for each line or mark in days; note that the y-axis is logarithmic

is confirmed by a comparison of the data in this section with those in the next. The mean temperature in each decade has been used here as the value measured on the fifth day of that decade. The use of decade values restricts the analysis to wave components with a period of 20 days or longer. A summary of the most relevant results is presented in Table 8.4.

The last column of the table gives the value of $\mathbf{A_0}$ required for any singular wave component in order to cause a deviation of the temperature at 0.6 m which is equal to or larger than 10% of the amplitude of the annual component at the same depth. This may be used as a criterion to judge whether there is a fair chance that the neglect of overtones in the formulae causes erroneous results.

Since the various overtones have different phases, the real noise must be calculated for each year separately by the superposition of the various wave components and a comparison with the annual one. This has been done by extending formula 8.3, with **a=b**, to incorporate all 18 components listed in Table 8.4. Note that, for each period, **a** (and **b**) have different values (see formula 8.1). The results have been summarized by calculating the standard deviation of the contribution of the overtones to the decade temperatures at a depth **z**, where the decade temperatures are expressed by ($\mathbf{T_{t,z}}$ - $\mathbf{T_{m,z}}$). These contributions can be considered normally

Table 8.4 Summary of Fourier analyses of the annual wave of the ten-days mean air temperature, 1.5 m above the soil surface (averaged values from KNMI stations De Bilt and Eelde).

Period (days)	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**mean**	**N**
365 (fundamental tone)												
T_m	8.68	9.28	8.61	8.98	9.33	9.48	9.50	9.39	8.69	8.10	9.00	
L	37	35	29	32	29	37	34	36	34	36	34	
A_0	8.75	7.38	7.22	7.81	5.52	7.47	8.57	6.48	7.14	8.57	7.49	
A_0 of overtones:												
183	**1.06**	0.42	0.31	**1.51**	**1.33**	**2.28**	0.79	0.66	0.67	**1.02**	**1.01**	0.9
122	0.41	0.68	**1.30**	0.48	**1.13**	0.92	0.52	0.98	0.41	0.77	0.76	1.1
91	0.99	0.86	0.48	0.37	0.53	0.46	0.73	0.22	0.32	**1.37**	0.63	1.2
73	0.35	0.36	0.39	0.56	1.06	0.16	0.33	0.82	**1.45**	0.59	0.61	1.4
61	0.33	0.85	0.14	0.74	0.48	0.52	0.88	1.08	0.78	1.34	0.71	1.6
52	0.91	1.45	0.72	0.38	0.61	1.44	1.00	0.26	0.96	0.89	0.86	1.7
46	0.87	0.59	0.33	0.90	0.65	0.17	**1.90**	0.93	0.81	1.06	0.82	1.9
41	0.52	0.60	0.26	0.68	0.74	0.54	0.91	1.12	0.14	0.77	0.63	2.1
37	0.46	0.43	0.93	0.28	0.24	0.12	1.06	0.16	0.48	0.83	0.50	2.2
33	0.37	0.64	0.58	0.45	0.22	0.32	0.17	0.16	0.95	0.37	0.42	2.4
30	0.30	0.17	0.87	0.34	0.63	0.54	0.28	0.14	0.69	0.42	0.44	2.6
28	0.52	1.22	0.39	0.40	0.14	0.73	0.45	0.39	0.47	0.58	0.53	2.8
26	0.89	0.71	0.33	0.65	0.28	0.28	0.42	0.38	0.37	0.25	0.46	3.0
24	0.76	0.25	0.60	0.24	0.61	0.73	0.89	0.37	0.76	0.87	0.61	3.2
23	0.50	0.15	0.49	0.29	0.26	0.76	0.83	0.66	0.36	0.92	0.52	3.5
21	0.09	0.75	0.11	0.46	0.60	0.37	0.03	0.15	0.32	0.33	0.32	3.7
20	0.37	0.44	0.29	0.37	1.14	0.35	0.17	0.63	0.09	0.32	0.42	3.9

T_m: mean temperature (^{0}C); **L**: phase lag relative to January, 1st (days); A_0: amplitude (K); **N**: A_0 required to cause a serious chance of 10% effects on the temperature at 0.6 m below the soil surface (K; see text); Values of A_0 in excess of **N** have been printed in bold face.

distributed around 0, thus enabling a probability computation. By taking 0.6 m as a critical depth, the probability of these contributions to exceed 10% and 20% of A_z is listed in Table 8.5.

A possible incidence of 8.3% at the 20% contribution level compares to one out of 12 monthly temperatures having a deviation exceeding the one expected according to formula 8.3 at 0.6 m depth by 0.9 K or more. At greater depths the probability of such deviations decreases strongly, as is illustrated for the year 1979 in Fig.8.4. This figure illustrates the expected temperature according to formula 8.3 next to the one according to the complete Fourier series, where it was assumed that the decade temperatures in the meteorological box equal the temperatures at the soil surface in the same decade, and where the calculations were performed for a wet peat soil with conductive heat transport only. The differences between the measured decade temperatures and the Fourier series at **z = 0** are due to numerical errors, since the Fourier

Table 8.5 The possible incidence of overtones contributing more than 10% (P10) or 20% (P20) of A_z to the measured temperatures $T_{t,z}$ at z=0.6 m

Year	**A_z** K	**s(ΔT)** K	**P10** %	**P20** %
1970	5.23	0.61	39	9
1971	4.41	0.52	40	9
1972	4.31	0.50	39	9
1973	4.66	0.63	46	14
1974	3.30	0.68	62	33
1975	4.46	0.91	62	33
1976	5.12	0.60	40	9
1977	3.87	0.54	47	15
1978	4.26	0.54	43	11
1979	5.12	0.71	47	15
mean	4.47	0.62	47	15

A_z is listed for the annual wave component at 0.6 m
s(ΔT): standard deviation of contribution of overtones to actual temperature at **z**=0.6 m

series provides an exact description of the measured data. This figure also shows that, as the depth increases, the remaining deviations from the fundamental sine wave occur in a grouped manner. This is due to the fact that only deviations resulting from overtones with relatively long periods can remain of importance at greater depths. Especially measurements performed during a short period of up to about two months may thus suggest an annual wave different from the actual one.

It can be concluded that the use of only one wave component (*viz.*, the annual one) in this investigation provides a fair approximation of the real situation, although it is not entirely reliable. The single-profile implementations of the Doppler analogy method are very sensitive to local deviations of the measured temperature. For this reason time series are being used here, and the annual component is singled out by Fourier analysis in the implementation of the Stallman method. The results given in the following sections do not suffer from serious errors of this kind, therefore, and the values derived for **a** and **b** must be considered more reliable than those obtained with graphical methods as proposed by Stallman (1965).

8.3 The estimation of seepage in De Stobbenribben

The gauges for temperature measurements

The gauges used for measuring temperature profiles will not be discussed in detail here. The first was provided by the TFDL (Technical and Physical Engineering Service for Agricultural Research, Wageningen) in 1969: a sounding rod with a thermistor mounted in the tip. An improved version was built at RIN in 1977, and this one was regularly calibrated. The sensor tip was replaced by a specially designed air chamber in 1979 at RIN. This reduced the reaction

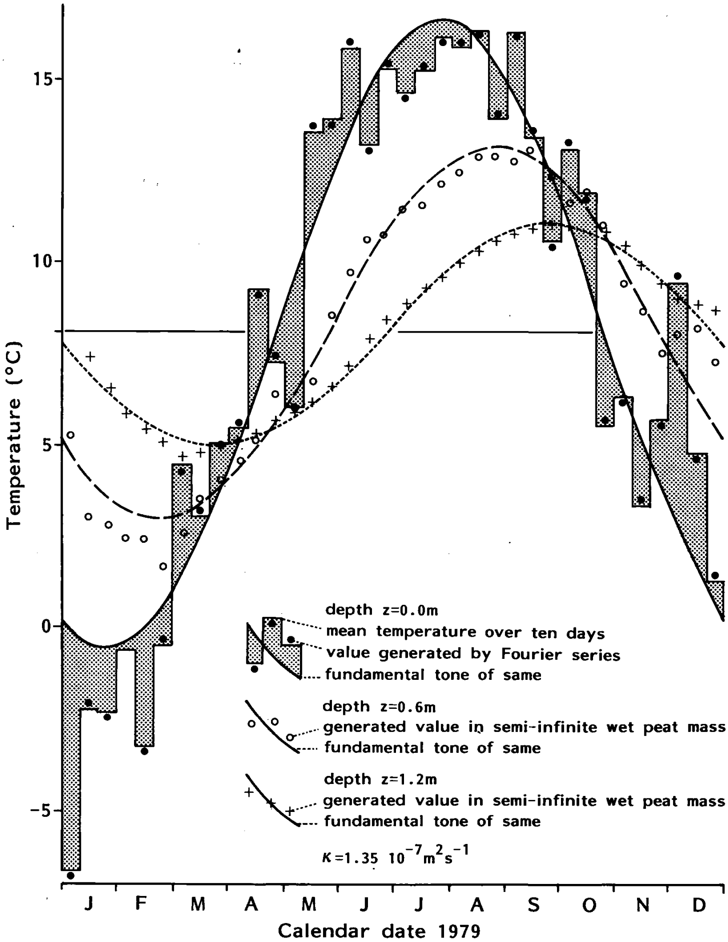


Fig. 8.4 Data and simulated penetration of annual course of meteorological-box temperature
Mean temperatures of ten-day periods from De Bilt and Eelde meteorological stations averaged

time of the instrument considerably, and thus the errors associated with too short an equilibration in the soil at each depth The measurements described in this report were made with this instrument. The accuracy in the laboratory was 0.02 K, in the field it will have been between 0.05 and 0.1 K. The further development of the instruments has been summarized by Van Wirdum (1984).

Simple implementations of the Doppler analogy method (DOPPSOL)

In 1969 and 1970 the soil temperature was measured at several places in De Weerribben. The data were entered in diagrams and compared with standard graphs, produced by means of goniometrical methods in accordance with formulas 8.1 and 8.2. The standard diagrams were based on a variety of expected values of $\mathbf{T_m}$, $\mathbf{A_0}$, **t**, and **b'**, assuming a fixed value **b** = 0.86 m^{-1} in case **v** = 0. It was concluded (Van Wirdum 1972) that these observations indicated a downward water flow rather than an upward one, and this conclusion was backed by analyses of the chemical composition of the mire water at several depths. Essentially the same method was used in 1973-'74. From 1975 to 1980 the comparison of graphs was preceded by a computation on an HP-25 programmable pocket calculator. This method, which still proves useful in several situations, has been reprogrammed for various other computing devices.

It runs as follows[3]:

1) Select three depths **z1**, **z2**, and **z3** and their temperatures for one record;
2) Choose a value for **b'** in formula 8.2 and use this for **b** in the formulae below;
3) Calculate the following parameters:
   $\gamma_z = e^{-bz}\cos(-bz)$ for **z1**, **z2**, and **z3**;
   $\sigma_z = e^{-bz}\sin(-bz)$ for **z1**, **z2**, and **z3**;
   $C_1 = \gamma_{z2} - \gamma_{z1}$, $C_2 = \gamma_{z3} - \gamma_{z2}$;
   $S_1 = \sigma_{z1} - \sigma_{z2}$, $S_2 = \sigma_{z2} - \sigma_{z3}$;
   $\mu = S_1C_2 - C_1S_2$;
   (Note that, for the same set of three depths, and for **b'**=**b**, these calculations need only be performed once!)
4) Calculate
   $D_1 = C_2(T_{t,z1} - T_{t,z2}) - C_1(T_{t,z2} - T_{t,z3})$, and
   $D_2 = S_1(T_{t,z2} - T_{t,z3}) - S_2(T_{t,z1} - T_{t,z2})$ (the formula $\cos(\alpha+\beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta)$ is used);
5) Solve A_0 from $A_0^2 = (D_1^2 + D_2^2)/\mu^2$ (since $\sin^2(\alpha) + \cos^2(\alpha) = 1$);
6) Solve $t=\varphi\tau/(2\pi)$ from $\tan(\varphi) = D_1/D_2$ (since $\tan(\alpha) = \sin(\alpha)/\cos(\alpha)$);

(Note that there are two solutions, one half period apart!)

7) Solve T_m from $T_m = T_{t,z} + \gamma_z D_2/\mu - \sigma_z D_1/\mu$;
8) With the obtained values, compute $T_{t,z}$ for several depths according to formula 8.1 and draw a graph of the results for comparison with the observed values.

Mathematically this basic DOPPSOL method yields exact solutions. The reliability of these solutions depends on the choice of **b'**, on the accuracy of the measurements, on the correctness of the model in the given situation, and, to some extent, on the dates of the measurements relative to the phase of the annual temperature wave. It is possible to vary **b'** in an iterative approach in order to find limiting values between which the solutions of $\mathbf{A_0}$, $\mathbf{T_m}$, and **t**, respectively, cannot be rejected. It is now possible to use formula (8.2) in Section 8.2.1 to solve **v**, since **b** = **0.86** m^{-1} will approximately hold true for most soft and very wet peat soils, such as those in the area investigated here. A final check is possible by drawing a calculated temperature profile, which can easily be calculated from formula 8.1.

[3] In a non-Doppler approach, the same recipe can be used with **a** and **b** (formula 8.3), scenarios for **v** supplying the values to be used in steps 2 and 3.

Summary of results with varieties of DOPPSOL

Many varieties of the DOPPSOL method were developed in the course of years. Especially some of these varieties were designed to use several sets of three temperatures out of one profile so as to find a fit and to evaluate an average solution. The general use of 0.6, 1.0, and 1.6 m for **z1** through **z3** yielded satisfactory results. The Doppler analogy method was also extended so as to take account of measurements at several dates. In this extension it was possible to compute a best fitting value for **b'**, provided enough data were available, and somewhat depending on the time of the year. Some results for De Stobbenribben have been summarized in Table 8.6, under the heading 'DOPPSOL findif', indicating a finite-differences solution. A downward water movement with a gross velocity of 4.8 mm/d (mean) was found. Similar results were obtained by graphically estimating the attenuation and the time-lag of the temperature wave in time series of temperature profiles, but this procedure consistently suggested different values for **b'** as derived from the amplitude damping and the phase shift, respectively. This difference was confirmed by the application of Fourier analysis to the time series, and initiated a further literature search leading to the implementation of the Stallman model.

Implementations of the Stallman model (FOUSOL)

The work of Suzuki (1960) and Stallman (1965) led to the development of the method introduced in Section 8.2.1. In 1981 a set of programs was written in order to implement this method on an HP-41C programmable calculator with a cassette drive and a printer. The implementation is called FOUSOL here after the name of the main program involved. The FOUSOL method runs as follows:

1) Enter monthly temperature profiles into a data file. In our case each station yields 12 (data) times 16 (depths) numbers, which refer to temperature with a precision of 0.01 K;
2) Run a Fourier analysis of these data, and save the mean temperature, the amplitude, and the phase of the fundamental tone for each depth in a second data file;
3) Run the main program FOUSOL, which requires the second data file. FOUSOL needs instructions with regard to the possible subdivision of the soil profile into layers. With 16 depths represented, the soil may be subdivided into 1 to 15 layers, which is specified by the number of depths to be used per layer ($2 \leq n \leq 16$). The solution is thus given for a 'window' which moves downward along the **z** axis. The solution of **a** and **b** uses exponential and linear regression, respectively, whenever $n>2$. A fixed value may be specified for **ρc**.

The problem of estimating the sensitivity and accuracy of this method has not been completely solved. Stallman suggests that the value of **a** must be affected as much as, or even by more than, 5% by the liquid flow to ensure a satisfactory observation of **v**. Referring to Fig.8.1, this compares, in the case of very wet peat soils, to $|\mathbf{v}| \geq 1$ mm/d. How realistic this is depends on the errors in **a** and **b**, which are difficult to assess. From the range of the thermal diffusivity derived in Section 8.2 it can be concluded that the maximum value for **b**, for the annual wave, falls between 0.83 and 0.89 m^{-1}, with a typical value of 0.86. The results reported below show that the maxima actually found there do not extend beyond this range. Assuming opposite errors of 1-3% in **a** and **b**, the error in **v** would be 0.8-2.3 mm/d in the critical region where **a** approximately equals **b**. Taking account of the coefficients of determination of the regressions for **a** and **b**, I expect that this estimation is on the safe side, and that violation of model

Table 8.6 Comparison of results obtained by the application of different methods of solution of **v** from soil temperature profiles in De Stobbenribben.

petgat:

station nr: | distance from ditch (m): | method: FOUSOL 790521- 800422 **κ** *10^7^ (m² s⁻¹):

D	C	B	A	D	C	B	A	D	C	B	A	D	C	B	A
15	11	7	1	171	171	171	183					1.43	1.87	1.32	1.60
			2				159								1.42
16	12	8	3	123	123	123	139					1.68	1.34	1.31	1.94
17	13	9	4	73	73	73	99					1.42	1.55	1.78	1.75
			5				57								1.89
18	14	10	6	25	25	25	20					1.54	2.26	1.37	1.65

method: FOUSOL, time series 790521- 800422

v (mm d⁻¹): | date **φ**=0 (in February): | A_0 (K): | T_m (°C):

10.6	2.8	2.7	2.1	17	10	9	11	7.7	8.5	7.6	8.7	9.5	9.4	9.2	9.7
			6.3				15				8.3				9.5
-1.1	4.4	3.4	3.3	16	12	15	15	9.2	7.5	8.9	8.8	9.7	8.2	9.3	9.3
-0.9	4.5	1.3	2.1	20	8	17	16	10.0	7.3	9.5	9.3	9.8	8.4	9.6	9.6
			4.1				16				8.7				9.6
0.7	1.6	0.9	6.4	18	16	20	15	8.9	9.4	9.5	9.1	9.9	10.4	9.8	9.7

method: DOPPSOL-findif, time series 790710- 800513

v (mm d⁻¹): | date **φ**=0 (in January!): | A_0 (K): | T_m (°C):

10.0	5.8	3.8	5.4	26	25	30	26	8.4	8.9	7.4	8.7	9.6	9.4	9.2	9.6
			7.1				28				8.7				9.4
1.9	4.0	3.9	5.1	16	25	25	17	9.1	7.6	8.7	9.7	9.7	8.1	9.4	9.2
2.0	5.0	5.5	3.0	17	29	17	12	9.3	8.0	9.2	10.4	9.9	8.4	9.6	9.5
			6.5				17				9.3				9.6
2.8	6.8	1.4	6.4	15	19	14	20	8.9	9.7	9.6	9.8	9.9	10.3	9.7	9.8

The table should suggest schematic maps of De Stobbenribben, where drawn lines represent the baulks. Note that the DOPPSOL-findif method was applied to a slightly different time series. A further explanation is given in the text. Where a credible value was found for **κ** with FOUSOL, the values obtained for **v** and **κ** are printed in bold face. The DOPPSOL method was applied with a fixed value **κ** = 1.35 10^{-7} m² s⁻¹.

assumptions, including any disturbing factors may become of greater importance than small errors in precision.

The main problems are those caused by a lateral flow of water and heat (see Section 8.4), and those caused by the uncertainty with respect to the depth **z**. Unlike DOPPSOL, FOUSOL out of necessity uses numerical data collected in all seasons. Since the *kragge* rises and sinks with the water level, the question arises what reference should be used for the depth **z = 0**. The fixed null-surface is a model construct that, by visual inspection in the terrain, can only be approximately located. In this investigation, the average *kragge* surface at the time of

Table 8.7 FOUSOL results based on monthly temperature profiles from May, 1979 to April, 1980.

petgat:

T_m (°C): D	C	B	A	stand. dev. T_m (K): D	C	B	A	κ *10^7 ($m^2\ s^{-1}$): D	C	B	A	v (mm d^{-1}): D	C	B	A
9.5	9.4	9.2	9.7	0.3	0.1	0.1	0.2	1.43	1.87	1.32	1.60	10.6	2.8	2.7	2.1
			9.5				0.2				1.42				6.3
9.7	8.2	9.3	9.3	0.2	0.1	0.1	0.4	1.68	1.34	1.31	1.94	-1.1	4.4	3.4	3.3
9.8	8.4	9.6	9.6	0.2	0.2	0.1	0.3	1.42	1.55	1.78	1.75	-0.9	4.5	1.3	2.1
			9.6				0.4				1.89				4.1
9.9	10.4	9.8	9.7	0.1	0.2	0.1	0.1	1.54	2.26	1.37	1.65	0.7	1.6	0.9	6.4

A_0 (K): D	C	B	A	a (m^{-1}): D	C	B	A	r^2 for a (%): D	C	B	A
7.7	8.5	7.6	8.7	0.45	0.64	0.75	0.71	99.8	99.2	99.7	99.5
			8.3				0.59				99.5
9.2	7.5	8.9	8.8	0.81	0.67	0.72	0.62	98.7	99.7	99.4	99.6
10.0	7.3	9.5	9.3	0.87	0.64	0.71	0.68	99.5	99.2	99.7	99.0
			8.7				0.60				98.9
8.9	9.4	9.5	9.1	0.78	0.62	0.81	0.56	99.1	97.7	99.5	99.5

date ($\varphi_0 = 0$) in February: D	C	B	A	b (m^{-1}): D	C	B	A	r^2 for b (%): D	C	B	A
17	10	9	11	0.78	0.73	0.86	0.79	100	99.8	99.9	99.8
			15				0.82				99.9
16	12	15	15	0.77	0.85	0.86	0.71	99.8	99.8	99.9	99.7
20	8	17	16	0.84	0.79	0.75	0.75	99.2	99.8	99.9	99.6
			16				0.72				99.8
18	16	20	15	0.80	0.66	0.85	0.76	99.6	98.9	99.8	99.9

No separate layers were distinguished (**n**=16), and a heat capacity of 4 10^6 J m^{-3} K^{-1} was assumed for the peat. The arrangement of the table is as in Table 8.6. Numbers in bold face refer to very credible solutions for κ.

measurement was referred to, and the sounding rod was inserted in the profile through a hole in a 15 cm diameter disc, which was slightly pressed down onto the *kragge*.

Results obtained with the FOUSOL method

The complete results shown in Table 8.7 were already summarized in Table 8.6 for comparison with the results obtained by the application of the Doppler analogy. The mean of the values for **v** is 3.1 mm/d (all values used) or 3.9 mm/d (less credible values omitted), which is in the same order of magnitude. The solution of κ shows that the model yields less credible data for 11 out of the 18 sites. Subdivision of the soil profile into layers yields curves of **v** as depending on **z** (Fig.8.5). The shape of these curves varies, but there is a slight general tendency of a decrease of **v** above a depth of, approximately, 1.0 m. This may be due to the influence of evapotranspiration causing an upward component in the flow of water through the root zone. As will be shown in Chapter 9, compensation for water loss is supplied by a lateral water flow underneath the *kragge*, so that the downward flux due to seepage is less important or even absent in the uppermost part of the profile.

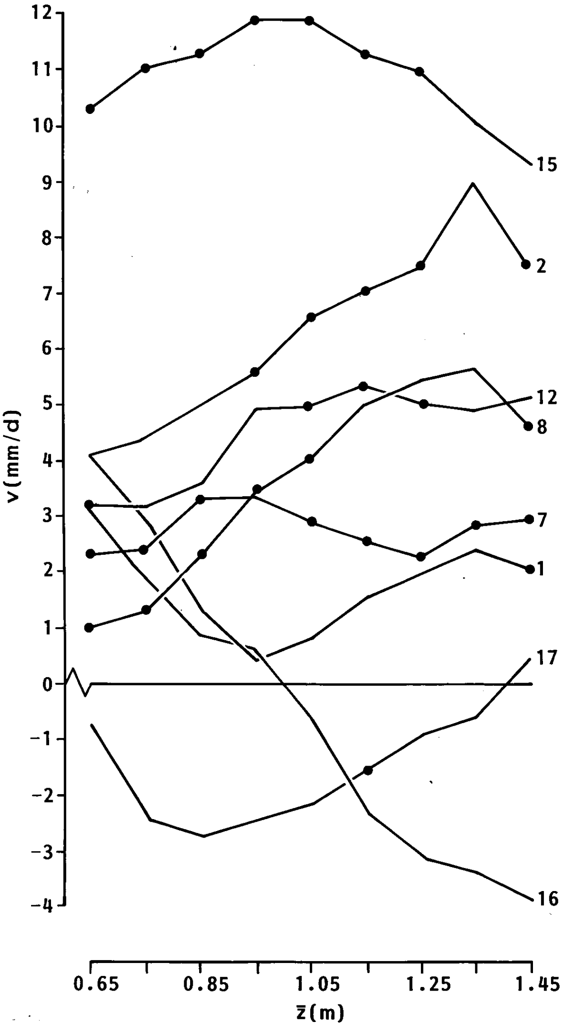


Fig. 8.5 Variation of estimated v with depth

Each record refers to a soil layer with a thickness of 0.7 m. Layers overlap by 86%. Numbers indicate measuring stations (see Table 8.6). Solutions satisfying $\kappa = 1.35\ 10^{-7}\ m^2\ s^{-1} \pm 7.5\%$ have been marked with a dot.

Other explanations, such as the influence of several disturbing factors, cannot be excluded, however. An illustration of FOUSOL output for station 7, with **n**=8, is provided by Table 8.8. Each of the overlapping layers, *i.e.*, each window, is 0.7 m thick here. A decreasing **n** results in a more fluctuating pattern of **v**, as illustrated in Fig.8.6 by showing the result for **n**=3 together with those for **n**=8 and **n**=16. When **n**=3, the thickness of each layer is 0.2 m.

Table 8.8 FOUSOL solution for station nr.7 (De Stobbenribben), nine overlapping soil layers of 0.7 m thickness being distinguished.

Layer	from (m)	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
	to (m)	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
T_m	(°C)	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.2	9.2
stand. dev.	(K)	0.1	0.1	0.1	0.1	0.02	0.02	0.03	0.04	0.1
A_0	(K)	7.7	7.6	7.2	7.3	7.5	7.7	7.7	7.4	7.4
a	(m^{-1})	0.78	0.75	0.70	0.72	0.75	0.76	0.77	0.74	0.73
r^2	(%)	98.9	98.9	99.7	99.8	99.8	99.9	99.9	99.9	99.9
date φ_0=0	(Feb)	10	8	7	8	10	10	9	8	8
b	(m^{-1})	0.88	0.85	0.83	0.85	0.87	0.87	0.87	0.86	0.85
r^2	(%)	99.6	99.7	99.9	99.9	<------------------------100.0------------------------>				
κ *10^7	($m^2 s^{-1}$)	1.28	1.36	1.43	1.35	1.30	1.29	1.31	1.35	1.36
v	(mm d^{-1})	2.3	2.4	3.3	3.4	2.9	2.6	2.3	2.8	2.9

Temperatures were measured at eight depths (**n=8**) in every layer.

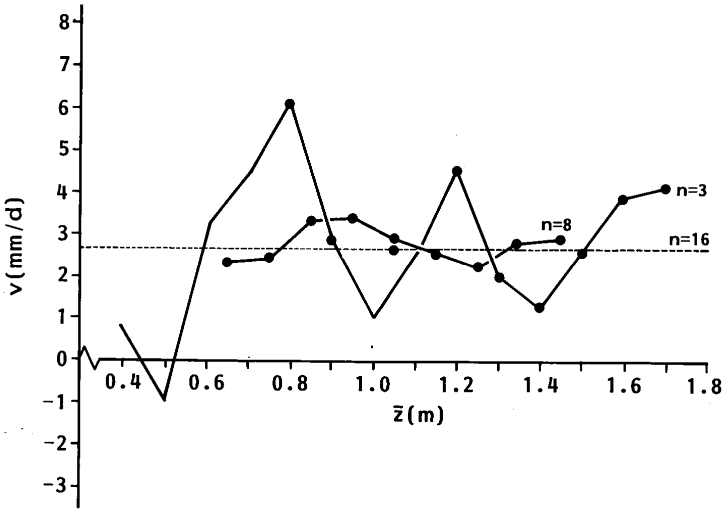


Fig. 8.6 The effect of subdividing the soil into layers at station 7

The thickness of each layer (window) is 0.3, 0.7, and 1.5 m at n= 3, 8, and 16, respectively. Solutions satisfying κ = 1.35 10^{-7} m^2 s^{-1} ±7.5% have been marked with a dot.

When comparing these results with computations on the basis of measurements of the hydraulic head, one should be aware of the uncertainty with regard to the hydraulic conductivity, which is probably not particularly smaller than that with regard to the thermal diffusivity. In fact, the results obtained here may be considered quite reliable in view of the values found for **κ**. Note, however, that the areal extent to which the thermal method applies is small in comparison to that in a hydraulic survey. An interesting result is the upward flow which was found at the stations 16 and, quite reliably, 17. It appears that a mineral bottom is present here at a level 0.5 m higher than elsewhere underneath De Stobbenribben (see Fig.7.3). This elevation of the mineral bottom was also traced under the nearby ditch situated to the north-east, and it is supposed that leakage of water from that ditch is possible either through or over this elevation. The electrical conductivity measurements presented in Chapter 9 provide support for this hypothesis. In any case, there is no reason to suppose that groundwater is upwelling here from a greater depth.

8.4 Lateral heat flow: a disturbing factor

The vertical heat flow through the mire was used in Section 8.3 as a tracer for water flow. It was assumed there that no appreciable lateral heat flow was present. This assumption is not justified by the following quantitative approximation of the importance of lateral heat flow in De Stobbenribben. This approximation is only a rough one.

The water budget of one *petgat* in De Stobbenribben can be written as:

$$\mathbf{P} - \mathbf{E} + \mathbf{I} - \mathbf{S} = 0,$$

where
P precipitation gain in m^3;
E evapotranspiration loss in m^3;
I surface water influx in m^3;
S seepage loss in m^3,
the volume of water in the *petgat* supposed to remain constant.

P, **E**, and **S**, are inputs and outputs through the surface and the bottom of the *petgat*, respectively, with an approximate area of 30 (width) times 200 (length) m^2. The flux density of **S** was estimated at 3 (-5) mm/d in Section 8.3, while the flux density of **P-E** may reach values of -2 mm/d (in the extremely dry year 1976 even -3 mm/d) during prolonged dry periods (see Appendix E on evapotranspiration). Over a period of 100 days, (**P-E-S**) may thus amount to -0.5 times 30 times 200 m^3.

I is an input through one narrow side of the *petgat*. Although the depth of the *petgat* to the mineral bottom is about 2-3 m, **I** may be channelled through a somewhat thinner layer with an area of, say, 30 (width) times 1 (height) m^2. The flux density of **I** during this period of 100 days would thus be 1 m/d. This is probably an over-estimation, since a considerable drop of the water table in the mire can be observed during such dry periods. The flux density moreover decreases linearly with the distance from the ditch. On the other hand, the downward seepage may be up to twice as large, and the main lateral flow channel may be still narrower and thinner.

From the value 1 m/d near the ditch, occurring during a dry period, a reasonable estimate of the mean lateral flux density within the preferential channel in the whole *petgat* is 0.5 m/d. This value can be used in connexion with formulas 8.3 and 8.4 in Section 8.2 to resolve the amplitude of temperature fluctuations which may be ascribed to lateral heat flow at a distance **L** from the ditch. For this purpose formula 8.3 is applied along the longitudinal, rather than the vertical axis, and **z** and **v** are replaced by **L** and the lateral water velocity $\mathbf{v_l}$, respectively. $\mathbf{A_0}$ now represents the amplitude of the temperature variation in the ditch. Since the drought influx has a short duration, the overall contribution to the temperature fluctuation in the mire will probably show up as one with a period considerably shorter than 1 year, say $\boldsymbol{\tau}$ = 91 d. A value of 5 K will be used for the amplitude of the temperature fluctuations in the ditch during this period. The same values as before will be used for $\boldsymbol{\kappa}$ (1.35 10^{-7} m^2 s^{-1}) and $\boldsymbol{\rho c}$ (4 10^6 J m^{-3} K^{-1}).

From formula 8.3 it can be seen that

$$\mathbf{L} = -\ln(\mathbf{A_L}/\mathbf{A_0}) / \mathbf{a},$$

where **L** is the distance from the source of fluctuation in the direction of heat flow. In order to find a reasonably critical value for $\mathbf{A_L}$, the variation of $\mathbf{A_z}$, for **z**=1.0 m, with the flux density of downward seepage, according to the vertical application of the Stallman model, is investigated first. From Fig.8.1 it is apparent that **a** is almost linear in **v** when **v** is only some mm/d; the decrease of **a** is roughly 0.04 m^{-1} when **v** increases by 1 mm/d. For **z** =1.0 m, $\mathbf{A_z}$=3.81 K when $\mathbf{A_0}$= 9 K and **v** = 0 mm/d. Accordingly, when **v** increases by 1 mm/d, $\mathbf{A_z}$ increases by approximately 0.16 K. Taking this as a critical value $\mathbf{A_L}$= 0.16 K in the lateral application of the model, the values listed in Table 8.9 are found for the distance from the ditch where the amplitude remains this large.

This means that, if the assumptions of the Stallman model apply, the measured temperature may be more than 0.16 K in error at the critical depth of 1.0 m almost everywhere in the *petgat*.

This would cause problems when it happens to coincide with other deviating values so as to suggest a different annual amplitude in the Fourier analysis. I have not numerically investigated the chance that this occurs.

The previously used Doppler analogy is much more optimistic at such large values of $\mathbf{v_l}$. According to formula 8.2 in Section 8.2, with **b**= 1.72 m^{-1} ($\boldsymbol{\tau}$= 91 d!) and $\mathbf{v_l}$ = 1.0 m/d, **b'**= 0.066 m^{-1}, so $\mathbf{A_L}$= 0.16 K at a distance **L**= 52 m from the ditch.

These calculations are, needless to say, only tentative, but they show that there is a fair probability that lateral flow of water and heat may seriously interfere with the use of the DOPPSOL and the FOUSOL methods. The FOUSOL method is less sensitive to such interferences since it isolates the annual wave component. The distance from the ditch at which interference may be disregarded varies according to the assumptions made. In an optimistic scenario this distance is some decametres, in a pessimistic one it reaches up to the ‘dead’ ends of the *petgaten*, where $\mathbf{v_l}$ approaches 0. This point will be reviewed in a discussion of observed temperature gradients along the length axis of the *petgaten* in Chapter 9 (Section 9.4). Apparently the qualitative conclusion that no groundwater is discharged into De Stobbenribben is not affected by this problem. However, if groundwater were welling up, this would be discharged into the ditch, at least in winter, and the temperature profiles would reflect the upward flux, at least in the dead ends of each *petgat*.

From Tables 8.6 and 8.7 it appears that the FOUSOL method resulted in anomalous values for the thermal diffusivity of the peat at most sites in the terrain parts within ca 80 m from the ditch.

Table 8.9 Critical distances from a source of lateral heat flow for some values of $\mathbf{v_l}$ (with τ=91 d) according to the Stallman model.

v_l m/d	a m^{-1}	L m
1.0	$6.4\ 10^{-5}$	$5.4\ 10^{4}$
0.5	$5.1\ 10^{-4}$	$6.7\ 10^{3}$
0.2	$8.0\ 10^{-3}$	$4.3\ 10^{2}$
0.1	$6.2\ 10^{-2}$	$5.6\ 10^{1}$

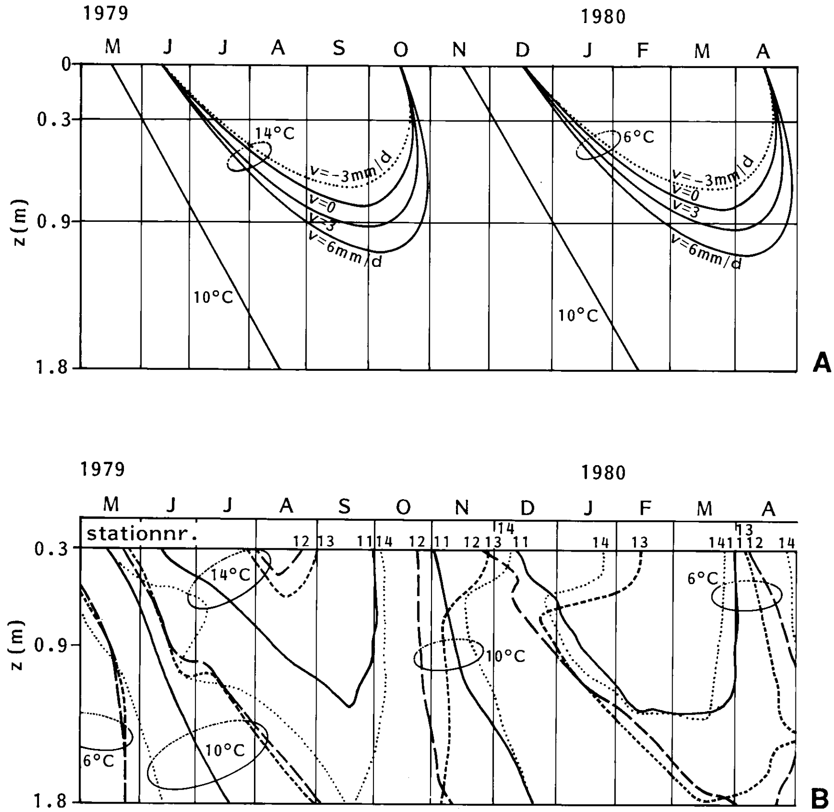


Fig. 8.7 Isotherms in mire profiles during the year

a: Computed with Formula 8.3 ($\mathbf{T_m}$=10 ^{0}C, $\mathbf{A_0}$=8 K, κ=1.35 10^{-7} m^2 s^{-1}, ρc=4 10^6 J m^{-3} K^{-1}, φ_0=0 on February, 15th)

b: Measured at stations 11-14 (parcel C, De Stobbenribben; see Table 8.6).
Station 14 is near the ditch.

Table 8.10 The period in 1979 when the temperature at 0.3 m below the *kragge* surface exceeded 14 ^{0}C.

Parcel D			**Parcel C**			**Parcel B**			**Parcel A**		
from	**to**	**days**	**from**	**to**	**days**	**from**	**to**	**days**	**from**	**to**	**days**
Jun, 6	Sep, 26	112	Jun, 11	Oct, 1	112	Jul, 21	Sep, 10	51	Jun, 3	Oct, 5	124
									Jun, 1	Sep, 30	121
Jun, 7	Oct, 2	117	Aug, 1	Aug, 26	25	Jun, 9	Sep, 14	97	Jun, 3	Sep, 29	118
Jun, 10	Sep, 30	112	Jul, 27	Sep, 3	38	Jun, 5	Sep, 22	115	Jun, 1	Oct, 3	124
									May, 25	Sep, 29	127
Jun, 14	Sep, 24	92	May, 14	Oct, 4	143	Jun, 7	Sep, 13	104	Jun,71	Oct, 3	118

The measuring stations have been arranged as in Tables 8.6 and 8.7; see also Fig.8.7b

In conclusion it is observed that the uncertainty with respect to the quantitative value of the flux density increases as the flux density along the vertical axis increases, and so causes an important lateral inflow.

8.5 The temperature regime in the root zone

The formulae presented in this chapter also enable a calculation of the temperature in the root zone and the influence of seepage on this ecologically relevant factor. The available data can be used to describe the actual temperature regime in the *kraggen* of De Stobbenribben. This has been illustrated in Fig.8.7. The theoretical approach (Fig.8.7a) reveals that a 1 mm/d downward seepage may prolong the duration of the period for which the soil temperature at a depth of ca 0.3 m exceeds a certain biologically critical temperature, *e.g.*, 14 ^{0}C, with ca 3 days. At **v**=0 mm/d this period lasts 101 days according to the Stallman model with $\mathbf{T_m}$=10 ^{0}C and $\mathbf{A_0}$=8 K. It appears (Fig.8.7b, Table 8.10) that the duration of this period varies to an even greater degree among sites in De Stobbenribben. According to these differences, the apparent start and length of the growing season will also vary. While this may in itself result in different plant communities, it also controls microbial activity governing the nutrient state. The possible consequences in De Stobbenribben have not been investigated, however.

It is worthy of note that the results shown in Fig.8.7b and Table 8.10 are not only, and probably even not primarily, due to hydrological differences between sites. The temperature regime at the soil surface is influenced by various other factors, which will be partially mentioned in Chapter 9. An obvious anomaly is shown in Fig.8.7b for the measuring stations 13 an 14 in the period November 1979 - January 1980, when a thermal discontinuity has developed at the lower boundary of the *kragge*. Apparently the local unmown stand of *Cladium* vegetation strongly delays the cooling of the *kragge*, while the body of water underneath is cooling through a lateral influx of colder water. The short duration of the warm season at these stations is also largely due to the combined insulation by the unmown vegetation and a relatively strong mixing of water underneath the *kragge*. In quagfen parcel B (Table 8.10), the measuring stations far from the ditch also exhibit a relatively short growing season. This is caused by a vegetation cover with much *Polytrichum* and *Erica*. Although this vegetation is low, it forms a relatively dry and thermally insulating layer.

Even more local factors become important in the upper 1-3 dm of the *kragge*, where short-term fluctuations of the air temperature and radiative exchange of heat substantially contribute to the temperature regime. In De Stobbenribben and similar quagfens the local variation in such factors are no-doubt decisive for the daily temperature regime in shallow pools.

8.6 Conclusions

The conclusions from the material treated in this chapter can be divided over two main groups: those with respect to the thermal assessment of seepage, and those with respect to seepage in De Stobbenribben.

The following conclusions belong to the first group:

1 The thermal assessment of seepage in wet peat soils requires accurate measurements of soil temperature below a depth of 0.4 m;

2 The Doppler analogy method may be applied to single temperature profiles. It is suggested that these profiles comprise at least 3 values, and that the depths be chosen so that these values are definitely different. This method can only be used when **v** is small and when the thermal diffusivity of the porous medium is nearly equal to that of water, as in the case of very wet peat soils. A further analysis of the reliability of this method is desirable;

3 The Stallman method is based on a physically more precise model, but the method is also more demanding. It is suggested that measurements be performed at least monthly[4]. The concept of the model is most efficiently used when each temperature profile comprises several values, *e.g*, 0.1 m apart. The sensitivity to violation of model assumptions deserves more attention (see also 4);

4 It is necessary to consider the possible influence of lateral flow whenever the results have to be quantitatively interpreted;

5 In De Stobbenribben both methods yielded similar results which could not be rejected by reference to results of any other method and which are in accordance with hydro-geological considerations.

The following conclusions refer to De Stobbenribben:

6 A downward seepage in the order of magnitude of some mm/d could be confirmed. The spatial variety of the flux density appears to be considerable, however;

7 In some places about a 1 mm/d upward seepage was found, which could be in the range of reliably determined values. There is some corroborative evidence for these anomalous results from other studies. This seepage originates probably from a nearby ditch at a higher level;

8 The Stallman model assumptions are not satisfied always and everywhere in De Stobbenribben;

9 At different depths in the profile the flux density of seepage may have different values. There is some indication that this coincides with water loss through the root zone to the atmosphere;

10 The measured data and the heat transport model enable a description of the temperature fluctuations in the root zone. Seepage may alter the annual temperature regime to an ecologically significant degree, but the measurements suggest that the structural aspects of the local stands of vegetation are even more important in this respect.

[4] Single gradients can be solved with the same formulae used in the Doppler method, however. In this case a range of scenarios for **v**, with known thermal properties providing values for **a** and **b**, can be tested.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 9

Lateral water flow in longitudinal transects

9.1 Introduction

The pattern in the cover of vegetation of De Stobbenribben shows an obvious gradient in the longitudinal direction. Since there appears to be a downward flow of water (Chapter 8) this could be caused by a compensating influx of surface water from the ditch at one side, while, towards the other side, an increasing influence of rainwater is indicated by the local stand of vegetation (Chapter 7). It will be shown that the hydraulic head of the phreatic water in the quagfen parcels, during drought, decreases as the distance from the ditch increases. Only heavy rainfall is capable to invert this pattern temporarily. A descriptive approach suitable for routine surveys was developed and used to monitor the presence of chemically different types of water in longitudinal sections through the *petgaten*. The survey method includes a detailed study of the temperature and the electrical conductivity of the peat, and, in addition, chemical analysis of the mire water.
This chapter shortly describes the method and then summarizes the results obtained in De Stobbenribben. Only a small, but representative, selection of the various maps is shown here in order to deliver a *de facto* proof of the existing longitudinal gradient and the influx of ditch water through a preferent flow channel

just underneath the *kragge*. The chemical identity of the mire water could be assessed on the basis of chemical analyses treated here and in Chapter 10.

In the long run the water level in De Stobbenribben remains nearly constant. Since the downward loss of water, in the order of magnitude of 3 mm/d, or 1 m/a, is far greater than the estimated precipitation surplus (0.2 m/a), there must be a considerable lateral influx of water. The topography of the area suggests that the influx originates mainly from the ditch at the north-eastern narrow ends of the *petgaten*. Since in this area rainwater and surface water have quite different solute concentrations (Appendix D), conceivably the different types of water may be traced in the mire by their electrical conductivities. The influx of ditch water is controlled by a hydraulic head gradient in the quagfen parcels and it has appeared that this gradient is large enough to be measured.

It is worthy of note that conductivity as such is not a measure of the concentrations of nutrients in the water. I will therefore not denote high-conductivity and low-conductivity waters as nutrient-rich and nutrient-poor, respectively. A high conductivity indicates a relatively concentrated solution and a high base state; in some geochemical literature it is referred to as "strongly mineralized", suggesting the solution of minerals from the lithosphere. This term is not very adequate in the present context and I have not used it. A low conductivity indicates dilute and base-poor waters.

In order to compare the conductivity values accurately account was taken of the ambient temperature. The availability of temperature data also allowed for an assessment of longitudinal temperature gradients which shed some light on the problem of lateral heat flow interfering with the computation of vertical water flow by the heat transport method (Chapter 8).

Water samples with a similar electrical conductivity may still be different with regard to the concentrations of the various solutes. Chemical analysis of water samples were used to confirm the identification of coherent bodies of mire water.

9.2 Data acquisition in longitudinal transects

Hydraulic head (water manometers)

Hydraulic head differences at first appeared difficult to assess due to the small differences and various problems associated with the measurement in piezometers in quagfens. Firstly, it is no trivial matter to fix the usual pvc pipes in the mineral subsoil, so as to guarantee a fixed reference height which is independent of the vertical movement of the *kragge*. Of course the lower part of such pipes should be separated from the upper part containing a filter in the body of phreatic water above the mineral soil. Secondly, the weight of an observer on the *kragge* exerts a local pressure possibly altering the water table in the gauge. Thirdly, the installation of many semi-permanent observation gauges was inacceptable from the point of view of nature management: it attracts occasional visitors, damaging the vegetation (and frequently also the installed water gauges!), and it hampers the mowing and cutting of the vegetation. A classical water manometer, used by J.Bon in studies of the hydraulic gradient in rivulets (pers.comm.) was adapted for the use in quagfens and appeared to provide a suitable solution (Fig.9.1).A comparison of measurements of the hydraulic head gradient with different methods has shown that the water manometer method is superior to piezometer methods.

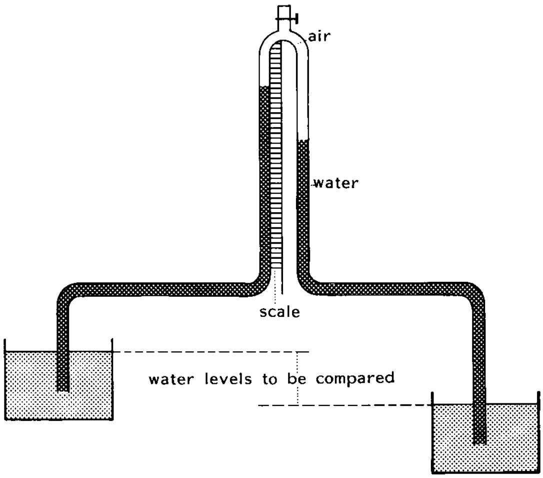


Fig.9.1 Water-manometer for the measurement of water-level differences in quagfens

Since both lengths of flexible tubing in this water manometer are about 20 m long, it is possible to obtain the readings at a considerable distance from the measuring points (pools or open pits in the *kragge*). When possible, the readings were performed on the baulks between the *petgaten*. A series of measurements can be executed in a closed loop, beginning and ending with the same water level in part of the *boezem* system. The highest accuracy, which was not reached at all occasions, was about 0.5 cm over a distance of 30 m, or ca 0.00017%.

Kragge movement

In order to check for a possible variation of the water level in the root zone, several experiments were performed to measure the vertical movement of the *kragge*. This was done with small tins, firmly attached in the *kragge* and moving around an iron post driven into the mineral bottom (Fig.9.2). The results for De Stobbenribben have been reported by Touber (1973). It appeared that the movement of most parts of the *kragge* is about 30-90% of that of the phreatic water level. The *kraggen* are attached to standing baulks, and near these baulks their movement is strongly reduced. A similar reduction is seen in certain firmer parts of the *kragge*. The movement of the floating mat is also reduced at extreme water levels, which may result in a local flooding. At the level of accuracy of the present treatment and for the periods chosen for water balance calculations the varying storage of water in the *kragge* itself could be disregarded.

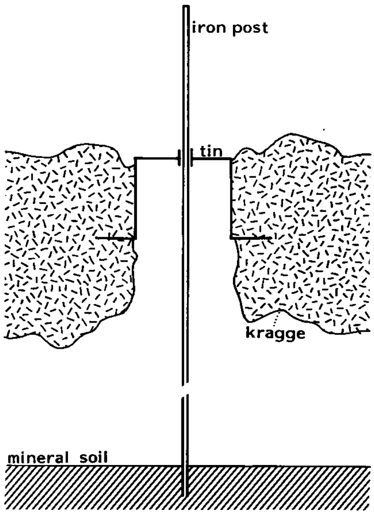


Fig.9.2 Gauge for measuring *kragge* movement

Conductivity and temperature sounding

The electrical conductivity probes were mounted in the same sounding rods as used for the assessment of temperature profiles. The earliest models had two platinum rings as electrodes, and were connected with conventional conductivity meters. The platinum rings were later replaced by stainless steel ones, of which several sets were mounted in a single sounding rod, so as to enable the simultaneous assessment of conductivity profiles. The temperature was noted separately, and the conductivity at 10 °C was calculated afterwards according to the formula presented in Appendix D. The code EC_{10} is used. Since the measurement of the electrical conductivity hardly requires any equilibration, it was, without any appreciable time loss, performed in one run together with the temperature measurements discussed in Chapter 8. The instruments were frequently re-calibrated in the laboratory. From time to time a comparison was made between the *in situ* measurements with the sounding rods, and measurements with a standard conductivity meter in water samples from the same place and depth. These samples were collected according to the method described in Section 9.5. As a consequence, these measurements do not refer to exactly the same bodies of water. Moreover, the sounding method is influenced by the presence of the peat matrix. The results should, therefore, not be regarded as straightforward conductivities of water. Since the deviation reflects a 'soil factor' which is more or less the same everywhere in De Stobbenribben, it was decided to use the results as relative numbers, showing the conductivity patterns in the sections, rather than trying to convert the numerical data into an absolute conductivity of water. The difference is not large in this extremely wet substance, but it has appeared that differences are flattened out somewhat.

Thus, the numerical data presented here reflect the electrical conductance of the medium in mS measured with the specific sort of cell used. They may be interpreted as electrical conductivity values, which should be multiplied by a variable c close to 1 in order to get electrical conductivity of water at 10 °C in mS/m.

Measuring schemes and data processing

Occasional observations in 1969-'70 suggested a clear longitudinal gradient in the vegetation, in the electrical conductivity of the water at various depths, and in the chemical composition of this water. Periods of more systematic measurements followed in 1973-'75 and 1978-'83. In 1978 the program was reduced to a sounding at fixed measuring stations and the assessment of water level differences between the closed ends of each quagfen parcel and the *boezem* system. A quantitative description of the relation between the hydraulic head and conductivity gradients, which would have required the continuation of time consuming levellings, was not aimed at.

Representative data were selected on a basis of comparison of conductivity patterns as seen in hand-drawn isopleth maps. As the amount of collected data increased it became desirable to develop a database on a computer and to program the production of isopleth diagrams. This was done by C.H.van Leeuwen for the computers and plotters used at RIN in those days. The hundreds of diagrams produced have been filed in databooks at RIN.

It appeared that the construction of isopleths on the basis of the calibrated, but further unprocessed numerical data yields rather irregular patterns as a result of very local deviations of the conductivity. This problem was reduced by averaging three values in a moving window from the upper part of the soil down to 1.8 m. In one profile, each value is thus replaced by the mean of the three values provided by itself and by the 0.1 m upper and lower neighbouring ones, respectively. This variable is shortly called $EC_{10}(3)$ here. The intersection with each isopleth is then found by linear interpolation. Similarly, linear interpolation along the length axis through each measuring depth is applied, and the various points of each isopleth are connected by smooth lines. The isopleth maps were visually compared. Their general pattern is discussed in Section 9.2.4 with some representative diagrams, which were redrawn in block schemes.

9.3 The general pattern found

The hydraulic head gradient

Some typical results of the water levelling program are shown in Fig.9.3. They show the development of a longitudinal gradient in all four *petgaten* during summer. This gradient is less pronounced during winter, but inversions, *i.e.*, a hydraulic head surplus in the body of phreatic mire water in the quagfens, are only observed during and after heavy rainfall. Such inversions rarely exist longer than two or three days. A very interesting feature is the difference among the four quagfen parcels: as the drought continues, parcel D, which is closest to the drained polder area to the south-east, presents the lowest phreatic levels. In time this may vary, however, according to various local circumstances. In various summer seasons the gradient from the ditch towards the closed end of the *petgaten* reached a value of 13-21.8 cm over 160-200 m. In the transverse direction almost ten times steeper gradients are found near the canal running along the outer baulk of parcel D, causing small local seeps as suggested by the thermal measurements presented in Chapter 8 and also by the conductivity measurements.

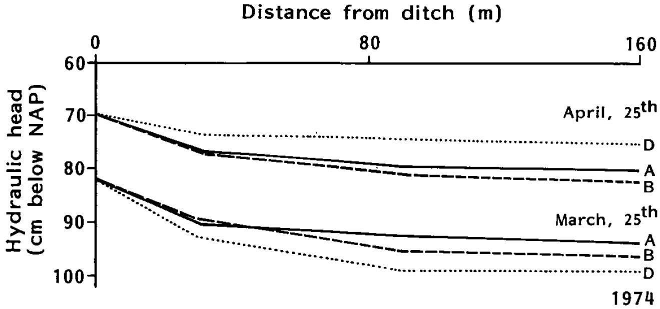


Fig.9.3 Hydraulic head gradients measured in De Stobbenribben, parcels A, B, D from Vromen, Klamer & de Vries 1974

The longitudinal conductivity gradient

A longitudinal gradient of the electrical conductivity was apparent in all four *petgaten* (Fig.9.4). Near the 'dead' ends of the *petgaten* the conductivity is low, while it is higher towards the ditch. In *petgat* B the higher values are confined to a narrow zone near the ditch, but they reach much farther towards the dead ends in the other ones. The mean values for the period 1979-1980 show a pattern very similar to the one of May, 1979. Next to the longitudinal gradient there is also some difference along the vertical axis. Especially near the surface of the mire, the values tend to be lower. On average the conductivity values have decreased somewhat between 1973 and 1984.

The general pattern may be explained by:

1) An influence of precipitation in the uppermost part of the mire profile;
2) An influence of ditch water penetrating to just below the *kragge* over a length which depends on the flux density of the downward seepage and on the lateral hydraulic conductivity of the mire.

Petgat B has a thicker and firmer *kragge* than the other ones, as is easily observed by the way it yields underfoot. Also the vegetational succession appears to reflect a later stage of terrestrialization. This *petgat* is somewhat narrower than the other ones, which might have caused an earlier overgrowth. It cannot be excluded that it was even dredged earlier, since there is a trend of early dredgings being narrower and shallower than later ones.

Many isopleth maps show "fingers" which extend from a body of water with a high electrical conductivity into one with a lower conductivity, or the reverse. The higher conductivity fingers are typically confined to a layer between, very roughly, 0.7 and 1.2-1.6 m, which is just underneath the *kragge*. This layer is the most transmissive part of the profile, the preferent flow channel for the inflow of ditch water.

The seasonal movement of bodies of groundwater

The successive isopleth diagrams suggest a seasonal movement of the transitional zone between a body of high-conductivity water, originating from the ditch, and a body of low-conductivity

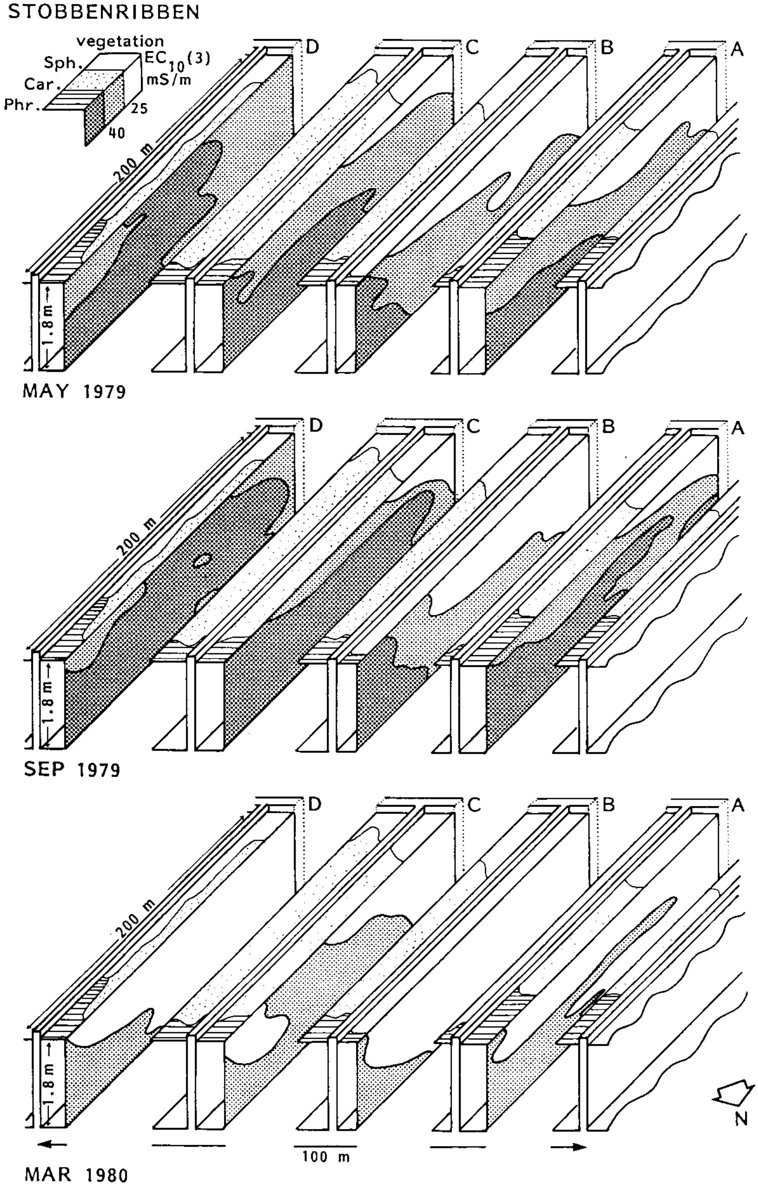


Fig.9.4 Fluctuations of the electrical conductivity in sections A-D through De Stobbenribben, viewed from the ditch towards the closed ends

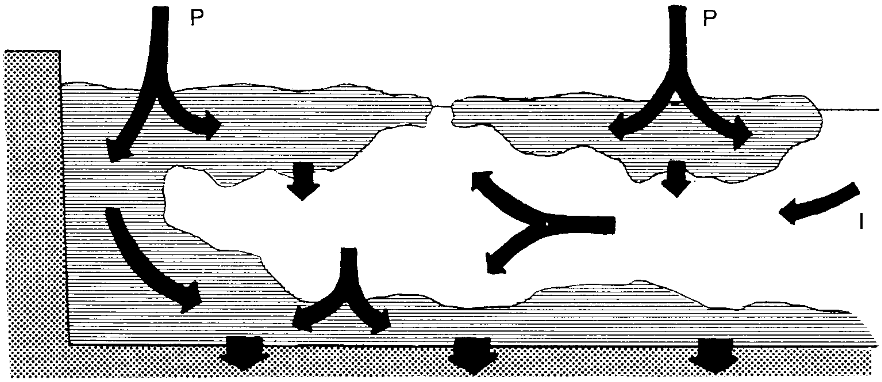


Fig.9.5 The main flow patterns of inflowing ditch water (I) and precipitation surplus (P) in De Stobbenribben

water originating from local precipitation (Fig.9.4). The measuring scheme and the interpolation method used in the construction of isopleth diagrams obscure any sharp boundary between the bodies of water along the length axis. Occasional checks suggested that the transitional zone is indeed rather wide, however, and that both types of water become mixed in this zone. This can be understood from the fact that the net position of this zone results from dispersion occurring during the displacement of the transition zone.

It appears that the closed ends of the *petgaten* are nearly always under the influence of the body of low-conductivity water, while the zones bordering the ditch are mostly in the reach of more concentrated water. During the dry season a tongue of water with a high conductivity penetrates the transitional area in a zone just underneath the *kragge*. During the cold season it is expelled again by more dilute water. The expansion of the latter exhibits a remarkable pattern. It is first observed in the superficial part of the *kragge*, where it indicates an increasing precipitation surplus. This is for a short time followed by a finger which extends underneath the tongue of high-conductivity water still present, as schematically indicated in Fig.9.5. It can also be seen in the isopleth diagrams of Fig.9.4. This pattern suggests the peaty matrix outside the most fluid part of the profile as the preferred medium for the expansion of this body of water. There are several weaker spots in the *kragge*, some of which may be remains of the open-water stage. Others originate from the uprooting of young trees and shrubs to favour reed cultivation and hay-making. Such weak spots have formerly been taken as evidence for small groundwater wells; they are often filled with a high-conductivity water amongst a *kragge* containing a type of water poorer in solutes.

As a result of the rather irregular form of the isopleths, it was not so easy to quantify the velocity of the displacements. From May or June to October there is a net inflow of ditch water, with a conductivity of over 40 mS/m. The tips of the fingers of the bodies of water enclosed by representative isopleths travel about 60 m forward from their original position in some 120 days.

During winter, from October to April, the 25 mS/m isopleth may move about 100 m in the direction of the ditch. In the course of years, however, the movement seems to depend on many singular circumstances, such as ditch dammings, cloggings, and cleanings, and infiltration works in neighbouring reedbeds. In the period 1973-'82 the fluctuations due to these causes and to the extremely dry summers of 1975 and 1976 appeared to be of greater importance than any other trends.

A quantitative interpretation of the isopleth patterns is further interfered with by the vertical movement of the *kragge*, thus changing the thickness and volume of the most transmissive layer just underneath it. Although the porosity of this layer is generally assumed 100 %, the actual situation is probably one of a subsurface channel with irregular lumps of less transmissive peat and root masses. The effective porosity might therefore be well below 80 or even 50 %, so that the velocity which is associated with the displacement of electrical conductivity isopleths could be much higher than the Darcy velocity. Locally, displacements of even 2-20 m/d along the length axis, and of 5 cm/d along the depth axis, were quite clearly noted in isopleth diagrams with an interval of about one week. It should be kept in mind that the movement of electrical conductivity isopleths results from a combination of the movement of whole bodies of water, and such processes as diffusion, mixing, and concentration by evaporation. Local and short-term disturbances may also originate from ephemeral pressures exerted on the *kragge*, such as when people or machines go over it, as happens especially during mowing and hay-making.

The conductivity map

The presence of baulks at relatively short distances improves the suitability of De Stobbenribben for such investigations as reported here, but the same factor introduces several influences in gradients perpendicular to the length axis. The longitudinal transects discussed above were chosen just in between and parallel to the baulks. Occasional measurements in perpendicular transects proved that the inflow of ditch water underneath the *kragge* is strongest in the middle of the *petgaten*. Along its edges the *kragge* is fixed to the baulks and prevented from rising with the water level. Here occasional floodings may penetrate further across the mire surface. The same marginal areas convey a part of the precipitation surplus from the *kragge* towards the ditch as surface flow.

Unfortunately, conductivity mapping to visualize these points was not systematically applied in De Stobbenribben. However, sounding data obtained in 1973, 1979, and 1980 enabled the reconstruction of an approximate conductivity map for 1979-'80 (Fig.9.6). Reference was also made to soundings reported by Boeye (1983) and Kooijman (1985). A striking difference appears to exist between various places as regards the range of fluctuations. This range is especially large in the middle part of the individual quagfen parcels.

One deviation of the general pattern became obvious in *petgat* D. Along the southeastern baulk, at the left in the map, the conductivity was mostly intermediate to low throughout the profile from the dead end to about halfway the distance to the ditch. Further towards the ditch, however, a high conductivity was found close to the baulk, where a very weak part of the *kragge* suggests a direct connexion with the ditch. Several longitudinal sections, such as the May and September ones in Fig.9.4, show a high-conductivity 'plume' near the end of this supposed connexion, which itself lies outside the plane of these sections. This plume is fairly well seen in the isopleth diagram from October 8, 1975. In that very dry period there was no direct access of ditch water along the supposed connexion. From the conductivity map it appears that the high-conductivity area in the *kragge* extends far beyond the underlying body of high-

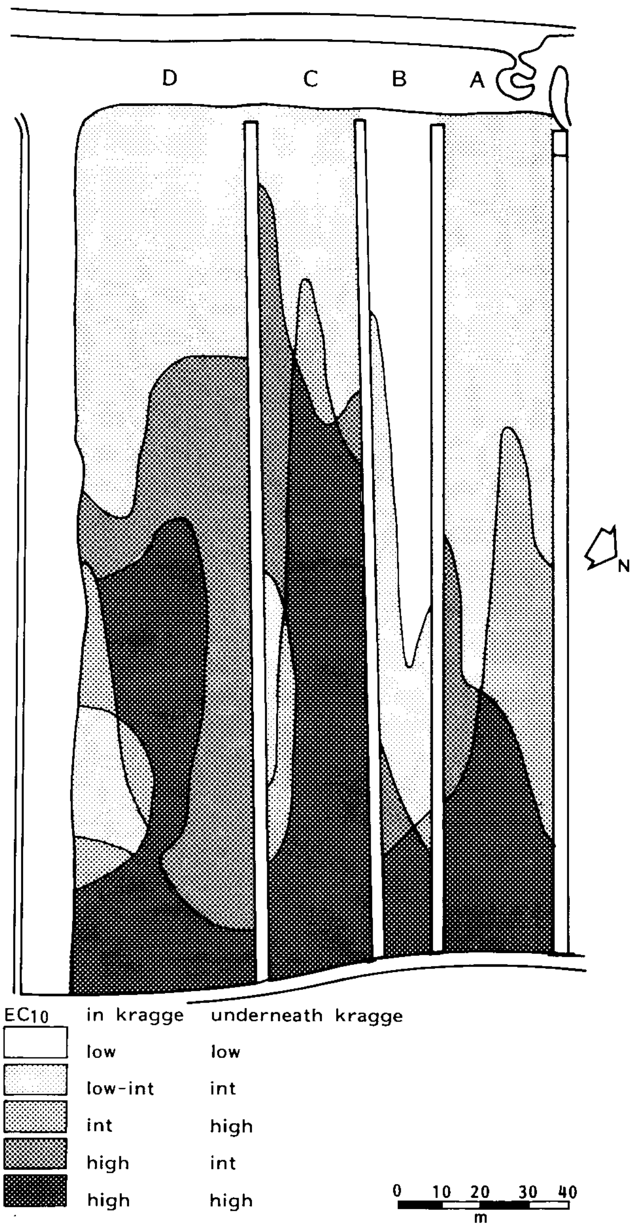


Fig.9.6 The average distribution of conductivity values in and underneath the *kragge* in De Stobbenribben, ca 1980

conductivity water. The pattern suggests an influx of "ditch-type" water near the baulk, about 75 m from the ditch.

The same part of the terrain frequently yielded somewhat anomalous temperature soundings, which even led to the solution of an upward flow velocity in Chapter 8. Further investigations revealed that a sand ridge runs underneath De Stobbenribben in this place (Fig.7.3). These observations might be explained as indications of some seepage through or over this sand ridge originating from a ditch a few meters to the south-east, parallel to the length axis of the *petgaten*. At this place some water samples from a depth up to 1.6 m in the baulk were drawn and analysed in 1973. They showed an electrical conductivity of ca. 50 mS/m, which I am now inclined to interpret as an indication of ditch water seeping through the baulk. Since the baulks exceed the *kraggen* in height by about 0.5 m, this level corresponds to a depth of 1.1 m with respect to the top of the *kragge*. This seepage may be caused by the transverse hydraulic gradient already mentioned. Incidentally, the ‘plume’ area in *petgat* D was recognized as an area of seepage pools by botanists already before 1960, and the permanent quadrats mentioned in Chapter 7 were situated in it. Seeping parts of baulks were frequently observed elsewhere in De Weerribben during conductivity mapping.

It is concluded that a clear longitudinal gradient in the electrical conductivity is developed in the quagfen parcels due to the influx of ditch water. This influx is mainly channelled through a very transmissive layer in the profile just underneath the *kragge*. A combination of processes, rather than just the mass movement of whole bodies of water, determines the chemical composition of the mire water, and this results in a considerable variation of the amplitude of fluctuations in the water quality.

9.4 Temperature gradients in longitudinal sections

Isopleth patterns

The isopleth patterns of the annual mean and the amplitude of the temperature, derived by Fourier analysis of monthly profile measurements during May, 1979 through April, 1980, are shown in Fig.9.7 and 9.8. These maps typically show a gradient along the length axis, which is different in each *petgat*. Similar patterns were found in isotherm maps. It appears, from these patterns, that the annual mean temperature increases slightly in the direction of the ditch and in the upper part of the profile.

Several other intriguing patterns can be noted. The mean temperature is considerably lower than elsewhere in the middle of *petgat* C. In A and C it increases somewhat towards the dead ends, especially underneath the *kragge*.

The temperature amplitude isopleths strongly reflect the attenuation of the amplitude with depth. In the *petgaten* A and C this attenuation decreases as the ditch is approached, but in C the amplitude is small in the same part of the *petgat* where the mean temperature is low. The attenuation of the amplitude in B increases towards both ends of the *petgat*. Parcel A shows a gradual decrease from the closed end towards the ditch, as is apparent from the slope of the 5 K isopleth.

The amplitude of the temperature fluctuation at the soil surface, as computed with the FOUSOL method, is also given in the block diagram of Fig.9.8. The values show a variation which is not easily interpretable. Very high values are not found near the dead ends of the *petgaten*. The low values in the middle of C, and near the dead ends of B and of C, respectively,

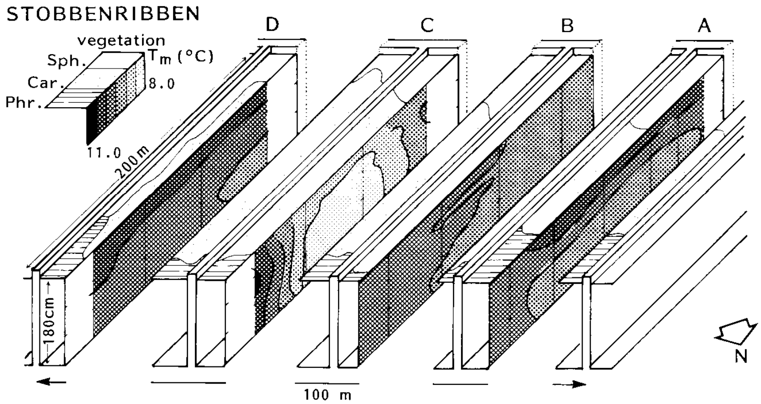


Fig.9.7 The annual mean temperature according to Fourier analysis of frequent measurements in longitudinal transects through De Stobbenribben (May 1979-April 1980)
The ditch from which water penetrates into the parcels is at the front side of the block diagrams

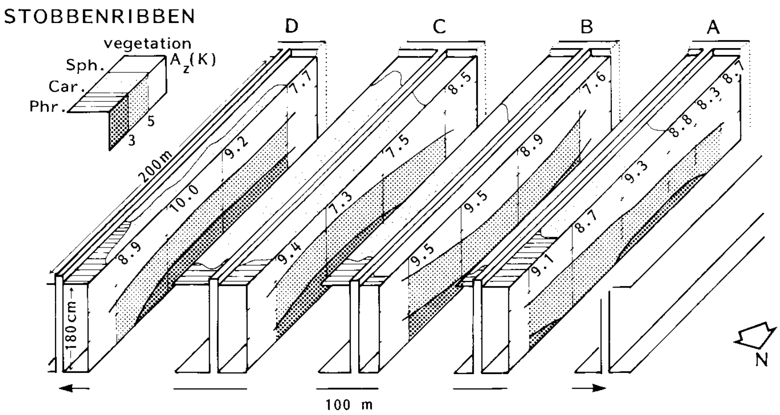


Fig.9.8 The amplitude of the annual temperature fluctuations around the mean temperature in longitudinal transect according to Fourier analysis as in Fig.9.7
The numbers written into the diagrams represent FOUSOL-computed amplitudes at the mire surface in °C

are somewhat unexpected, but they can be explained from the characteristic structure of the vegetation (*cf*Chapter 8). In the middle of parcel C an extensive and unmown stand of *Cladium mariscus* is found, while the vegetation at the closed end of B is rich in the mosses *Polytrichum commune* and *P.juniperinum,* and in *Molinia caerulea* and *Erica tetralix.* These types of vegetation provide an insulating blanket over the soil.

The causes of the spatial patterns of temperature data

A longitudinal temperature gradient may be caused by the fact that the surface water in the *boezem* area, and consequently in the ditch, has a different temperature as compared to the mire water, owing to (1) a different radiation budget, and (2) the mixing of water in the ditch. The annual fluctuation of the open water temperature is typically smaller than that at the mire surface, but larger than the variation underneath the *kragge*. Since ditch water penetrates into the *petgaten* during summer, when the ditch water is warmer than the mire water underneath the *kragge*, the influx of ditch water will probably enlarge the amplitude of the temperature in the mire profile. A similar effect, *i.e.*, a deeper position of the isopleths, is to be expected for places with a stronger downward water flow. It is doubtful whether these effects can be separated from other influences in the amplitude diagrams, but in those of the mean temperature the influx of ditch water is probably the main cause of the patterns seen in the *petgaten* A, B, and D. The higher annual mean near the dead end of parcel A may have been caused by the incidental working of a replica of an ancient small wind-pump (‘tjasker’) placed there as a sight-seeing object.

Next to these there are several other causes of variation. The main one is certainly the nature of the surface, especially its vegetation structure and the height of the water table with respect to the top of the *kragge*. The middle part of *petgat* C was overgrown with a dense cover of *Cladium mariscus* during this investigation. This stand was never mown, and the water level nearly always lay a few centimetres above the top of the *kragge*. These factors may modify the heat budget considerably by reducing both radiative and advective heat transfers. In this place, where the *kragge* is only weakly developed, the possible incidence of density currents cannot be excluded, although this is not very probable (see below). There is also an obvious variation in the overshading of various parts of the *petgaten*, and in the protection against the prevailing winds.

Temperature recordings and freezing observations during the winter 1969-'70 yielded several unexpected results, which could not be explained with hydrological parameters.

All in all the main conclusion from the isopleth patterns of temperature data is that there are many factors that cause variation which may be both relevant and attributable to plant growth and that the hydrological factors cannot always be readily singled out.

The possible incidence of density currents

The interpretation of isopleth patterns and the application of the thermal method for the assessment of seepage heavily depend on the absence of density currents. Density currents, or convective currents, may occur when the water in the superficial layers of the profile, while cooling, acquires a higher density than the deeper water. Its starting depends on the temperature gradient and on the hydraulic conductivity of the porous medium. Although an accurate prediction seems a tall order, it is possible to determine under which conditions density currents will not be generated.

According to the pertaining theory (Bear 1972, p.653-660), the generation of density currents as a result of a temperature gradient in a medium with about 100 % porosity can be described by Lapwood's non-dimensional convection parameter, which is a modified Rayleigh number:

$$\mathbf{Y} = (\mathbf{T}_1\text{-}\mathbf{T}_0)\ \boldsymbol{\eta}\ (\mathbf{z}_1\text{-}\mathbf{z}_0)\ \mathbf{K}\boldsymbol{\kappa}^{-1},$$

where the subscripts $_0$ and $_1$ indicate the upper and the lower boundary depths between which the currents may develop; $\boldsymbol{\eta}$ is the coefficient of thermal volume expansion of water (approximately $2\ 10^{-4}\ K^{-1}$), $\boldsymbol{\kappa}$ is the thermal diffusivity (approximately $1.35\ 10^{-7}\ m^2\ s^{-1}$), **T** is the temperature (°C, the difference between temperatures being expressed in K), **z** is depth (m), and **K** is the (saturated) hydraulic conductivity of the porous medium ($m\ s^{-1}$). The critical value of Lapwood's convection parameter above which density currents may be generated is

$$\mathbf{Y} = 4\pi^2, \text{ or: } \mathbf{Y} \approx 40.$$

Converting **K** to the more convenient units m/d, it follows that the hydraulic conductivity above which density currents are started, obeys the relation:

$$\mathbf{K_{max}} = 2400\ (\mathbf{T}_1\text{-}\mathbf{T}_0)^{-1}\ (\mathbf{z}_1\text{-}\mathbf{z}_0)^{-1}.$$

Table 9.1 lists $\mathbf{K_{max}}$ for a representative range of values of the other variates[5].

Table 9.1 The hydraulic conductivity above which density currents may be generated at typical temperature gradients

$\mathbf{T_1\text{-}T_0}$ (K)	$\mathbf{z_1\text{-}z_0}$ (m)	$\mathbf{K_{max}}$ (m/d)
2	1	1200
4	1	600
8	1	300

The hydraulic conductivity in the *petgat* profiles varies with depth and with the firmness and thickness of the *kragge*. Although the electrical conductivity profiles prove that a quagfen as a whole is an anisotropic medium, in which the hydraulic conductivity in the horizontal direction by far eceeds that in the vertical direction, it is assumed that the medium in the preferential flow channel, where the conductivity may approach the listed critical values, is approximately isotropic. Boundary values are derived from the water balance and the hydraulic gradient in the longitudinal direction, yielding ca 500 <**K**< ca 1000 (m/d) (see Chapter 10).

In conclusion I believe that the hydraulic conductivity of the profile only very locally, if at all, reaches such high values as are needed for the generation of density currents. Apparently, the conditions for the generation of density currents are usually not satisfied in De Stobbenribben, except in some places with a very weak or even nearly absent *kragge*, such as occur in small spots in the *petgaten* A and D, and in a larger area in C. The latter is characterized by a dense vegetation cover of *Cladium mariscus*. Remarkable isothermal patterns were obtained here, but a detailed check of all relevant temperature profiles did not provide support for the occurrence of regular temperature inversions and density currents.

[5] The symbol $\mathbf{K_{max}}$ refers to the *maximum* of the range of values for which density currents are *not* expected

9.5 The chemical identity of different bodies of mire water

Bodies of mire water were distinguished in Section 9.3 by means of the electrical conductivity. The electrical conductivity is a parameter of overall ionic concentration. It is neither sufficient to asess the origin of the water, nor is it in itself an important growth factor, at least not in the range of values observed in De Stobbenribben. More complete chemical analyses of water samples are needed to assess the chemical identity of the bodies of mire water that were traced by the electrical conductivity soundings. In this section I will treat the chemical identity of the mire water on the basis of a selection of water samples analysed for this purpose.

Methods of sampling and analysis

Free surface water was sampled in ditches and pools by immersing the sampling bottle in the body of water concerned. Permanent sampling sites were installed in order to sample the uppermost layer of mire water in the *kragge*. The installation involved the digging or cutting of a small pit, which was always emptied the day before sampling took place.

Water samples from below the *kragge* were drawn with samplers (Fig.9.9), consisting of an inner and outer length of p.v.c. (polyvinylchloride) pipe. The inner length is provided with a filter wrapped with a nylon filter cloth (during the first years of this study a cotton cheese-cloth was used). The inner pipe is sealed underneath with a plug or cap that protrudes just enough to seal the outer pipe (jacket) when that one is pushed down over the filter. The inner pipe diameter is 3 cm. The samplers were installed the day before sampling by pushing them down through the *kragge*. With the filter at the desired depth, the jacket was raised so as to open the filter. The next day the filter was closed again and the whole sampler was carefully removed and tilted to pour out the sample. By using these samplers no instruments were permanently left to the curiosity and, possibly, disturbance by occasional visitors; the samplers could be thoroughly cleaned after and before use, and a total of 40 samplers sufficed for the investigation of several mire areas during the same period.

A first determination of pH and electrical conductivity was done before the samples were bottled. Two methods of bottling were followed, depending on the requirements of the chemical laboratory:

1) (Hugo de Vries-Laboratory of the University of Amsterdam) Two subsamples were made. The first one was passed through a coarse filter into a 0.5 l glass bottle. The second one was passed over a 0.45 µm micropore filter with the help of a foot pump. This appeared to be a very time-consuming job and it was therefore often put off till the same evening. This subsample was poured into a 0.25 l glass bottle for the analysis of P and N. Occasionally, a similarly treated 100 ml subsample was collected in a glass bottle with a drop of HCl for the analysis of Fe. Clean medical glass bottles were provided by the laboratory.
2) (Laboratory of the water supply company ‘Midden Nederland’) A 1 l sample was put in a clean p.v.c. bottle provided by the laboratory, after passing it through a coarse filter.

Whenever possible, some surplus of the sample was used to rinse the bottles, and the sample was enclosed free of air. Samples were stored at 5 °C in the dark. During sampling and transportation on warm days a crate with a wet cloth was used to avoid the warming-up of bottled samples. In some cases it was not possible to collect the prescribed quantity of sample.

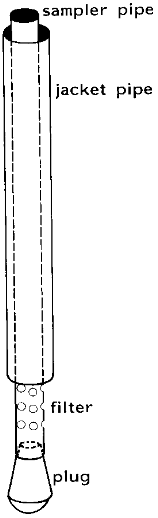


Fig.9.9 Water sampler used to draw samples from underneath the *kragge*

This may have reduced the number and representation of subsamples for each analysis in the laboratory.

In either laboratory the samples were allowed to settle and the supernatant was used in the analyses. Alkalinity, electrical conductivity and pH were mostly determined within two days after arrival of the samples. All analyses were performed according to laboratory standards (N.E.N., the Dutch organization for standardization) by laboratory personel.

At least the concentration of the major ions (see Appendix D) was consistently determined in the majority of the samples. A variety of N- and P-containing constituents was analysed in most of them. Occasionally Si, Fe, Al, and Cu were determined.

Analyses used

Two groups of water samples were collected from De Stobbenribben in order to identify the chemical constitution of the various types of water detected with the electrical conductivity method.

During the first period of the present investigation, 1973-'74, 5 sampling sites were selected in parcel A, covering the supposed gradient described with conductivity sounding. The same sites were sampled on the dates 730724, 730920, 731125, and 740403, where dates are coded as (19)xx, month number, day number. The analyses were performed by the Hugo de Vries-Laboratory. Many of these analyses did not satisfactorily pass the MAION (Appendix D) electroneutrality and conductivity tests. For this reason I have given priority, in this discussion, to the analyses resulting from the second group. The main conclusions which have earlier been derived from the interpretation of the 1973-'74 analyses (Bergmans 1975, Van Wirdum 1982) appeared to be valid on the basis of the more reliable analyses in the second group, and some of the analytical results are used in Chapter 10.

From 1980 through 1983 a sampling scheme was followed in connexion with the temperature and conductivity soundings in longitudinal transects. Samples were approximately collected bimonthly, and a total of 22 seres of analyses covering four surface stations and three deeper ones was made available. The samples were analysed in the laboratory of the water supply company "Midden Nederland".

Method of interpretation

The water analyses were subjected to the calculations associated with the MAION method described in Appendix D. The electroneutrality test was interpreted as follows:

If the difference between the sums of the priciple cations and anions was less than 8% of the total concentration of these ions, on a moles-of-charge basis, the sample was accepted. Otherwise account was taken of N, P, Fe and all additionally analysed components, and the calculation repeated. The same criterion was applied again, but an additional requirement was that the calculated conductivity must likewise not differ more than 8% from the measured conductivity. The remaining analyses are rejected or at least not allowed to play a major role in the interpretations. The experience with this method suggests that the additional elements do not predominantly occur in an ionic form in the samples considered. As appears from Malmer (1963) and Gorham *et al.* (1985) it is quite normal for interstitial water from peaty sites to show electroneutrality errors if only inorganic ions are being considered.

Special attention will be given to the similarity of the chemical composition of each sample to the groundwater (rLI), rain water (rAT) and sea water (rTH) benchmark samples, respectively (see Appendix D). The results are presented in rLI-rTH and EC-IR diagrams, where

$$IR = [{}^{1}/_{2}Ca^{2+}] / ([{}^{1}/_{2}Ca^{2+}] + [Cl^{-}]).$$

Special attention was paid to the carbonate equilibrium. The interpretation of this equilibrium is not free of ambiguity, since it is uncertain which factors may be involved in the natural situation. The calculations are based on a relatively simple model situation (Kelts & Hsü 1978; see also Appendix D). Moreover, artifacts may have been introduced due to a changing physico-chemical equilibrium in the samples between the times of, (1), sampling, (2), analysis of pH, conductivity, and alkalinity, and, (3), analysis of calcium, respectively. Over-saturation with respect to $CaCO_3$ was frequently met with in the ditch site **a** (see below). It is possible that some of the elements involved were present in a non-ionic form in the sampled water, as is reported by Kelts & Hsü. The clouding phenomenon described there was frequently seen in surface waters in North-West Overijssel. Various mechanisms may explain the formation of colloidal forms of calcium, especially in the presence of phosphorus and humic substances, acting as surface inhibitors by masking the charged particles. Since the ionic balance of most samples was in order, there is no particular reason to reject the results.

1980-1983 analytical results

The results of the analysis of 149 water samples from June, 1980, to June, 1983, are summarized in Tables 9.2 and 9.3. Site **a** is a shallow ditch. Sites **b**, **c**, and **d** are *kragge* sites where the uppermost layer of mire water was sampled. At these sites water was also sampled underneath

Table 9.2 Mean and standard deviation of analytical results and computations concerning water samples from De Stobbenribben

		n	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	EC_{25} mS/m	IR %	x %	y %	sat	rLI %	rAT %	rTH %	rRH %	Ca %	Mg %	Cl %
a	m	21	7.60	70.23	10.17	41.38	4.70	76.39	185.24	46.70	60.75	61.95	1.05	-7.76	7.63	80.90	-23.00	49.76	79.57	55.38	13.86	34.43
a	s	21	0.24	17.58	0.96	9.74	1.64	22.25	52.17	14.22	10.20	5.58	2.22	0.23	10.83	0.89	8.89	7.38	6.90	2.65	5.28	
b	m	20	7.14	44.67	6.91	30.40	4.07	57.35	117.25	31.75	42.43	58.05	0.35	-6.95	8.01	76.35	-15.80	29.75	70.70	52.55	13.45	38.30
b	s	20	0.58	11.79	2.01	7.89	2.17	17.00	37.92	11.35	9.54	4.10	1.04	0.23	0.26	8.38	2.94	13.13	9.64	2.72	1.23	4.66
c	m	21	6.51	20.46	3.89	17.52	4.06	32.84	51.62	21.95	23.76	51.29	-0.38	-5.14	8.78	51.38	6.05	1.43	51.05	45.00	14.38	41.95
c	s	21	0.66	9.68	1.65	5.83	3.50	11.24	29.43	9.38	7.99	10.06	0.71	2.25	0.62	29.60	23.04	11.83	12.45	9.35	2.22	6.25
d	m	21	5.22	5.05	1.80	8.12	4.08	14.43	11.01	15.76	10.68	37.19	-1.48	-8.38	9.34	-11.71	52.33	-22.14	19.14	27.52	15.95	44.90
d	s	21	0.75	3.00	1.06	3.75	2.39	6.71	15.73	9.68	4.80	10.52	2.19	6.55	3.26	23.85	31.76	4.70	12.23	9.41	4.77	9.68
bb	m	22	6.67	64.80	9.63	39.27	5.85	76.01	201.58	22.73	57.45	60.41	-0.23	-7.14	7.60	85.95	-33.64	43.68	75.27	55.00	13.59	35.91
bb	s	22	0.17	7.73	1.19	5.42	6.34	13.94	33.01	12.81	6.59	2.87	0.53	0.12	3.39	7.17	5.16	2.37	1.05	3.45		
cc	m	22	6.34	49.79	7.56	32.95	4.67	62.01	154.17	19.32	45.80	58.77	-0.05	-7.82	7.82	83.36	-29.77	30.68	68.55	53.09	13.36	37.50
cc	s	22	0.25	8.06	1.29	4.42	0.82	10.62	29.92	6.36	5.98	3.45	0.82	0.15	6.30	7.52	6.08	1.80	1.29	4.70		
dd	m	22	5.80	16.59	4.11	18.02	2.50	24.97	68.77	10.45	20.38	54.59	-0.95	-8.18	8.59	67.86	-20.50	-7.55	37.86	41.09	17.00	34.00
dd	s	22	0.18	2.74	0.79	4.09	0.74	7.24	12.30	4.32	3.05	6.13	0.95	1.31	0.15	10.39	3.49	1.54	8.08	3.39	1.69	6.63

a-dd sampling stations; m mean values; s standard deviations; n number of samples

Table 9.3 Total concentrations of inorganic N, P and Fe in De Stobbenribben water samples; means and standard deviations as in Table 9.2

		n	**P_{tot}** 10^{-2} mg/l	**N_{tot}**	**Fe_{tot}** 10^{-1} mg/l			**n**	**P_{tot}** 10^{-2} mg/l	**N_{tot}**	**Fe_{tot}** 10^{-1} mg/l
a	m	21	3.29	81.90	12.76						
a	s	21	3.91	49.18	11.38						
b	m	20	1.85	16.55	2.00	bb	m	22	5.09	40.68	13.73
b	s	20	3.57	12.39	2.15	bb	s	22	5.96	19.46	15.03
c	m	21	5.90	24.95	6.57	cc	m	22	5.55	24.73	9.18
c	s	21	13.58	25.81	15.79	cc	s	22	5.40	8.74	7.10
d	m	21	6.62	21.19	11.76	dd	m	22	8.50	39.18	81.09
d	s	21	13.68	11.50	14.84	dd	s	22	7.79	22.42	188.46

a-dd sampling stations; m mean values; s standard deviations; n number of samples

the *kragge* at a depth of 1.2 m. These deeper sampling sites have been coded **bb**, **cc**, and **dd**, respectively.

The electroneutrality and conductivity tests (x and y in Table 9.3) were successfully passed in 90% of the cases. The **d** and **dd** samples, 830208, show a considerable deviation in both x and y. These deviations disappear when the concentration of Fe is accounted for as Fe^{++}. Note, however, that there are several samples with appreciable concentrations of Fe where the same procedure would only violate the electroneutrality found. Two of the remaining three large deviations in x ($|x|$>8%) are from site **d** where most concentrations are low and where the numerical inaccuracy of the reported concentrations can explain the deviations found. The deviation of 10% in **a**, 801215, coincides with high concentrations of $NO3^-$ and K^+, but a formal explanation was not found. There are 10 further cases where $|y|$>8%. These are all associated with samples with a low EC_{25}. If the test and the EC measurements are both reliable here, this may indicate some change in the sample composition during the sojourn in the laboratory.

The following points become apparent from the analyses:

1) Mineral N concentrations (Table 9.3) show strong fluctuations, especially at sites **a** and **bb**. The highest values are mostly found in winter. Guessing from the concentrations, the *boezem* might act as a source of nitrogen. The time series for **dd** shows a puzzling similarity to that of **bb**, but this cannot be explained by the influence of *boezem* water. Probably most of the mineral nitrogen originates from local processes in the mire; the accumulation of N in the *boezem* water may be due to the receiving function of the *boezem* in winter for surplus water from the mire and from adjacent polders. Mineral N is not used by the vegetation in any appreciable amount during the winter season.

The *kragge* sites **b**, **c**, and **d** feature more constant and also lower concentrations of mineral N.

Nitrate is mostly the dominant mineral-N component, but occasionally ammonium reaches a higher concentration.

As regards nitrogen, the differences between open surface water, water in the *kragge*, and water from underneath the *kragge* dominates over a longitudinal gradient, if such exists.

2) The phosphate concentrations show a remarkable pattern. They have been low during 1981 and 1982 and became higher at the end of that period. These higher concentrations do not necessarily reflect a trend. There is probably no relation through transport of dissolved phosphate from **a** to **d**, however. The source of phosphate is probably mainly a local one.

The samples from underneath the *kragge* display higher concentrations than those from within the *kragge* and from the *boezem*. This may be due to the physico-chemical conditions which govern the solubility of phosphate, especially to the redox conditions. As for nitrogen, any longitudinal gradient is obscured by these differences.

3) The EC-IR and rLI-rTH diagrams (Fig.9.10) reveal a clear gradient from atmotrophic water at site **d** to polluted (molunotrophic) water, with a lithotrophic component, in the *boezem*. The water underneath the *kragge* features less pronounced fluctuations than the water in the *kragge* and in the *boezem*. According to their position in the atmo-molunocline, the sites can be arranged as: d-(c,dd)-(b,cc)-bb-a. This arrangement reflects the influence of the *boezem* water penetrating underneath the *kragge* and then into the *kragge* itself, where it becomes mixed with rain water and is changed by various processes taking place in the root zone.

Note the position of the *boezem* water samples in dry periods approaching RH LOB (Rhine water) as a result of the inlet of water from Friesland, which is in accordance with the results obtained in Chapter 5 for the *boezem* system.

There is no trace of any different, especially lithotrophic, influences in the mire.

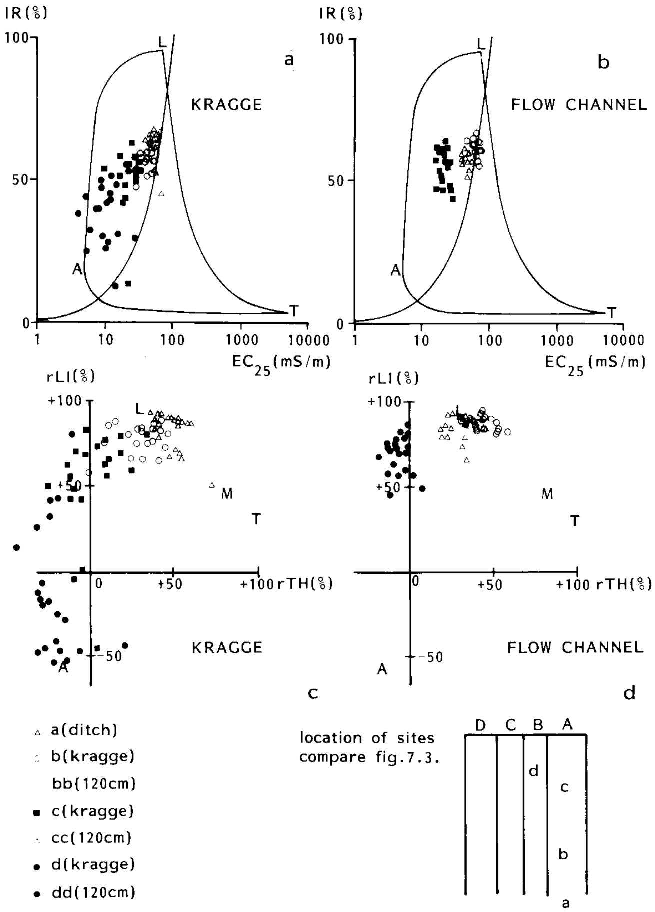


Fig.9.10 EC-IR (a,b) and rTH-rLI (c,d) diagrams of water analyses from De Stobbenribben, 1980-'83

a,c Kragge samples a-d shown in graphs at the left side; b,d samples from flow channel bb-dd shown in graphs at the right side; L, A, T, M: litho-, atmo-, thalasso-, and molunotrophic benchmark samples; Mixing contours and the line IR(%)=EC_{25}(mS/m) added to Fig.9.10a for convenience (see Appendix D). In the upper right graph dd samples are erroneously shown with a solid block rather than a solid disc.

9.6 Conclusions

The investigations treated in this chapter lead to the following conclusions:

1 The electrical conductivity sounding method is suitable for the detection and demonstration of a longitudinal gradient in the chemical composition of the mire water;

2 The demonstrated gradient is caused by a different macro-ionic composition of the mire water rather than by differences in the contents of the nutrients nitrogen and phosphorous;
3 The IR-EC and rLI-rTH diagrams are suitable to summarize certain differences in the macro-ionic composition of the mire water, and they strongly suggest a gradient from atmo- to litho-molunotrophic water caused by the interaction of rain water and *boezem* water;
4 *Boezem* water penetrates the quagfen parcels from the ditch at one side through a preferent flow channel underneath the *kraggen*, and it exerts an obvious influence upon the chemical composition of the water in the *kragge*, even at a distance of more than 100 m from the ditch in parcel A. At the closed end of the *petgaten* the influence of rain water is predominant;
5 Conductivity mapping allows for an extension of the sounding results so as to characterize the sites of the vegetation in terms of hydro-chemical parameters;
6 The middle part of the longitudinal gradient displays strong fluctuations of the electrical conductivity and chemical composition of the water;
7 The influence of the *boezem* water can be traced in the temperature regime underneath the *kragge*, but this influence can not be separated from influences associated with the varying structure of the local stands of vegetation (see below);
8 The structure of the vegetation, as it results from the species composition and management, has a strong influence upon the local temperature regime. This influence could be ecologically significant (*cf*. Chapter 7);
9 Although the hydraulic conductivity, in the horizontal direction, in the preferent flow channel underneath the *kragge* is large, it is probably not large enough that temperature inversions may generate density currents;
10 In spite of the high hydraulic conductivity in the preferent flow channel a hydraulic head gradient in the order of magnitude of 0.001% establishes during the summer season; under these conditions the flow remains laminar;
11 The discharge of mire water towards the underlying body of groundwater in De Stobbenribben is large enough to prevent a discharge towards the ditch from continuing for more than a few days;
12 The layered and anisotropic nature of quagfen complexes as porous media is fundamental to the understanding of the inflow of water.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 10

Environmental and vegetational processes in De Stobbenribben

10.1 Introduction

It has been shown in Chapter 7 that a significant longitudinal gradient exists in the vegetation of De Stobbenribben. The floral composition indicates an increase of atmotrophic water effects at the cost of lithotrophic ones as the distance from the ditch at one side of the quagfen complex increases, although the effects are somewhat obscured by edge effects near both ends of the parcels. Typically eutrophic species are only present in any substantial number near the ditch. Elsewhere oligotrophic species dominate.

It was also shown (Chapters 8 and 9) that the quagfen parcels lose a considerable amount of water through evapotranspiration and through seepage towards the underlying body of groundwater. The water loss is only partially compensated by rainfall, even during the cold season. As a result, a gradient in the hydraulic head of the phreatic water in the semi-floating quagfen develops, which drives an influx of ditch water into the various parcels. The flux density decreases as the distance from the ditch increases. A distinct spatial pattern of bodies of mire water of various types results, which is related to the characteristic nature of the mire as a porous medium. The pattern changes with the season.

Apparently, the influx of *boezem* water is an important ecological factor, both chemically and physically, and it therefore deserves quantitative attention. In the present chapter it will be ascertained whether the supposed influx of ditch water is quantitatively consistent with the hydraulic head gradient in the flow channel and the apparent hydraulic conductivity of the medium in this channel. Next a ‘model’ to explain a fundamental aspect of the water composition gradient will be derived. Finally it will be discussed how various processes may act together in the differentiation of the functionally operational environment of the local stands of vegetation. The basis of that discussion will be formed by a rough balance drafted for water and chloride.

10.2 Flow rate and hydraulic conductivity in the preferential flow channel

The flow rate underneath a quagfen *kragge* can be derived from the precipitation surplus and a possible recharge or discharge of water through the mire bottom. It also depends on the hydraulic conductivity of the porous medium and on the hydraulic head gradient in the preferential flow channel. Although but few values for the hydraulic conductivity in quagfen profiles have been published, an attempt is made to check whether the assumed flow rates are consistent with the observed hydraulic gradients and with realistic values for the hydraulic conductivity. Such values were already used in Chapter 9. In this discussion it will be assumed that the water flow is of the laminar type and Darcy's law may be applied. This is justified when Reynolds' number **Re**< ca 10. With an average pore size in the flow channel of ca 0.1 m and a flow rate of the order of magnitude of 10^{-5} m/s Re will have a value of ca 1, and the condition is satisfied.

The hydraulic conductivity in the *kraggen* in De Stobbenribben can be estimated from the hydraulic head difference measured between the phreatic level in the closed ends of the parcels, and the water level in the ditch. In various summer seasons this difference reached a maximum value between 13 and 21.8 cm, the highest values never pertaining to more than one parcel. During rainless periods in summer it stabilizes at ca 15 cm on average. Near the ditch the gradient of the hydraulic head is steeper than farther off (compare Chapter 9, Fig.9.3). At ca 160 m from the ditch the gradient approaches zero. The values for the hydraulic gradient in Table 10.1 have been chosen so as to be representative for a stable, but not extreme, summer situation. The duration of such periods is about one month. Since, in such periods, the sum of the precipitation deficit and the seepage towards the body of underlying groundwater can be estimated (Appendix E, Chapter 8), a balance sheet can be made up for a 1 m wide strip of a quagfen parcel, divided into three compartments (see Table 10.1).

A preferential flow channel with an average height of 1 m is considered. The influence of the somewhat lower position of the *kragge* as the hydraulic head decreases will not exceed 10-20% of this height and is, therefore, disregarded here. Three regions are distinguished:
1)The first 30 metres near the ditch, where plant growth is more vigourous than elsewhere;
2)The remainder of the quagfen parcel;
3)The baulk at the end of the fen parcel.

Conservation of mass and the Darcy equation yield

$$\mathbf{Q_i} = \mathbf{L_i}\,(\mathbf{E}+\mathbf{D}-\mathbf{P}) \quad \text{and} \quad \mathbf{Q_i} = -\mathbf{K_i}\,\mathbf{f_i}\,\mathbf{A}, \ \text{with } \mathbf{A}=1,$$

Table 10.1 Hydraulic conductivity and flow rate in a 1 m wide strip of a quagfen parcel

distance from fixed water level (m)	**0**	**15**	**30**	**95**	**160**	**baulk**
hydraulic head in flow channel (cm)	0		-8		-15	
head gradient (%)		-0.27		-0.054		+2.14
L (m^2)		145		65		7
height of flow channel (m)		1		1		2
solutions with (**E**+**D**-**P**)=0.004 m/d						
$\mathbf{Q_i}$ (m3/d)		0.58		0.26		0.16
$\mathbf{K_i}$ (m/d)		218		483		7.5
solutions with (**E**+**D**-**P**)=0.007 m/d						
$\mathbf{Q_i}$ (m^3/d)		1.08		0.455		0.28
$\mathbf{K_i}$ (m/d)		404		845		13.1
solutions with (**E**+**D**-**P**)=0.010 m/d						
$\mathbf{Q_i}$ (m^3/d)		1.45		0.65		0.40
$\mathbf{K_i}$ (m/d)		54		1207		18.7

where

Q the volume of water flowing laterally through the middle of the i-th region (positive for inflow from the ditch side; m^3/d);
A the cross-sectional area of the flow channel (m^2)
L the surface area of the quagfen strip between the middle of the i-th region and the assumed 'dead end' at 160 m from the ditch (the 'hinterland'; m^2);
E the evapotranspiration (m/d);
P the precipitation (m/d);
D the discharge to the underlying groundwater (m/d);
K the hydraulic conductivity in the preferential flow channel and in the flow direction (m/d);
f the gradient of the hydraulic head in the preferential flow channel (f is positive at an increasing hydraulic head, negative at a decreasing one).

The hydraulic conductivity can now be solved for the first 30 m and the next 130 m of the quagfen length assuming a typical hydraulic head gradient and chosen values for (**E**+**D**-**P**) as listed in Table 10.1. The hydraulic conductivity is smaller near the ditch, probably as a result of the deposition of ditch dredge on the banks, a more vigorous growth of plant roots, and a blocking of the porous medium with bacteria and peaty material. Also a solution is given for the hydraulic conductivity of the approximately 7 m wide peat baulk separating the closed end of the quagfen parcel from another ditch, which has the same water level as the ditch at the open end of the parcels. Accordingly, for this dam, **f**=0.15/7. Assuming that the seepage through the dam occurs over a height of 2m, the hydraulic conductivity of the peat dam is listed in Table 10.1. Vegt (1978) found values in the range 0.4-2.9 for peat baulks in this area with the piezometer method, and Van der Perk & Smit (1975) reported a value of 5.5 m/d, solved from the Darcy equation, for De Wieden. The present value is apparently at the high end of the range, but this can easily be explained in view of the rough assumptions made, the uncertainty of the reference values, and the incidental water

Table 10.2 Typical values for the hydraulic conductivity in *kragge* profiles in De Stobbenribben

layer	from (m)	to (m)	K (m/d)
field test (Vegt 1978):			
kragge	0	0.5	> 75
just underneath *kragge*	0.5	1.5	>400
peat mud	1.5	2.5	1-10
firm peat, mineral soil	2.5	-	ca 1
derived from hydraulic gradient and balance sheet (see text):			
underneath *kragge*	0.5	1.5	500-1000

supply through the 'tjasker' wind-pump.

Since the chosen hydraulic head gradient is more or less representative for summer conditions, the highest values for **Q** and **K**, obtained with the extreme value (**E**+**D**-**P**)=0.01 m/d, are improbable. For the non-extreme situation to which the chosen hydraulic gradient applies, the precipitation deficit must be ca 2 mm/d, so that, for (**E**+**D**-**P**) between 0.004 and 0.007 m/d, the discharge of water from the quagfen towards the underlying groundwater must be 2-5 mm/d. Note that the solution for **K** depends on the assumed height of the preferential flow channel, while this is not so for **Q**.

The hydraulic conductivity in quagfen profiles varies with depth and with the firmness and thickness of the *kragge*. Typical values obtained with piezometers in field tests in various layers in the profile of De Stobbenribben are listed in Table 10.2. Extreme values of up to 1500 m/d have been found in certain other quagfen complexes with a very weakly developed *kragge* on the basis of hydraulic head gradients (Van der Perk & Smit 1975). Much lower values were obtained by De Boer *et al.* (1977) and by Huijsmans & Zwietering (1980), but their results are based on field tests with unsuitable piezometers prone to stoppage by the fine and humic peat muck. Koerselman (1989) derived an average hydraulic conductivity of 64.5 m/d from balance sheets for quite similar quagfens in the Vechtplassen area (Province of Utrecht, The Netherlands). His results provide an average for various layers in the profile, with a considerably thinner preferential flow channel than in De Stobbenribben. Seepage tube tests yielded an average of 0.19 m/d for the flow channel in his investigations, but the use of such values in his water balance calculations would strongly violate the mass conservation law for water. According to his description the method used was not especially suitable for the determination of the hydraulic conductivity in the horizontal direction. In conclusion, the hydraulic conductivity in the preferential flow channel in De Stobbenribben is probably between 500 and 1000 m/d. This value is found on the basis of the hydraulic gradient and the water balance, but it is consistent with local field tests with suitable piezometers. This result is probably also consistent with Koerselman's, if the different nature of the profile to which it applies is taken into account.

Since, under the assumptions made, acceptable solutions for K are found, it is concluded that the influx of water underneath the *kragge*, with the assumed flow rate, does not violate reasonable assumptions as regards the hydraulic properties of the porous medium. This justifies the treatment of solute transport in the following section.

10.3 QUAGSOLVE: the mixing of water in the preferential flow channel

In the long run, the movement of water in the preferential flow channel depends on an alternation of movements in shorter periods. Different water compositions will result from a complex of processes. These include the movement of whole bodies of water, the mixing of waters with a different composition, absorption of substances to, or release from, the peat, plant uptake and release, and dissolution and precipitation. In a simple approach, I will consider mixing as the dominant process and try to describe the chemical composition of the water in a quagfen as a result of hydrological relations. Obvious anomalies will the indicate the importance of processes other than mixing. I will tackle the problem for chloride first, since chloride is not much involved in the other processes. With regard to chloride the mixing concept includes the mixing of waters with different concentrations and the diffusion of ions. The quantification will be treated on an annual basis and checked with the results of water analyses. Quite a few assumptions have to be made in the resulting ‘model’, called QUAGSOLVE. The model assumes a steady-state. Most quagfens in The Netherlands are not in a steady state, but the equilibrium case will assist to find out what factors may cause a change, and whether a particular true quagfen is likely to be involved in change processes. It has appeared (see Chapter 7 as regards De Stobbenribben) that the vegetation of quagfens can remain in a near-equilibrium state for several decennia at least.

In the initial solution for chloride concentrations in De Stobbenribben the following parameters are being used:

D Annual discharge to the underlying groundwater (m/a, variable);
E Annual evapotranspiration: 0.35 m/a (Appendix E);
$\mathbf{L_i}$ Surface area of i-th compartment of quagfen strip (m^2; width is 1 m);
P Annual precipitation: 0.8 m/a (KNMI 1972);
$\mathbf{Q_i}$ Annual lateral inflow into i-th compartment in flow channel (m^3/a, variable);
$\mathbf{Q_{i+1}}$ Annual lateral outflow from i-th compartment (m^3/a, variable);
$\mathbf{T_i}$ Annual exchange between floating mat and flow channel in i-th compartment (m/a, solved variable); in time a downward transfer will alternate with an upward transfer as a result of the asynchronous incidence of precipitation and evapotranspiration and a variety of other processes. Over the year the upward and downward components are equal in magnitude, but the upward movement transports salts with the concentration of the flow channel, whereas the downward flow has a salt concentration equal to that in the *kragge*;
$\mathbf{c_i}$ Chloride concentration in i-th compartment (g m^{-3}, numerically equal to mg/l);
$\mathbf{c_0}$ Chloride concentration in precipitation (3 g m^{-3}, Appendix D);
Prefixed subscripts denote concentrations in different bodies of water:
- $\mathbf{c_k}$ upper layer (variable);
- $\mathbf{c_z}$ average in preferential flow channel (variable);
- $\mathbf{c_l}$ lateral inflow in preferential flow channel (variable; $c_{l,1}$= 75 mg/l).

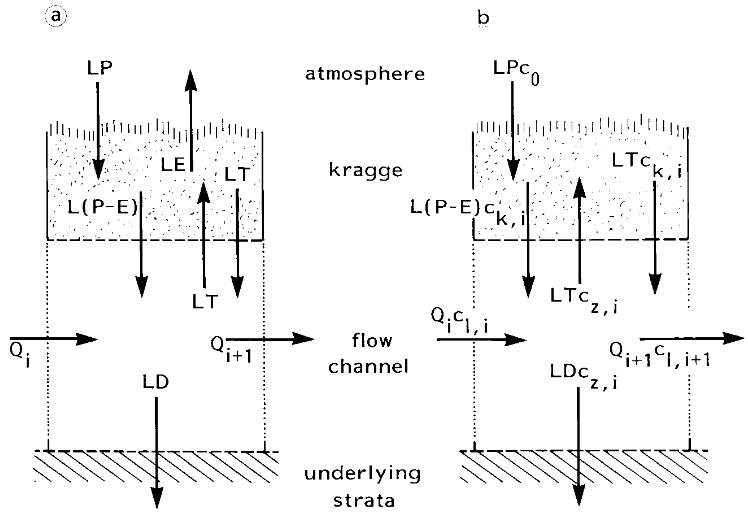


Fig.10.1 QUAGSOLVE balance sheets per compartment
a: Water balance for compartment i
b: Chloride balance for compartment i

A diagram for the concentrations and the balance sheets for water and chloride is given in Fig.10.1. A steady state is assumed (no change in water storage and chloride concentrations). It is also assumed that the *kragge* layer is well-mixed in all directions, while the flow channel is well-mixed in the vertical direction and over the full width of the quagfen strip, but not in the longitudinal direction. Note that the electrical conductivity and temperature soundings prove that a small vertical gradient also exists in the flow channel. The 'well-mixed' assumption is a simplification justified only by the importance given to the gradient in the longitudinal direction and to the concentration difference between the floating mat and the flow channel.

In the steady state (no change in water storage and chloride concentrations) the following formulae apply:

(1) $$\mathbf{Pc_0 + T_i c_{z,i} = (T_i + P - E) c_{k,i};}$$
(relation between floating mat and flow channel)

(2) $$\mathbf{Q_i c_{l,i} + L_i P c_0 = Q_{i+1} c_{l,i+1} + L_i D c_{z,i};}$$
(relation within flow channel, in the longitudinal direction)

(3) $$\mathbf{Q_i c_{l,i} + L_i (T_i + P - E) c_{k,i} = Q_{i+1} c_{l,i+1} + L_i (T_i + D) c_{z,i};}$$
(combination of (1) and (2))

(4) $$\mathbf{Q_i + L_i (P - E) = Q_{i+1} + L_i D.}$$
(mass conservation of water)

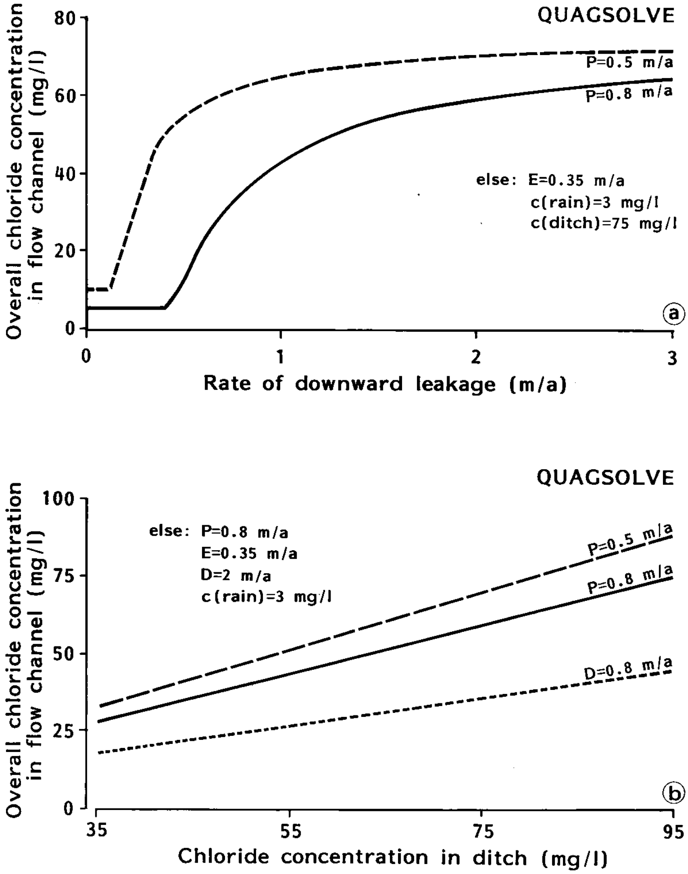


Fig.10.2 Chloride concentrations underneath a *kragge* as a function of downward leakage of water (a), and of chloride concentrations in the supplying ditch (b)

With the exception of the values mentioned in the diagram, **L**=160 m, **P**=0.8 m, **E**=0.35 m, $\mathbf{c}_1$=75 mg/l, **D**=2 m/a, and $\mathbf{c}_0$=3 mg/l

By adhering to the probably reliable assumption that the influx of ditch water does not reach much further than $\Sigma \mathbf{L}_i$=160 m into the quagfen, the overall equilibrium chloride concentration in the flow channel can be calculated. Since the chloride content in the floating mat is considered constant, no matter at what level, the annual inputs into the flow channel equal the sum of the inputs with **P** and $\mathbf{Q}_1$ with the respective concentrations $\mathbf{c}_0$ and $\mathbf{c}_{l,1}$. The output is entirely determined by **D** with the concentration $\mathbf{c}_z$, so that this can be solved for given values of **D**: for **D**=1 and **D**=2, with $\mathbf{c}_{l,1}$=75, $\mathbf{c}_z$ is 44 and 59 mg/l, respectively. Fig.10.2a illustrates the variation of $\mathbf{c}_z$ with **D** for **P**=0.8 m/a and for **P**=0.5 m/a. It appears that $\mathbf{c}_z$ decreases sharply when **D** falls below some critical value. An increase of **E** has a similar effect as a decrease of **P**: the curve for **E**=0.5 m/a would lie in between the curves for **P**=0.8 and 0.5 m/a, with **E**=0.35 m/a. At this instance it can be concluded that relatively high chloride concentrations at a considerable distance from the ditch can only be explained, in our climate and in the absence of upwelling groundwater, by a substantial downward discharge of mire water, provided that a compensating lateral influx of water is activated. In a reverse application, **D** can also be solved on the basis of observed $\mathbf{c_z}$ and $\mathbf{c_{l,1}}$ values, where $\mathbf{c_z}=(\Sigma\mathbf{L_i c_{z,i}})/(\Sigma\mathbf{L_i})$. Such applications with the average concentrations for 1980-'83 and those for 1984, with $\mathbf{c_{l,1}}$= 90 and 75 mg/l, respectively, yield a range of 2-3 m/a for **D**, but still higher values would result if the observed lower chloride concentrations in the ditch were used (see Table 10.3 and later comments). The linear dependence of $\mathbf{c_z}$ on the concentration $\mathbf{c_{l,i}}$ in the ditch is shown in Fig.10.2b. The influence of deviations in $\mathbf{c_0}$ is small and disregarded here.

The basic QUAGSOLVE formulation only requires the boundary conditions that the concentrations at the ditch end equal the ditch water and that at the opposite end of the flow channel, where the inflow is zero, an 'atmotrophic quagfen' concentration is found. The latter is the equilibrium chloride concentration in an entirely atmotrophic system, $\mathbf{c_k}=\mathbf{c_z} = \mathbf{Pc_0}/(\mathbf{P}\text{-}\mathbf{E})$ = 5.3 mg/l under the assumptions made. When the quagfen is partitioned into segments, analogous boundary conditions apply to each segment, and a 'pattern' can be generated for the chloride concentrations.

The QUAGSOLVE model will now be used to compute the chloride concentrations with $\mathbf{Q_1}$, $\mathbf{c_{l,1}}$, $\mathbf{c_0}$, **E**, **P**, and **D** as input data. In order to do so the compartments are taken very small, and it will be assumed that $\mathbf{c_{z,i}}=\mathbf{c_{l,i+1}}$. This means that complete mixing is assumed in the flow channel in each compartment. The floating mat is not considered, since $\mathbf{c_k}$ can be derived from $\mathbf{c_z}$ when **T** is given.

With **(5)** $\mathbf{c_{l,i+1}} = \mathbf{c_{z,i}}$,

the essential formulae now become

(2a) $\mathbf{c_{z,i}} = (\mathbf{Q_i c_{l,i}} + \mathbf{L_i P c_0}) / (\mathbf{Q_i}\text{-}\mathbf{L_i}(\mathbf{E}\text{-}\mathbf{P}))$, and

(4a) $\mathbf{Q_{i+1}} = \mathbf{Q_i}\text{-}\mathbf{L_i}(\mathbf{E}+\mathbf{D}\text{-}\mathbf{P})$.

D has vanished from the solute balance sheet (2a) due to the mixing assumption (5). Fig.10.3 shows the resulting gradient for chloride concentrations, for a variety of input data, along with some observed values from Table 10.3. **Q** was derived from **P**, **E**, **D**, and Σ**L**, the distance from the ditch over which the lateral flow is present (the distance to the 'dead end'). Σ**L**, **P**, **D**, and $\mathbf{c_{l,1}}$ were varied. The influence of variation of **D**, noticed already in Fig.10.2, is obvious: when the downward discharge of mire water decreases, the gradient in the chloride concentrations in the flow channel changes from convex with a sharp drop at the dead end of the parcel to concave and gradually approaching a stable atmotrophic state at a relatively short distance from the ditch (Fig.10.3). A smaller value for **P** (or a larger value for **E**) results in a more pronounced concentration drop at the dead end (Fig.10.3). Due to a variation of these factors between years, a relatively strong variation of the chloride concentrations in the 'back end' of a quagfen parcel may be expected. The graph also shows that it will not always be easy exactly to locate the sharp drop at the dead end in field situations. For this reason it will also be difficult to estimate Σ**L** within 30%. A variation of the chloride concentrations in the ditch will be of relatively great influence, especially when **D** and **E** are large and **P** is small, since this may cause high

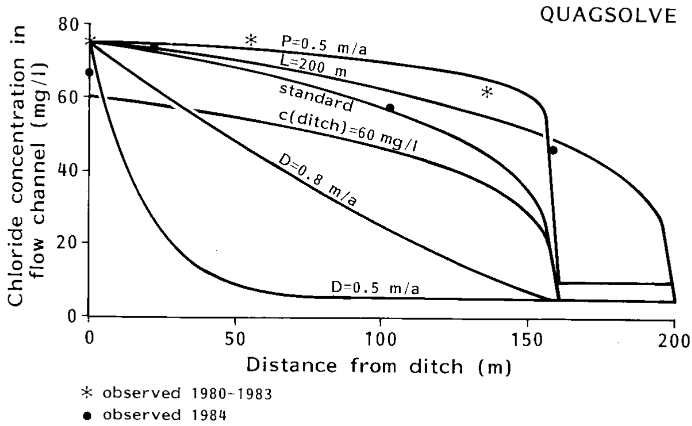


Fig.10.3 Chloride concentrations underneath a *kragge* as a function of the distance from the supplying ditch

With the exception of the values mentioned in the diagram, **L**=160 m, **P**=0.8 m, **E**=0.35 m, $\mathbf{c_1}$=75 mg/l, **D**=2 m/a, and $\mathbf{c_0}$=3 mg/l

concentrations at a large distance from the ditch.

Chloride concentrations in parcel A have been observed in 1970, 1973-'74, 1979, 1980-'83 (chapter 8), and 1984 (Kooijman 1985). A tabular summary of these data is given in Table 10.3. It appears that the concentrations have varied considerably. Noticeably, at distances farther than ca 100 m from the ditch a decreasing trend is exhibited. I have especially considered the 1980-'83 and 1984 data, since these represent estimates of the average for each period. The 1980-'83 values are each based on 20-22 samples. For the 1984 $\mathbf{c_k}$-means n_k=22, for the $\mathbf{c_z}$-values n_z=44, since both the 0.7 and 2.5 m depth values were used to estimate the concentration in the flow channel proper. Differences between $\mathbf{c_z}$ values within each data set were all significant (t-test, level 0.01), with the exception of the 1980-'83 pair (0 m, 55m).

In addition to the calculations reported above, QUAGSOLVE can be used to check the consistency of these observed values. This is done for separate compartments with all chloride concentrations given and no restrictions on **Q** and with **D**=1 m/a (2.74 mm/d) and **D**=2 m/a (5.48 mm/d). Three compartments are defined, for which the parameters and variables, including model solutions, are listed in Table 10.4. The annual exchange **T** is included in this model solution, although it does not interfere with the gradient of concentrations in the flow channel as long as a steady state is assumed. The results for **T** will be discussed later in this section.

It appears that the solution with **D**=2 m/a (5.5 mm/d) almost satisfies the condition $\mathbf{Q_{i+1}}$=0 at the end of the last compartment, at 198 m from the ditch, rather than at 160 m. This solution also nearly satisfies the condition that the lateral outflow from a certain compartment must equal the lateral inflow into the next one and it is very close to the '**L**=200' case in Fig.10.3. Solutions with substantially different values for **D**, at the chosen situation in De Stobbenribben, obviously violate the continuity of water flow required by the direct linkage of compartments. Apparently

Table 10.3 Chloride concentrations observed in De Stobbenribben, parcel A

Distance from ditch (m)		**0**	**5**	**22**	**35**	**55**	**102**	**110**	**135**	**158**	**175**
701118/23	c_k				66						5
	c_z	84			73						64
730724	c_k		57					41	48		40
	c_z	96	78					79	91		60
730920/21	c_k		10					49	64		37
	c_z	84	31					86	85		69
731125	c_k		67					24	44		22
	c_z	82	91					84	98		61
740403	c_k		93					23	42		38
	c_z	?	74					92	68		76
791017	c_k								41		
	c_z	93				80			64		
791115	c_k								43		
	c_z	55				73			56		
1980-'83	c_k					57			33		
	c_z	76				76			62		
1984	c_k			69			18			13	
	c_z	67		73.5			57.5			46.5	

mg/l; in several cases average values have been given

the seepage rate **D**=2 is consistent with the results found in Chapter 8: the DOPPSOL and FOUSOL methods yielded average values of 5.6 and 4.1 mm/d, respectively, for parcel A. Further calibration does not seem to be very useful, since tests are difficult for this rough model, which does not include any kinetic details. An extension of QUAGSOLVE to cover non-steady-state situations, in relation to more detailed measurements of conductivity profiles and hydraulic gradients, seems possible, but lies beyond the scope of the present project. It is worthy of note that the balance sheet approach followed in the QUAGSOLVE model only considers the overall results of processes. The details of these processes remain untreated.

Table 10.4 Application of the model QUAGSOLVE with assumed values for De Stobbenribben, parcel A.

Run		**I**			**II**	
D (m/a)		**1**			**2**	
Compartment (i)	**1**	**2**	**3**	**1**	**2**	**3**
L (m^2)	110	48	40	110	48	40
c_k (mg/l)	42	16	8	42	16	8
c_z (mg/l)	70	54	35	70	54	35
$c_{l,i}$ (mg/l)	75	58	46	75	58	46
$c_{l,i+1}$ (mg/l)	58	46	30	58	46	30
Solutions:						
T_i (m/a)	0.59	0.13	0.04	0.59	0.13	0.04
Q_i (m^3/a)	231	105	40	308	137	53
Q_{i+1} (m^3/a)	171	79	18	138	63	-9

Compartment 1 starts at the ditch

One other solved variable, *viz.*, the annual exchange **T** of water between the floating mat and the flow channel, can be evaluated (Table 10.4). The decrease of **T** with the distance from the ditch suggests that the *kragge* at a greater distance is more capable of temporarily storing a precipitation excess. This corresponds to the images produced on the basis of conductivity soundings (Chapter 9), and it might be explained by the firmer *kragge* structure,by an obviously lower density and smaller area of weak spots and pools providing windows to the flow channel below, and by the opulent growth of *Sphagnum* species. *Sphagnum* vegetation is capable of storing a substantial amount of water above the phreatic level and it considerably reduces the hydraulic conductivity in the vertical direction. The highest value for **T**, 0.59 m/a, in the first compartment, says that about 75% of the rain falling on the *kragge* is, after some mixing with water already present there, discharged into the flow channel, thus urging an additional supply from that channel during drought. **T** apparently reflects the asynchronous incidence of precipitation and evapotranspiration as this is controlled in the *kragge*, but the higher values are obviously caused by additional processes, such as a forced exchange under the influence of pressures exerted on the *kragge* during mowing.

The general conclusion is that the gradient of the chloride concentrations observed in 1980-'84 is approximately consistent with the quantified influx of ditch water and a reasonable variance of the exchange rate between the *kragge* and the underlying flow channel. The *kragge* structure governs this exchange rate, possibly due to the varying frequency of pools and weak spots and to the varying abundance and characteristics of the moss layer. Apparently the exchange rate may approach zero, thus allowing the floating mat to become atmotrophic. However, deeper-rooting species may still be able to reach the underlying body of mire water in the flow channel, which is maintained at higher concentrations of solutes. The rate of discharge from the flow channel towards the body of groundwater is possibly some 3-5 mm/d. Substantially different assumptions would definitely lead to unrealistic results. At the divide between the influx zones the quagfen and the underlying body of mire water may become atmotrophic. In De Stobbenribben the entirely atmotrophic situation is not properly reached in parcel A, but almost so in parcel B, where the *kragge* is very thick and firm, and the transmissivity of the flow channel is, therefore smaller. This is in accordance with chloride concentrations measured in the flow channel below the *kragge* in parcel B between 1970 and 1983 at a sampling site 145 m from the ditch. They were ca 25 mg/l. The quagfen surface is also slightly dryer here in summer, however.

10.4 Deviating concentrations of non-conservative constituents

The QUAGSOLVE exercise showed that the chloride concentrations at various locations and depths in the quagfen can be explained by the mixing of ditch water flowing in at one side of the quagfen parcels with rain water penetrating from above through the *kragge*. Most other ions, however, are involved in various other processes and it seems worth-wile to check the deviations found. This was done by computing, on the basis of the relative volumes of rainwater and ditch water as expected from chloride concentrations, the concentrations of other constituents as these would follow from mixing, and checking this against analytical results. Note that the EC-IR and rTH-rLI diagrams presented in Chapter 9 already suggest a general applicability of mixing processes as regards the major ions, although the IR decreased a bit more than was expected as the rain water influence increased. Roughly three groups of additional processes are to be considered. These are summed up below with an indication of the constituents expected to be involved to such an extent that the deviations can be large enough in regard of the actual concentrations to be observed.

1) Seasonal uptake or release by the soil and the biocoenosis, governed by biological processes and possibly different in magnitude according to local factors reflected in the structure of the vegetation. Expected to hold for phosphorus, nitrogen, potassium, and carbon;
2) Exchange between the solution and the peat matrix. Expected to hold for calcium and possibly for the other cations;
3) Transformations due to the very different environment in the flow channel and the *kragge*, as compared to the surface water system. Expected to hold for sulphur, nitrogen, phosphorus, and carbon.

These processes are characterized by different time scales and parameters that have not been quantified, so that only tentative suggestions can be raised as regards their relative importance. In some cases, *e.g.*, when transformations are involved, ditch water and rain water analyses are no appropriate sources for the calculation of mixing processes within the quagfen. This was checked by replacing rain water and ditch water, in the calculations, with analyses of *kragge* water at the same location and analyses pertaining to the nearest ditchward site in the flow channel, respectively. I will refer to the fundamental assumption of this calculation as *local* mixing below.

Some initial problems must be solved: reference analyses for ditch water and rain water, and a representative set of analytical data must be chosen.

For statistical reasons the 1980-'83 data-set will be the main one to be used. The calculations have also been applied to mean analytical results reported by Kooijman (1985) for 1984, and I will comment on the comparison when relevant. The ditch water reference for the 80-'83 data was taken from the data-set itself. The ditch water samples in the 1984 set exhibit slightly lower chloride concentrations than samples at a distance of 22 m from the ditch. The 1980-'83 ditch water reference could not serve the same purpose for the 1984 set since especially the calcium concentrations were more than proportionally lower in the 1984 data. I therefore considered the ditch water itself a mixture of rain water an a more extreme, ‘unmixed’ ditch water, for which I computed the concentrations. The benchmark analysis AT-W80 (Appendix D) was used as a reference analysis for rain water with the 1980-'83 data. For 1984 rain-water analyses were available in the data-set. This RAIN-84 reference is more concentrated for all constituents than AT-W80. This is of significant influence when the deviations for K and P are calculated, as commented below. The various reference analyses are summarized in Table 10.5. Fe was not analysed in AT-W80 (the value 0 was used in the calculations).

Table 10.6 gives the results of the calculations for the 1980-'83 data set. Included in the table is a site in parcel B, 145 m from the ditch (see chapter 9). Since parcel B has a much firmer and thicker *kragge*, this site is more or less representative for the ‘dead’ end of that quagfen parcel. It was selected to replace a site at ca 190 m from the ditch in parcel A that was disturbed by edge effects due to the proximity of the peat baulk at the closed end proper, the frequent visitation by people, and the occasional influence of a replica of a small local type of wind-pump (*tjasker*).

The means in the data-set were considered as estimates of the time average, and apparent gains and losses (negative gains) for each constituent were computed, referring to the expected concentration in a mixed sample of ditch water and rain water, of which the ratio was derived from chloride concentrations. Two (null-)hypotheses are tested for the various constituents with a t-test (one-sided, 0.05 level of significance).

The first hypothesis is that the means for the sites do not differ significantly from the ditch mean. The hypothesis is rejected for almost all data. The exceptions are: 1.2 m depth at 55 m from the ditch (only SO4, pH, N-inor different), Fe, K, and P at all sites and depths except at 1.2 m, 145 m from the ditch in parcel B (Fe is also different at 0.0 m depth and 55 m from the ditch). Apparently there are no depth and longitudinal gradients, at this level of significance, for P, K, and Fe, and, at its entrance in the flow channel, SO4, pH, and N-inor are the first variables marking the changing ditch water composition.

The second hypothesis is that the means for the sites do not differ significantly from what would be expected on the basis of a mixing of ditch water and rain water according to the method used. The rejection of this hypothesis is shown in bold face in Table 10.6 (right-hand side), expressing, among others, significant losses of Ca and N-inor at all sites and depths, a reasonably good match with the mixing assumption for Na, and a loss of SO4 in the flow channel. As far as this, similar results were obtained with the 1984 data set.

Below the tested ‘behaviour’ of some constituents in the quagfen is reviewed, and reference is made to a possible ecological impact of this behaviour. In some cases an additional t-test was applied to see whether the concentrations differed significantly also *within* the quagfen.

P and K

P and K concentrations in the quagfen do not differ significantly from the ditch-water concentration, thus appearing to be relatively constant. When the sites are grouped, it appears that the concentrations for P actually show an increase as the distance from the ditch increases. P and K are important plant nutrients. At low supplies they may prevent a dominance of large helophytes in the quagfen and thus favour a high species-richness. P is involved in many transformations, and it is unclear how these interfere with the dissolved fractions represented in the analyses.

Table 10.5 The composition of the reference samples used to compute gains and losses of various constituents in the mire water in De Stobbenribben

NAME	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	EC_{25} mS/m	NO_3 mg/l	NH_4 mg/l	P mg/l	Fe mg/l	N_{inor} mg/l
AT-W80	4.2	0.4	0.2	1.6	0.23	3	0	6	5.0	3.41	1.70	0.01		2.09
RAIN84	5.8	3.4	0.78	2.7	1.76	5	7	8	5.4	3.87	2.42	0.05	0.08	2.76
DITC84	7.6	43.3	8.50	38.7	3.47	67	116	24	61.1	1.34	0.43	0.02	0.10	0.64
UNMIX	-	47.7	9.36	42.7	3.66	74	128	26	67.3	1.06	0.21	0.02	0.10	0.40
DITC80	7.6	70.2	10.17	41.4	4.70	76	185	46	60.8			0.03	1.28	0.82

Table 10.6 Concentrations (left side), percentage rain water and deviations from the expectedconcentration in the mixture (right side) in samples from De Stobbenribben (1980-'83)

	CONCENTRATIONS									MIXING WITH RAIN WATER, GAINS AND LOSSES								
Parcel	<---A--->		<B>	<---A--->		<B>	<---A--->		<B>	<---A--->		<B>	<---A--->		<B>	<---A--->		<B>
Distance from ditch (m)	55	135	145	55	135	145	55	135	145	55	135	145	55	135	145	55	135	145
		mg/l [Cl]			mg/l [Ca]			mg/l [Mg]		% rain water based on [Cl]			mg/l gain of [Ca]			mg/l gain of [Mg]		
0.0 m	**57.4**	**32.8**	**14.4**	**44.7**	**20.5**	**5.1**	**6.91**	**3.89**	**1.80**	**26**	**59**	**84**	**-7.5**	**-8.4**	**-6.3**	-0.67	-0.37	+0.04
1.2 m	76.0	**62.0**	**25.0**	64.8	**49.8**	**16.6**	9.63	**7.56**	**4.11**	1	**20**	**70**	**-5.1**	**-6.8**	**-4.8**	**-0.49**	**-0.66**	**+0.92**
		mg/l [Na]			mg/l [K]			mg/l [HCO3]			mg/l gain of [Na]			mg/l gain of [K]			mg/l gain of [HCO3]	
0.0 m	**30.4**	**17.5**	**8.1**	4.07	4.06	4.08	**117**	**52**	**11**	-0.7	-0.3	+0.3	+0.53	**+2.01**	**+3.15**	**-20**	**-24**	**-18**
1.2 m	39.3	**33.0**	**18.0**	5.85	4.67	**2.50**	202	**154**	**69**	-1.9	-0.6	**+4.5**	+1.17	**+0.85**	**+0.93**	**+17**	+5	**+13**
		mg/l [SO4]		[Fe]	mg/l			mg/l [P]			mg/l gain of [SO4]			mg/l gain of [Fe]			mg/l gain of [P]	
0.0 m	**32**	**22**	**16**	**0.20**	0.66	1.18	0.02	0.06	0.07	-4	-0	+4	**-0.75**	+0.14	**+0.98**	-0.01	+0.04	**+0.05**
1.2 m	**23**	**19**	**10**	1.37	0.92	**8.11**	0.05	0.06	**0.09**	**-24**	**-19**	**-8**	+0.10	-0.10	**+7.73**	+0.02	**+0.03**	**+0.07**
		mg/l [N-inor]			mS/m EC25			- pH			mg/l gain of [N-inor]							
0.0 m	**0.17**	**0.25**	**0.21**	**42.4**	**23.8**	**10.7**	**7.1**	**6.5**	**5.2**	**-0.98**	**-1.32**	**-1.68**						
1.2 m	**0.41**	**0.25**	**0.39**	57.5	**45.8**	**20.4**	**6.7**	**6.3**	**5.8**	**-0.49**	**-0.82**	**-1.32**						

Significant results (t-test, one-sided, significance level 0.05) have been printed in bold face

The absence of any significant differences in the P and K concentrations in the quagfen leads to different conclusions depending on the assumed inputs with rain water. If the concentration in rain water is low, as in the AT-W80 reference, a net mobilization of K and P within the quagfen is found. Assuming a larger atmospheric input of P and K, as in the RAIN-84 data, which could easily result from local factors, would lead to the conclusion that P and K are immobilized in the quagfen. The 1984 data, with reference samples for rain water and ditch water from that data-set, indeed yield this result.

An analysis of the variation of K concentrations in time shows relatively strong fluctuations. Occasionally a decrease of K concentrations during the growing season was noticed, especially in dense stands of helophytes, whereas burning, thawing after frost periods, and the activities associated with mowing sometimes led to extremely high peak concentrations for both P and K.

In conclusion it is not possible to attribute a gain or loss in P and K concentrations to the vegetation cover. Their concentrations in the quagfen seem to result from local processes. The total stock in the peat and the vegetation is probably large, but mobilization and diffusion rates may limit the supply of these elements to vigorously growing vegetation.

Inorganic nitrogen

Sulphate and inorganic nitrogen concentrations and pH differ between the surface water in the ditch and the mire water in the quagfen. They are determined by processes that in turn depend on the redox state of the medium, as this is controlled by barriers for the exchange of gases with the atmosphere. The assumptions on which the QUAGSOLVE model was based are irrelevant as regards these constituents. While, at both depths, pH and SO4 differ along the gradient, there is no such significant trend in the case of N. Upon its entrance into the flow channel underneath the *kragge* nitrate is replaced by ammonium, and a considerable amount of N is lost. According to a test on *local* mixing the concentrations do not change very much *within* the quagfen.

As are P and K, N is often investigated as a possibly limiting nutrient. Next to the supply of nitrogen in various inorganic and organic forms with (rain-) water, a fixation of atmospheric nitrogen has been frequently reported for mires (Dickinson 1983, Koerselman *et al.* in press) and this will also occur in De Stobbenribben, where *Myrica gale* and *Alnus glutinosa* are the most important species with associated microbial N-fixation. The possible importance of N-fixation by blue-green algae in quagfens is unknown. As is the case for P and S, N is strongly involved in many transformations. The concentration in rain water is 2-3 times as high as it is in the ditch water, and this explains the greater apparent losses seen in samples with a greater percentage of rain water. The concentrations do not show any clear time dependence in De Stobbenribben, so there is no sound basis to attribute losses from the dissolved phase to plant uptake. Rather, the nitrogen input from the atmosphere becomes immediately involved in uptake and transformations. A check with the assumption of *local* mixing only shows a substantial loss (0.40 mg/l) at 55 m from the entrance of the flow channel. If this were due to an uptake by the vegetation between the site proper and the ditch, the average supply of dissolved inorganic N from the inflowing water over this distance would be, somewhat depending on assumptions concerning a possible gradient, 1.5-2.5 g m^{-2} a^{-1}. This will be shown to be a relevant supply later.

Calcium

Calcium losses from the dissolved phase in the quagfen are appreciable. This must be due to processes here collectively named ‘exchange’ with the peat matrix, since there is no evidence of any substantial precipitation of calcareous minerals. The differences between sites are highly significant, but a test on local mixing reveals that the deviations from the mixing assumption especially apply to the *kragge* compartment and the first length of the flow channel. These are the parts of the quagfen where the peat matrix reaches its greatest bulk density, and where, accordingly, exchange processes may be expected to be more pronounced.

The exchange of cations in peats is a notoriously difficult matter (Clymo 1983), and only few data are available for the interpretation of the Stobbenribben data. According to Sikora & Keeney (1983) and to Clymo (1983) at pH near 6-7 a peat may be expected to have a cation exchange capacity of ca 1-2 mmol(c)/g. With a bulk density of 80 g/l in the *kragge*, the resulting capacity to hold and exchange cations would be 80-160 mmol/l. Moreover, there is some evidence (Malmer 1962, Clymo 1983) that the distribution of the various cations between the peat and the water exhibits a general pattern, such that about 1-2 % of the calcium, 3.5% of the magnesium, 10-15 % of the potassium, and 40% of the sodium remain in the water at equilibrium. If this is applied to the sampling site at 135 m from the ditch, it would appear that some 80 mmol(c) were held at the exchange sites of the peat, so there is a possibility that there is room for more. The concentrations at 1.2 m are more than twice as high, at this sampling site, and the bulk density is certainly lower, so that the peaty matrix in the flow channel is probably saturated with cations and an exchange of ions may occur depending on the ionic composition of the water. On average, the calcium concentration in this part of the flow channel will not change much. While this is in accordance with the results obtained from the *local* mixing calculation, the significant decrease of the calcium concentration at 55 m from the ditch can not be similarly explained. The peat matrix near the entrance of the flow channel would, in spite of its greater bulk density, be saturated with cations at the high ambient concentration, so it would be unable to extract more calcium from the incoming ditch water. None of the other cations (except ammonium, for which the calculations are less reliable due to irregular fluctuations) show a possibly compensating increase here.

The 1984 data-set reveals a similar picture, although the ditch-water reference concentration was much lower for calcium than in 1980-'83 (see Table 10.5). The lower concentration and lower proportion of calcium in the solution apparently still suffice for a continued transfer towards the peat matrix, raising the question whether this may have discharged calcium during the winter. The available data are inadequate to answer this question.

On rare occasions in the 1970-'74 sampling period, and very clearly and systematically at 158 m from the ditch in 1984, samples taken from below 1.5 m underneath the *kragge* surface showed high Mg concentrations (12-20 mg/l). The calculations with the 1984 data set revealed that the relevant cases could be attributed to an exchange of magnesium against calcium. This would mean that the local peat (possibly inclusive of some clay) has formerly been in equilibrium with a type of water with a higher proportion of dissolved magnesium ions, probably due to the former influence of brackish water (see Chapter 5).

Whatever processes are involved, the evidence is that the quagfen is a substantial sink for calcium flowing in with the ditch water in the flow channel underneath the *kragge*. According to Kelts & Hsü (1978), calcium and magnesium molecules provide a surface for the sorption of phosphorus. Kemmers (pers. comm., 1990) found a statistical correlation between sorption of phosphorus at peats and the saturation of the exchange sites with calcium. While no precise information is available, the role of the base state of fen mires, as indicated by their flora and vegetation, could relate to the sorption capacity for phosphorus.

Conclusion

Summarizing the above results, it appears that the availability of phosphorus and potassium in the quagfen cannot be related to a direct supply with inflowing ditch-water. For nitrogen the situation is slightly different. In the quagfen zone bordering the ditch the additional supply of nitrogen with inflowing water may be of some importance. The atmospheric input is quantitatively important for all three of these ions and the possibility that a substantial amount goes into biomass production even before the main body of mire water is reached cannot be excluded. The uncertainty with regard to the magnitude of the atmospheric inputs of P and K renders any conclusion concerning these elements ambiguous, however. Calcium is accumulated in the peat matrix of the mire, but it is not clear to what extent various parts of this matrix are presently saturated, and whether, and at which rate, a discharge of calcium may occur. There can be no doubt, however, that the supply of calcium is governed by the influx of relatively calcareous ditch-water underneath the *kragge*.

10.5 Gradients in plant biomass and nutrient state in De Stobbenribben

In the preceding sections it was attempted to describe processes that possibly maintain the observed longitudinal gradient in the base state of the quagfen parcels in De Stobbenribben. This gradient concurs with a gradient in the species composition (Chapter 7), and the present question is whether this concurrence can be partially understood from quantitative relations with plant growth.

The first relevant question regards the biomass production. Judging from the height and density of the local stands of vegetation a gradient in plant biomass and production in De Stobbenribben has been presumed from the beginning of this research project. Indirect measurements of plant biomass became available through remote sensing images. Since near-infrared radiation is partially transmitted by plant leaves, its reflection increases with the number of leaf layers in the radiation path, until saturation is reached in fairly dense stands of vegetation. Radiation in the visible wavelengths, especially the red, is strongly absorbed by green leaves. The reflection therefore increases according as a greater part of the ground surface is covered with green plants. The ratio between near-infrared and visible reflection is accordingly correlated to the green biomass of vegetation (Hoffer & Johannsen 1969, Knipling 1969). Adequate numerical results not requiring the processing of remote sensing images were obtained in the field with hand-held radiometers by Brand & Leemburg (manuscript 1978) and by Boeye (1983). Brand & Leemburg incorporated a calibration through direct measurements of biomass by cutting, drying and weighing of small plots of vegetation, and by doing so recorded the development of living aerial biomass of vascular plants from near zero in April to ca 656, 341, 246, and 267 g m^{-2} in July in the vegetational zones A, B, C, and D, respectively (Fig.10.4). In remote sensing images the reflection ratio shows a sharp drop at the border of the *Calliergonella-Phragmites* reed zone (Chapter 7) bordering the ditch. This drop is also manifest from the measurements with a hand radiometer by Boeye (1983, Fig.10.5). These measurements confirm that the longitudinal pattern that has been observed on aerial photography including the near-infrared band, from 1971 onwards, and that was floristically identified as a pattern of vegetation types, also reflects a standing crop pattern.

A more detailed quantification of plant biomass in relation to nutritional factors was realized by Kooijman (1985, see also Verhoeven *et al.* 1988) with direct methods. Her results, summarized in Table 10.7, were obtained at three sites in quagfen parcel A in De Stobbenribben at distances of 22, 102, and 158 m from the ditch, in the vegetational zone AB (transition between *Calliergonella-Phragmites* reed and *Scorpidium-Carex* fen), B *Scorpidium-Carex* fen), and BC (transition between *Scorpidium-Carex* and *Sphagnum-Carex* fen), respectively. The maximum above-ground living biomass, determined from monthly measurements, was reached in the beginning of August. The biomass in zone BC was slightly higher than that in zone B, due to the higher moss biomass, but still markedly smaller than in zone AB. Moss biomass in zone AB was only about 50% of that in zone BC, however, with zone B in an intermediate position.

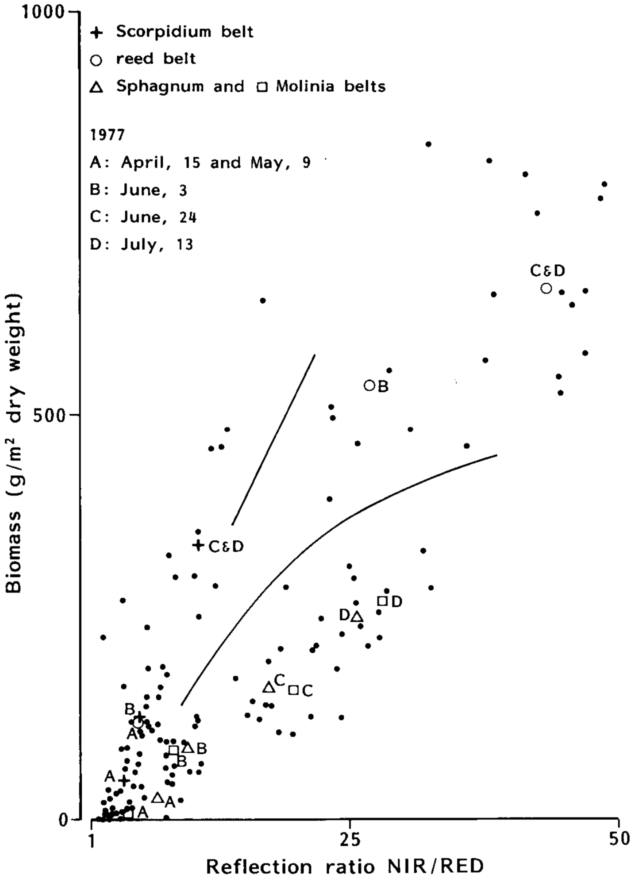


Fig.10.4 Relation between the near-infrared to red reflection ratio and measured above-ground biomass of phanerogams in various stands of vegetation in De Stobbenribben
Data from Brand & Leemburg (mscr.); The larger symbols indicated with a letter represent mean values

(Note that apparently some shifts in the vegetational pattern occurred between the 1970s and 1984 (see Chapter 7). At 102 m from the ditch the vegetation type indicated in Table 10.7 had replaced a vegetation dominated by *Typha angustifolia* and *Scorpidium scorpioides*.)

Most of the N and a substantial part of P released is not incorporated in the above-ground biomass in zones B and BC. Conversely, the stand of vegetation in zone AB seems to use as yet unidentified additional sources of nitrogen and phosphorus. As regards phosphorus this can not be ascribed to net inputs of rain and ditch water. For nitrogen the atmospheric input (Table 10.8) and the input with the surface water, which appears to apply to this zone only (*cf* Section 10.4),

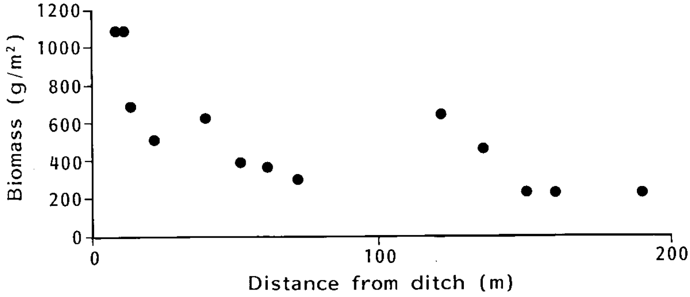


Fig.10.5 Decrease of the biomass (dry weight) with the distance from the ditch, De Stobbenribben, parcel A
Very roughly estimated on the basis of reflection measurements by Boeye (1983)

are substantial. If it is assumed that, within this zone, the stands of vegetation nearest to the ditch can benefit most from the dissolved inorganic nitrogen, this source might be of the order of magnitude of 4 g m^{-2} a^{-1} at 22 m from the ditch. At an atmospheric input of 4.8 g m^{-2} a^{-1} and a biological fixation of 2 g m^{-2} a^{-1} (see below) this would reduce the overall deficit to (14.3-2.8-10.8) g m^{-2}, or 5%. This is negligible in view of the probable errors in various terms and in view of the relocation of nutrients from the root system into the aerial shoots.

In conclusion, there is no straightforward relation between the local net mobilization (release) of nutrients and plant growth in any of the vegetational zones, but there possibly *is* a relation between (1) the input of dissolved inorganic nitrogen in the inflowing ditch water and plant growth in the zone near the ditch, and, qualitatively assessed only, between (2) the inflow of ditch water and the reduced release of nutrients from the soil in zone AB. Other factors apparently determine the rate at which the local stand of vegetation uses the resources in the quagfen.

These data and the results obtained in the preceding section can be combined into a, of necessity rough, nutrient balance sheet as presented in Table 10.8. The input with surface water was computed from the concentration in the feeding ditch and a 300 m/a inflow supplying 200 m of quagfen length (see section 10.3). Outflow with groundwater was calculated according to concentrations in the flow channel and a downward discharge of 2 m/a. The dry deposition figure was loosely derived from Heij & Schneider (in press), biological fixation is ‘guessed’ on the basis of data in Dickinson (1983) and Etherington (1975), considering that the values found by Koerselman *et al.* (in press) might be too low in regard of the contribution by blue-green algae, and the amounts of nutrients in biomass were based on the average for the three zones in Table 10.7 (Kooijman 1985). Note that 50-75% of this is harvested as hay. A near-equilibrium exists for N, while P and K are lost at relatively high rates. For these elements the internal

Table 10.7 Ecological characteristics of three measuring stations in De Stobbenribben, 1984

Vegetational zone	**AB**	**B**	**BC**	
Distance from ditch	**22**	**102**	**158**	**(m)**
Dominant mosses	*Scorpidium scorpioides* *Calliergonella cuspidata*	*Sphagnum subnitens*	*Sphagnum papillosum* *S. flexuosum*	
Dominant herbs	*Phragmites australis* *Carex elata*	*Juncus subnodulosus*	*Juncus subnodulosus*	
Moss species (0)	15	13	17	
Vascular plants (0)	39	24	37	
Above-ground living biomass				
herbs (1)	1065	234	243	(g m^{-2})
mosses (2)	98	154	228	(g m^{-2})
Water composition				
upper 0.5 m	similar to ditch	atmotrophic	atmotrophic	
below 0.5 m	similar to ditch	similar to ditch	varying	
Soil K release (3)	-0.9	4.5	8.5	(g m^{-2})
Soil N release (3)	2.8	15.0	16.8	(g m^{-2})
Soil P release (3)	-0.07	0.32	1.30	(g m^{-2})
N in biomass	14.3	3.8	4.6	(g m^{-2})
P in biomass	0.89	0.16	0.23	(g m^{-2})
K in biomass	12	4.6	5	(g m^{-2})

Source: Kooijman 1985, Verhoeven *et al.* 1988
(0) In 8 times 10 squares of 400 cm^2; (1) Maximum value, reached between July, 24, and August, 24; (2) Average of 8 determinations between April and October; (3) April-September, upper 0.4 m of *kragge*

mobilization must be the main source, also at the whole-quagfen scale, and a possible relation with the inflow of surface water should be explained by means of processes governing the internal availability.

This means that, for P and K, the quagfen largely exhausts its own formerly accumulated resources, whereas the processes involved are determined both by the state of the quagfen and by its surrounding environment, such as here analysed for the water flow system and the harvest. If it is considered that atmospheric inputs of N, and concentrations of this element in surface water, are generally agreed to have been (much) lower in the first half of the present century, then it appears that internal cycling of N may also have been more important in the past. Intuitively, the time of harvesting will be very important, since especially the large helophytes

Table 10.8 Rough balance sheet for nutrients in De Stobbenribben (all values in g m^{-2} a^{-1})

		N				P(×10)				K			
		+		-		+		-		+		-	
		A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Atmospheric deposition	(wet)	2.2	2.8			0.1	0.5			0.2	1.8		
	(dry)	2.0	2.0										
Surface water inflow		1.2	1.0			0.5	0.3			7.1	5.2		
Biological fixation		2.0	2.0										
Groundwater outflow				0.7	0.8			1.3	1.2			8.7	6.0
Sum total (mean of A and B)		7.6		0.7		0.7		1.2		7.2	7.3		
Net input			6.9				-0.5			-0.1			
Above-ground vegetation			7.6					4.3			7.2		

A: estimated for 1980-'83, B: for 1984

may relocate considerable amounts of the essential nutrient elements in the root system in autumn, thereby reducing the discharge of these elements when the harvest falls in the late autumn or winter.

10.6 Changes in De Stobbenribben and their possible causes

There is no clear record of change in De Stobbenribben, but a certain degree of ‘atmotrophication’ is indicated, and a similar process in the vegetation cover has been observed very clearly in De Bollemaat (Molenaar *et al.* 1990) and De Wobberibben (G.J.M. Ruitenburg, unpublished, Calis & van Wetten 1983), two other quagfen complexes in North-West Overijssel. I will shortly review some possible causes of a changing base-state in De Stobbenribben.

It is apparent from Table 10.3 (Section 10.3) that the chloride concentrations in De Stobbenribben have varied substantially. There are some still older, additional observations. The present author collected eight water samples in De Stobbenribben in August, 1969. Upon analysis by the Hugo de Vries Laboratory the chloride concentrations appeared to vary between 91 and 99 mg/l. Coesel-Wouda (1967) and Stegeman (1968) reported analyses of water samples collected in De Stobbenribben between August and October 1966. The first-mentioned authoress sampled small pools at quite some distance from the ditch. Chloride concentrations ranged from 67.5 to 125 mg/l. Stegeman sampled from between moss vegetation and found 18-64 mg/l chloride. In RIN files I found some other water analyses pertaining to De Stobbenribben and collected between 1961 and 1968. These fall within the same range found for the other analyses. Leentvaar (1960) in 1960 found chloride concentrations up to 114 mg/l in open surface water of a *petgat* nearby De Stobbenribben.

All this suggests that the surface water has, at least temporarily, been slightly brackish in the past. From the 1980-'83 and 1984 analytical results it is clear that a strong decline of the chloride concentrations has taken place in this segment of the quagfen. While brackish influences are by no means necessary for the development of a base-rich type of quagfen, such influences definitely may faciltate the process. The case history for De Stobbenribben in this respect fits in with the ongoing process of areal expansion of *Scorpidium scorpioides* and some other species, as documented in Chapter 6.

Several possible causes for the observed changes can be mentioned. A further quantitative treatment with models simulating the relevant processes and situations is necessary, however, to check the relevant importance of each of these possible causes, and I will, for this reason, just sum up some of the most obvious ones:

1) The hydrological situation of the area changed dramatically in the mid 1950s, when the polder Wetering-Oost, at a distance of only 250 m from De Stobbenribben, was reclaimed. This must have started a strong downward discharge of water from the mire area and so gradually removed most traces of the earlier brackish water. Note that such traces have been found in the groundwater system (Chapter 5) at a little distance from De Stobbenribben. More recently, a variation of the water composition in the *boezem* system, as also reported in Chapter 5, also involves the ditch feeding De Stobbenribben.

2) De Stobbenribben was probably dredged for peat by the end of the last century. Personal observations and older descriptions suggest that the *kragge* has grown definitely firmer in De Stobbenribben since 1960. Especially the number of weak spots and pools in the vegetational zone B in parcel A has decreased. According to the QUAGSOLVE model these processes, whatever be their causes, must have led to a decreased influence of the *boezem* water.

3) Irregular patterns in the time series may have been produced by the varying state of ditch management and an alternating incidence of ditch blocking. In the autumn of 1972 the ditches feeding the wider area of which De Stobbenribben is a part were separated from the *boezem* system in order to keep polluted and eutrophicated surface water out of this area which was then supposed, by the management authorities, to receive discharging groundwater from underneath. This management experiment was abolished when the water level had fallen by more than 20 cm (written comm. J. ter Hoeve). This incidence must have caused a relatively strong momentary inflow of ditch water. Similar ditch blockings have been frequently deliberately apllied since then in order to improve the accessibility of the terrain during mowing. Depending on the weather during such drainage periods (lasting 2-4 weeks) the influence on the water composition will not always have been the same.

4) As mentioned in Chapter 5, the management of the *boezem* water level has also changed during the 1970s and 1980s. Especially the sudden raising of the water level by 10-15 cm on the first of April, and a corresponding lowering in October, was replaced by the maintenance of a more constant level. At present water conservation strategies are applied which allow the water level to fall during the summer until a critical level is reached at ca 10 cm below the target level.

Although these effects have not been quantitatively analysed, QUAGSOLVE explains how they *could* have contributed to a certain ‘atmotrophication’ of De Stobbenribben. Especially the situation in zone B of parcel A, where an extensive *Typha angustifolia* stand was replaced by an at present species-rich quagfen vegetation raises doubts as regards the future of this area. Observations concerning the growth of *Sphagnum* vegetation and the changing water composition in the preferential flow channel suggest a continuing process which would ultimately lead to the disappearance of species depending on environmental conditions maintained through the local, but not necessarily constant, influence of a lithotrophic type of water. Although this would suggest a disturbance of the environment, it may well be considered a final stage in a continued process, starting from an open water system with slightly brackish water. The first, desalting phase coincides with the terrestrialization, as is still seen in other parts of De Weerribben (see Chapter 6). The apparent stability of the base-rich conditions during this phase originally seemed to confirm the theory of discharging groundwater. The present investigation has proved that in fact no discharging groundwater, but rather an inflow of lithotrophic surface water recharged the quagfen system with bases. The application of QUAGSOLVE shows that the remarkably zoned pattern in the area results from the directional supply of ditch water, governed by the particular lay-out of the parcels with one closed end at a length which suffices to exhaust the inflow. The zoned pattern is reinforced by the succession of the local vegetation cover, including structural changes in the *kragge* compartment and a decreasing exchange rate **T** between it and the underlying flow channel. When this exchange rate has become low enough a strong extension of *Sphagnum* vegetation is possible and accelerates the further atmotrophication. Recently ditch cleaning and influences exerted on the *kragge* by mowing and harvesting machines and by groups of volunteers seem to have partially counteracted these processes.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

CHAPTER 11

Summary and general discussion

11.1 Introduction

Two main types of mires are usually distinguished. *Bogs* are rainwater-fed and hence poor in bases and nutrients. *Fens*, in contrast, are fed by groundwater and surface water, and richer in nutrients and, especially, bases. They derive their higher base and nutrient states from water seeping through the peat. Quagmires form a less common category of mires usually developing as floating rafts over bodies of open water and strongly yielding underfoot. In the moist climate of North-Western Europe such rafts usually develop into *quaking bogs*, unless hydrological conditions favour a continued inflow of water from elsewhere. Such hydrological conditions apply to the *quagfens* in North-West Overijssel discussed here.

The distribution of quagfens in North-Western Europe is not very accurately known. The occurrence of extensive quagfens has been reported for fluvial plains with riverine environments and lakes, such as found in Norfolk, North-West Overijssel, the Danube-delta, and the Baltic Coast. Quagfens are usually characterized by a dominance of species indicating a eutrophic and base-rich environment, and they seem to be adapted to strong fluctuations of the water level as determined by a fluvial regime. Quagfens along lake shores often include less eutrophic zones. The latter also applies to the quagfens in Norfolk and in North-West-Overijssel

which are due to the terrestrialization of bodies of open water in old turbaries. In such less eutrophic, but still base-rich zones slender sedge species and extensive moss carpets determine the structure of the vegetation, rather than tall reeds. Similar types of vegetation are presently known to occur in extensive non-floating rich-fens and remains of such fens are still found in North-West Overijssel also. While possibly stable in the absence of human influences at a colder climate, such less eutrophic rich-fen vegetation seems to have developed especially under a mowing or grazing regime in our region (Ellenberg 1978).
Until the 1950's the relevant quagfens in North-West Overijssel were still highly valued by local farmers for their fodder yield. Presently the interest is almost entirely based on nature protection: substantial populations of many elsewhere threatened organisms occur in these quagfens. The number and extent of the stands of vegetation involved is strongly decreasing, however, not only in the Dutch quagfens, but also in rich-fens in Germany (Braun 1968, Succow 1988), Poland (Tomaszewska 1988), the Jura (Gallandat 1982), Czechoslovakia (Rybníček 1974, Balátová-Tuláčková 1976), and Norfolk (Wheeler 1980a, Wheeler & Giller 1982). Apart from the changed agricultural interests (decreased mowing and grazing of natural fen vegetation, reclamation of mires), this seems to be due to a general eutrophication of the environment. On the whole a loss of environmental and biological diversity is reported, calling for a more detailed analysis of the hydro-ecological factors responsible for the occurrence of the species involved. The relatively young quagfens in North-West Overijssel offer a suitable case for such an analysis since inherent influences of old peat and historical plant populations are less important here than in non-floating rich-fens with a long developmental history. The existing *seepage hypothesis* for Dutch quagfens is taken as a starting point in the present report.
In this résumé the course of the overall inquiry will be reviewed and some major choices of approach mentioned, to be compared with data not already referred to in the text. Note that frequent reference is made to key figures placed in other chapters.

11.2 The *seepage hypothesis* for Dutch quagfens re-formulated

Seepage

Chapter 2 reviews the hypothesis that many plant species and their associations in quagmires of the rich-fen type (*quagfens*) in The Netherlands depend on *seepage*. The hypothesis is gleaned from the original publications (Meijer & De Wit 1955, Kuiper & Kuiper 1958, Segal 1966, and others), and the arguments are checked with the pertaining international literature.

By the seepage or the intensity of water exchange in a mire Thomson & Ingram (in Ivanov 1981) understand the total quantity of water flowing per unit of time through a volume of peat 1 m^2 in area and equal in height to the depth of the peat deposit in that part of the mire massif. Hydrological definitions more specifically emphasize the exudation of groundwater or, even narrower, such an exudation under the influence of a larger hydraulic head outside the seepage area (CHO 1986).

The hypothesis of *seepage* in Dutch quagfens states that the occurrence of certain indicated species (Table 11.1) is bound to an artesian discharge of groundwater. Many of these *seepage indicators* were said to be characteristic of the phytosociological units *Scorpidio-Caricetum* *diandrae* and *Scorpidio-Utricularietum*. The supposed discharge was never measured, however, and various opinions are held as regards its bearing on the immediate environment of the plants. North-West Overijssel was frequently mentioned as a *seepage* mire area *par excellence* (Segal 1966, Westhoff *et al.* 1971, Gonggrijp *et al.* 1981). The *seepage hypothesis for quagfens* was widely accepted and various Dutch ecologists embraced the hypothesis and associated the occurrence of the plant species and associations involved with an artesian discharge of groundwater (Weeda *et al.*1988, Touw & Rubers 1989).

In spite of the missing evidence the *seepage* hypothesis cannot be rejected *a priori*. The following questions arise:

1) Is there indeed an artesian discharge present at the classic locations? This is a somewhat formal question of especially local importance, and subordinate to the second problem:
2) What ecological principle explains the rare and threatened occurrence of the species and communities involved? Although the research is carried out in The Netherlands, the findings may apply elsewhere if the effects of a different climate and other geographical factors can be accounted for.

As regards this second question, the working hypothesis is formulated that the sites under discussion derive their very characteristic cover of vegetation from the interaction of the substratum, the atmospheric precipitation, and through-flowing water, as modified by the microrelief. This re-formulation thus uses Thomson & Ingram's wider definition of seepage rather than a more specific hydrological one, while it is more restrictive in adding a (geographical) dependence on the climate and a dependence on the substrate. In the case of mires, substrate characteristics depend on the stage of development in time.

Base state as a nodal parameter

Any further work starting from this hypothesis obviously requires a more precise specification of the interactions mentioned. As suggested by the common elements in the reviewed treatises, the base state was chosen as a major parameter for the characterization of the influence of these interactions on the mire. In spite of the absence, in this investigation, of facilities for a direct measurement of the base state of the peat, in this way the problem can be bisected. Rather than considering the complex relation

(1) vegetation = f(climate, substratum, *seepage*)

in one go, I chose the base state of the mire as a nodal parameter simultaneously serving for the evaluation of the environmental interactions:

(1a) base state = g(climate, substratum, *seepage*),

and to determine their ecological significance:

(1b) vegetation = u(base state).

This construction facilitates a correction of estimates, both for errors and for deviations from the *ceteris paribus* principle under which the relations found will hold true. The solution of the *seepage problem* was probably retarded by the fact that such a step had not been taken earlier.

This point was envisaged by earlier authors, however, and I must credit S. Segal who charged me, as a student, with the question what bearing seepage could have upon *seepage indicators*.

The nodal parameter can also be used in applications involving the scanning of impacts of proposed measures concerning the water management, where the effects are evaluated according to the expected variation in the nodal parameter and to an agreed relation between the latter and some vegetational criterion fitting the field of application (*e.g.*, nature protection).

In the present treatment, the term 'seepage' is used for percolation in general, regardless of the possible causes and any preferential direction of water movement. The word is italicized in the designation of the *seepage hypothesis for quagfens* and in associated expressions. Although the primary authors reporting *seepage* in Dutch quagfens specifically envisaged a regional groundwater discharge, the non-specific term *seepage* is maintained here in view of the eco-hydrological conditions disclosed in this investigation. In addition to a seepage of water, *seepage sites* (italicized) apparently have some more specific ecological character in common, which possibly relates to their base state.

11.3 Relations between environment and vegetation

Chapter 3 deals with an 'anticausal' approach (Waldhauer 1982) according to formula (1b) above: what information about the environment, especially its base state, can be borrowed from the supposedly depending plants? The *seepage indicators* were compared with the majority of other species reported for the classical *seepage theory* locations and for *non-seepage* mire sites. The pertaining literature was searched for indications of the favoured environment attributed to these species. The interpretation required a rough model of the spatial organization of the mire environment and its variability. The first part of this chapter therefore concerns a reconciliation of a pragmatic approach with ecological theory.

Recurrent patterns of heterogeneity

Most applied research in this direction relies on one of the basic concepts of the Zürich-Montpellier school of phytosociology, *i.e.*, the concept of species association in an ecologically uniform habitat resulting from overlapping *ecological amplitudes* of the species concerned (Shimwell 1971, Ellenberg 1978, Klötzli 1981). Rather than exclusively accepting this *logical AND*-concept, I will consider the co-occurrence of species primarily as a result of ecological heterogeneity of a site providing the union of the possibly different requirements of the species present. This principle is accordingly called *OR*-association (Fig.3.1, Van Wirdum 1986, 1987). In a more precise theory the season, frequency and duration of the presence of each micro-environment, and the life history phases of the species involved should be taken into account (*e.g.*, Connell & Slatyer 1977, Grubb 1977, Huston 1979).

In the present investigation the presence of species is considered as solely depending on the environment, including other species, according to some determined 'biological program' (Van Wirdum 1982), and it is assumed that the set of 'available' species is constant. A corollary of this assumption is that the frequency distribution of species within a stand of vegetation statistically reflects the frequency distribution in space and time of suitable micro-environments. The *recurrent* co-occurrence of species must so be explained by non-random patterns in the environment for the *OR*-concept to work, rather than by direct species interactions. This lines up with recent approaches of succession theory (Grime 1979, Tilman 1982), but it differs from the position chosen by ecologists studying the evolution of species as a result of abiotic processes and competition (see Grubb 1977, Den Boer 1986). At the time scale of years it is assumed that sites including their stands of vegetation (‘ecodevices’) can be considered to represent a near-steady state.

Recurrent patterns of heterogeneity in the environment have long been recognized in northern European schools of vegetation and mire ecology. Since the relatively young (ca 70-100 years old) quagfens in The Netherlands, developing within the confined space of abandoned turbaries, exhibit a quite different pattern of heterogeneity than large and old mires do, the empirical rules of species association developed in northern Europe do not necessarily apply here. Somewhat intuitively leaning against different life-history characteristics and ecological ‘strategies’ of species, such as reflected by their root systems and phenology, it is argued that the terrestrializing *petgaten* with their developing quagfen typically provide a pattern of heterogeneity suitable for the co-occurrence of the following synusiae (Fig.3.2):

1) *Kragge* synusiae, often 10^3 to well over 10^5 m^2 in extent, and consisting of few plant species with extensive rhizomes, exploring the nutrient resources underneath the main body of the floating mat (*kragge*). Theoretically, the individual shoots can be considered to be the deciduous parts of few long-lived and extremely extensive individuals. Managerial measures can cause a dramatic reversal of dominance relations;

2) The synusiae adapted to the scale of hydro-environmental zones within single quagfen parcels. The distinction of hydro-environmental zones builds upon lateral inflow of water into many quagfens. The increasing density of the floating quagfen raft apparently gives rise to the development of a more isolated, rainwater-fed top-layer, deepening where the lateral inflow fades out. In case of an artesian water inflow, such a *spatial pattern* is replaced by a presumably slow *process* related to the accrual of peat, and displaying the relevant synusiae as hydro-environmental phases rather than zones. These synusiae consist of species rooting in the main body of the *kragge*, especially in the upper 2-4 dm. In the quagfens with any substantial lateral flow, the extent is of the order of magnitude of 0.1-2 10^3 m^2. The species involved are especially the slender species of *Carex*, herbaceous species, and amblystegiaceous and sphagnaceous mosses;

3) Hummock-and-hollow synusiae, thriving upon the substratum provided by hummock-building species, and also upon deformations of the quagfen surface resulting from faunal activity and management. The typical extent of hummocks and hollows in quagfens is 0.1-1 m^2. Several of the species concerned are short-lived and their abundance may vary from year to year;

4) A micro-zonation of synusiae of seedlings, certain mosses, hepatics (such as species of *Riccardia*, *Pellia*, *Cephalozia*, *Cephaloziella*, and *Calypogeia*) and blue-green algae, is found at the cm^2 scale. These synusiae often develop around decaying parts of large helophytes, at their stem bases, or in hummocks dying back from their centre.

This distinction means that the environmental conditions to which the involved species respond are to be measured in different compartments of the quagfen ecosystems, and at different spatial scales. The emphasis is laid on the second and third groups. The first group is also considered since it provides distinct light and litter conditions for the settlement and growth of species of the other groups. A preliminary indication of the synusial group to which the *seepage indicators* belong is given in Table 11.1.

Table 11.1 *Seepage indicators* according to Dutch authors and the state of their distribution in the study area 'De Weerribben'

Species	**state in De Weerribben**	**synusiae**
Calamagrostis stricta	rare	2
Carex buxbaumii	uncertain	2
Carex diandra	abundant	2
Carex lasiocarpa	abundant	2
Dactylorhiza incarnata	insufficiently known	2/3
Eriophorum gracile	uncertain	2/3
Liparis loeselii	distinct local distribution	3
Menyanthes trifoliata	distinct local distribution	1
Parnassia palustris	distinct local distribution	2/3
Sagina nodosa	rare	3
Utricularia intermedia	distinct local distribution	3
Bryum pseudotriquetrum	abundant	2/3
Campylium elodes	abundant	3/4
Campylium stellatum	abundant	2
Drepanocladus lycopodioides	outlying species	3
Fissidens adianthoides	abundant	3
Philonotis marchica	absent	3
Riccardia multifida	abundant	4
Aneura pinguis	abundant	3/4
Scorpidium cossoni	rare	3
Scorpidium scorpioides	distinct local distribution	2/3

The synusial groups are explained in Section 11.3

Indication by species

The various traditions in vegetation ecology have led to different attempts to use plant species as indicators of their environment. I have tried to use the empirical information included in the emerged systems of indication, thereby considering that the *OR*-concept possibly requires a different interpretation. In the central European phytosociological tradition the *AND*-concept prescribes that the *syntaxon* to which a stand of vegetation belongs is more indicative than single species. Only *character species* of the syntaxon are held to have a narrow ecological amplitude, almost coinciding with that of the syntaxon as a whole. Compiling a list of various indications per species for the study area, I assigned each species to a preferred 'syntaxon' which I defined wider as it was less specific for quagfen vegetation. As far as species of the synusial groups 3 and 4 are concerned, an interpretation according to the *OR*-concept implies that these species may respond to different micro-environments apparently frequently associated in the particular macro-environment specified for the syntaxon. A corollary of this interpretation holds that such macro-environments favour, or at least tolerate, the development of the different micro-environments. As a result, conflicts arising from the combined application of phytosociological indication and ecological indication are accepted as a possible indication of a heterogeneity of micro-environments within seemingly homogeneous sites. It follows from the distinction of synusial groups that various plants may themselves change the environment, provided that their required settling conditions are met.

Ellenberg (1974, 1978) summarized the indicated nutrient, base, and soil-moisture state for most vascular plant species occurring in Central Europe according to a multidimensional ordinal system. I have been advised that such lists are insufficiently accurate since the classes are wide and the lists do hardly account for the varying widths of ecological amplitudes, and it has been claimed that the situation should be improved by drafting lists of local validity only. I am opposed to these arguments, since I do not believe that our concepts of ecological relations, and the available survey methods, do provide facilities to improve precision without further reducing reliability. I am rather concerned about the fact that, where many species can be scored, the statistical evidence of a multitude of somewhat extremely expressed preferences provides a clearer picture than few precise indications plus many broad or indifferent indications. For this reason I assigned each species, including mosses and hepatics, to an extreme class, keeping the middle category for species that really do not seem to show any specific preference. Care was taken to base this on the pertaining literature and not on my personal and partially local experience, since that would clash with the independent character of the list. Due to the relatively broad concept of the environment in this indicative system, the indication will in some cases apply to the micro-environment, and in other cases to the macro-environment alone. The resulting list is presented in Appendix C.

Next to these entries reflecting the central European tradition, the complex system of Finnish indications of the nutritional relations of mire sites (Eurola *et al.* 1984) was analysed and used in a slightly modified form. It was hoped that this system would enable a separation of micro- and macro-environmental indications, but this could not be realized in account of the limited number of species for which indications are given in the Finnish system and to the problems I met with when applying the definitions to the specific quagfen situation.

Base state and quagfen vegetation

As might be expected from the basis of the original *seepage hypothesis*, a strong correlation appeared to exist between unanimously supposed *seepage indicators* as recognized by Dutch authors and certain phytosociological groups, especially the *Caricion davallianae*. The *seepage indicators* differ from other species by their strong association with indications of a low nutrient and high base state, and a preferential occurrence in terrain depressions (Fig.3.6). More weakly, the Finnish system revealed an association with inherent influences of the local peat type, which I interpret as a greater capacity of the peat to hold and exchange physiologically important elements. The vegetation of *seepage sites* includes several species indicating more acid and more eutrophic conditions, however, and this possibly reflects a micro-environmental heterogeneity promoted by a wet macro-environment with a high base state. This can be understood from the fact that, in the Dutch climate, characterized by an annual precipitation surplus, slightly elevated micro-sites will be prone to acidification unless base-rich water frequently floods them. Under these conditions a seepage of base-rich water promotes site heterogeneity. In the absence of base-rich water even from the lower terrain parts, the area of acidification will ultimately comprise the whole macro-environment. Of course the attribution of species to extreme categories in the indicators system could have led to a separation of ecologically related species, so artificially suggesting *OR*-association where they grow side-by-side. A check with the original Ellenberg indicatory values in relevant cases confirmed real *OR*-association by a range of several units on his scales for the base and nutrient states, however (*cf* Van Wirdum 1986). Apparently most species scored on either side of the middle categories in my system show a distinctly different ecological behaviour.

This analysis thus justifies the choice of the base state as a nodal parameter: there is no other parameter in the accumulated empirical evidence for which especially the *seepage indicators* are so unequivocally sensitive. While I can not claim this as a new idea -the indications were all derived from the pertaining literature- the corollary that supposed *seepage* vegetation in permanently wet quagfens could well rely upon *any* mechanism providing a high base state for a sufficiently long spell, brought some clarity in the myriad of existing 'causal' explanations of the influence of seepage, and it opened a domain of more specific hypotheses, especially those regarding the possible influence of flooding and surface water inflow underneath the *kragge*. This has resulted in the development of some specific methods for field survey and data interpretation, treated in other chapters and in Appendix D.

11.4 The study area

Chapter 4 provides a summary description of the study area North-West Overijssel. It is mainly based on literature and on summarizing publications by others. The mire area was formed on sand infillings in the deeply eroded valley of a Pleistocene melt-water river, the Oer-Vecht. Ter Wee's (1962, 1966) geological study of this valley, in addition to a thorough analysis of the descriptions of geological borings and one additional boring, sufficed to debunk the once, in circles of ecologists, prevailing idea that the mire area of De Weerribben in North-West Overijssel were underlain by an aquiclude at a depth of some 15 m. In fact the underlying strata mainly consist of transmissive sands to a depth of more than 100 m. These results have been confirmed by later borings (Geologische Dienst 1979, Ter Wee pers.comm.). This sand bed could transmit a groundwater flow from the higher morainic area to the East into the mire area if the hydraulic head differences between these areas would allow this.

The development of the original mire, as opposed to the recently terrestrializing turbaries, was described in detail by Veenenbos (1950) and Haans & Hamming (1962). It appears that the distribution of original mire types within the larger area of North-West Overijssel was strongly determined by the courses of a deltaic river system in an undulating plain. The central part of the area was formed by an extensive bog, with some draining streams contributing to river branches flowing through from the Pleistocene area to the east. Interestingly, a type of peat most similar in botanical composition to the recent quagfens was then formed especially in the zones of presumed incidental flooding, thus providing a similarity with the situation as it has been described from Poland (Pałzyński 1984) and East Anglia (Godwin 1978).

Man has strongly interfered with the development of the mire since the early Middle Ages and it is believed that the influence of incursions from the then developing Zuyderzee is interwoven with this historical development. These incursions, and the flooding of the western part of the area introduced brackish influences into the area, which could temporarily increase when the areal extent of open water had grown as a result of peat dredging. A large flood from the then brackish Zuyderzee destroying whole villages in the area occurred in 1825. Many more recent floodings before 1932 (enclosure of the Zuyderzee), and once during war conditions (1944), were possibly primarily due to the ponding up of freshwater at high sea levels.

The recent state of the area is especially tied up with the intensive management by the water authority and with social and demographic developments since the beginning of this century. The reclamation of some large polders in the 1928-1960 period, with a phreatic level maintained at ca 2-4.5 m below the *boezem* water level has been of great importance to the hydrological situation (Fig.4.3). It is more or less by coincidence that such a large area of terrestrializing ponds and broads still existed in a semi-natural state here when the interests of nature protection, environment and landscape were politically recognized.

11.5 Hydrology of De Weerribben

Chapter 5 treats the hydrology of De Weerribben. The main question concerns the possible incidence of discharging groundwater in this area, now and in the past five decades. It appears that no groundwater outflow of any importance is found at present: on the contrary, De Weerribben is an area of considerable groundwater recharge (Fig.5.3). The chemical composition of the underlying body of groundwater is largely determined by infiltrating surface water. This present infiltration of water includes the location of a classical *seepage site*, De Stobbenribben. Here the recharge must even be more substantial due to the proximity of a deep polder reclaimed ca 1955.

Interpretation of water analyses

Next to the measurement of water levels and the hydraulic head according to traditional methods, this part of the study included an extensive use of water composition parameters to trace water flow. Chloride concentrations have often been used as a means to investigate flow. Since influences of sea water, rain water, and groundwater were simultaneously expected to occur in the study area, a simple model for the mixing of groundwater, rain water and sea water was developed. Since three sources of water were concerned, it was necessary to add at least one parameter, which is derived from the base concentrations. The transformation of rainwater into calcareous groundwater is empirically included. The development of the relevant model and the associated computation of water composition parameters is treated and compared with existing graphical and statistical methods in Appendix D. The simplest of these procedures (Fig.D.9) consists of the construction of EC-IR diagrams, where EC is the electrical conductivity at 25 °C, plotted logarithmically, and IR is the 'Ionic Ratio' defined as:

$IR = [{}^{1}/_{2}Ca^{2+}] / \{[{}^{1}/_{2}Ca^{2+}]+[Cl^{-}]\}$ (concentrations in moles of charge per litre).

A very similar procedure appears to have been developed earlier by Gibbs (1970) in order to understand river water compositions at a global scale. Before returning to the application in North-West Overijssel, it suffices here to recall some terms introduced in the present study:

lithotrophic water: a calcium-bicarbonate type of water, usually owing its characteristic composition to a contact with soil;
atmotrophic water: a type of water with low concentrations of most constituents, usually owing its characteristic composition to atmospheric precipitation;
thalassotrophic water: a saline sodium-chloride type of water as found in the oceans;
molunotrophic water: polluted water as presently found in the Rhine.

Waters forming a series between two of these types, or a wide cluster obviously derived from one type are denoted as *clines, e.g.,* an *atmo-lithocline,* a *molunocline,* a *litho-thalassocline*.
Benchmark samples for the mentioned water types are given in Appendix D. They can be plotted in the diagrams, together with curves describing their mixing ratios (Figs.D.9, D.12).

Groundwater

In 1937 water was sampled at 10-15 and 20-30 m below the soil surface in a transect of 5 sets of piezometers from the morainic area through De Weerribben to the former Zuyderzee. The analyses reveal an atmo-lithocline and a litho-thalassocline, respectively (Fig.5.5). Interestingly the records of the groundwater composition in the central part of De Weerribben show slightly brackish influences at 12 and 16 m below the mire surface, but not at the depth of 29 m (Fig.5.4). Any upward flow of groundwater before the reclamation of the deep Noordoost-Polder in 1941 had apparently not annihilated these traces of brackish influence. Differences between the surface water level and the hydraulic head in deeper layers were very small in 1936-'40 and varying conditions may have caused some local recharge or discharge. When discharging in the surface water system calcite should precipitate from the groundwater found in the mire area in 1937. An indirect clue for the absence of any substantial exfiltration of this water therefore comes from the absence of calcareous deposits. This result was somewhat surprising, since it was expected that lithotrophic water, either originating from groundwater discharge, or from an inflow of fresh surface water from the morainic area, had been the predominant type in the mire basin in the beginning of the 20th century. In the pertaining Dutch literature, *seepage indicators* are usually assumed to avoid even slight thalassotrophic influences.

The reclamation of various polders caused a dramatic fall of the hydraulic head in the body of groundwater, resulting in a conspicuous infiltration of molunotrophic surface water to a considerable depth. In 1980 an aged lithotrophic type of groundwater was only found at one location at a depth of 50 m below the mire surface. An isotope analysis suggests that this water infiltrated during the growth phase of the virgin mire, in the Subboreal period. Local pockets of very slightly brackish groundwater were still found at a depth of 10-30 m. The raised chloride contents (169-540 mg/l, compared to 18-74 mg/l in lithotrophic and molunotrophic samples) may be due to flooding with brackish water in various periods. One sample, originating from a depth of 29 m, was analysed for tritium and ^{14}C, and its possible age accordingly estimated at 2000 years. The slightly brackish pockets of groundwater are considered remains of a more extensive body of such water now largely washed away by the strong infiltration of surface water. On the whole, the chemical variation among samples analysed in the 1980s is substantially smaller than that among the 1937 samples.

High tritium contents in most recent groundwater samples and a consideration of hydraulic head gradients led to an estimation of the rate of exchange between the body of groundwater and the overlying mire area, and of the corresponding upward and downward movement of groundwater for three periods, assuming a porosity of 30% in the sand bed:

1889-1920 exfiltration 0.2 mm/d; upward movement 6 m in 30 years;
1920-1941 exfiltration 0.3 mm/d; upward movement 6 m in 20 years;
1941-1980 infiltration >1 mm/d; downward movement >45 m in 40 years.

These very rough estimates show that the earlier influence of slightly brackish water may indeed have long persisted before the deep polders were reclaimed. The reclamation of deep polders had a large impact on the groundwater flow system. The groundwater survey does not support the *a priori* attribution of a lithotrophic character to the mire area at present or in the past, but it anyhow emphasizes a substantial presence of bases: no traces of atmotrophic groundwater were found underneath the mire area.

Surface water

The surface water in the main canals in the mire area was repeatedly sampled and analysed between 1972 and 1982. A reasonably large number of analyses covering the 1960-'72 period, and the ongoing monitoring program of the water quality authority *Zuiveringschap West-Overijssel* enabled an analysis of the surface water composition over a period of more than 25 years.

A lithotrophic character of the surface water was obvious in the 1960-'70 samples. This is attributed to the influence of an inflow of surface water from ditches, canals, and former rivulets draining the morainic area. At some isolated places Leentvaar (1960) found raised chloride concentrations, and there is some evidence that these were more abundant before 1960. After 1972 the influence of the controlled supply of polluted surface water from the adjacent Frisian area has become a dominant feature (Fig.5.14). The lithotrophic type of water is now solely associated with the inflow of water from the Steenwijk-Ossenzijl canal, which serves as a catchwater for the discharge from the morainic area. The lithotrophic character of the water entering the mire basin from the morainic area is obviously not associated with the infiltrating groundwater in the elevated parts of this area, since that appeared to be of an atmotrophic type in 1937, and it is presently polluted-atmotrophic.

A statistical analysis of time series at various places in the canals network within De Weerribben revealed different spheres of influence of the various sources of water (Fig.5.13). It appeared that variations in the operation of surface water supply and discharge facilities are of paramount importance to the distribution of these influences within the mire area. A precise explanation was not possible, however, due to the complex and changing nature of the canals network, to wind-generated circular currents, and to interactions with the mire in the meshes of the canals network.

The changing eco-hydrological state

The long-term variations of surface water composition stress the shortcomings of a spatial comparison on the basis of data that cover only a couple of years. During the development of the present quagfen vegetation a hydrologically steady environment, if any, was probably never present for longer than some ten or twenty years. ‘Base-rich’ seems to apply, but that in itself is not a feature unique enough to explain the predisposition of this area for the development of *seepage sites.*

A comparison between a ‘new’ and an ‘old’ steady state is not realistic either. Yet, the decreased availability of unpolluted lithotrophic water in the surface water system since about 1970 must be considered a significant change which became dramatically evident by an increased water supply during the extreme droughts of 1975-'76 (Fig.5.15). Due to subsequent changes in the execution of water management and to more favourable weather conditions the 1980s have brought a gradual return of lithotrophic, low-chloride surface water. Recent observations in De Weerribben (1989) have shown that aquatic macrophytes, such as *Stratiotes aloides* and species of *Potamogeton,* once considered to have disappeared, also returned.

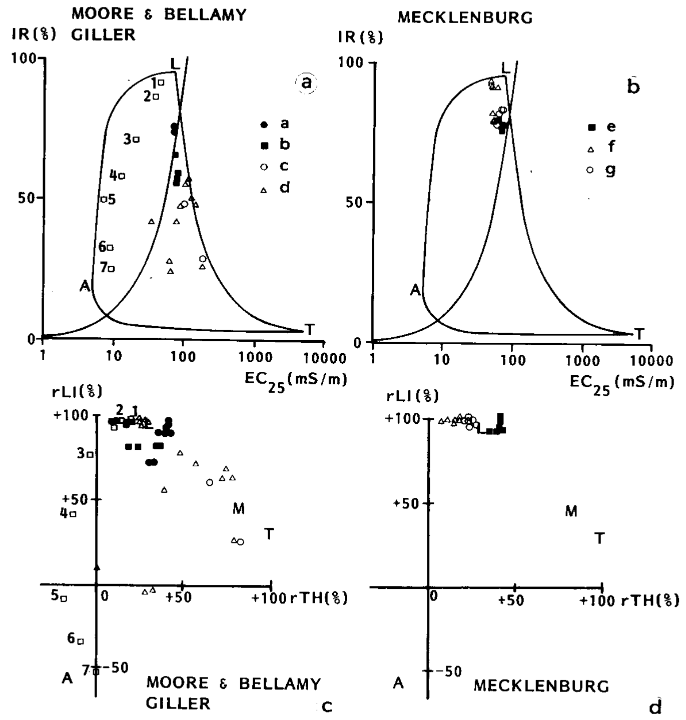


Fig.11.1 EC-IR (a,b) and rTH-rLI (c,d) diagrams demonstrating a natural range of mire water composition

Diagrams a, c: Mire types according to Moore & Bellamy (1973), ranging from extreme rich-fen (1) to bog (7), and analyses pertaining to the Norfolk Broads (Giller 1982): a rivers and broads; b *Peucedano-Phragmitetum caricetosum* with *seepage indicators*; c *Peucedano-Phragmitetum schoenetosum* with salt indicators; d other sites;

Diagrams b, d: Mire sites in Mecklenburg (Succow *et al.* unpublished): e rivers, ditches; f *Drepanoclado-Caricetum diandrae-lasiocarpae* with *seepage indicators*; g other sites.

L,A,T,M: Litho-, atmo-, thalasso-, and molunotrophic benchmark samples (Appendix D); mixing between these samples is indicated with contours in the EC-IR diagrams

It remains to be demonstrated whether the vegetation reported for the 1930-'60 period was also determined by a decrease of brackish influences to be replaced by an inflow of lithotrophic surface water. At this point it is of some interest to review the international literature for a comparison of the water composition at sites of *seepage indicators*. Various such analyses have been collected in Fig.11.1. Although the general pattern seems to confirm that (extreme) rich fen sites, the preferential habitat for *seepage indicators*, are at the lithotrophic side of a litho-atmocline (Fig.11.1a,c), data from the Norfolk Broads (Giller 1982, Giller & Wheeler 1986, see Fig.11.1a,c) demonstrate a thalasso-lithocline. According to Giller the sites involved probably do not receive discharging groundwater, but they have been influenced by flooding with brackish water in the past, and the underlying clays and peats are obviously brackish. Giller suggests that the sites are influenced by a diffusion of salts from these clays into the overlying mire. Unpublished data from sites near the Baltic in Mecklenburg (Eastern Germany), collected by the author and some colleagues under the guidance of M.Succow and L.Jeschke also show slight thalassotrophic influences (Fig.11.1b,d).

A more detailed analysis of data reported for other Dutch mire areas (Van Wirdum 1987, Van Wirdum *et al.* in prep.) has revealed that *seepage indicators* have been recorded in the Nieuwkoopse Plassen area and in mires in the province of North-Holland. Presently these areas exhibit a stage of acidification not yet reached in the greater part of the classic *seepage areas* North-West Overijssel and Vechtplassen. There is no doubt that thalasso-lithotrophic gradients existed and partially still exist in these mire areas, but a clear relation with the quagfen vegetation discussed here has not been assessed. The point will be reconsidered in Section 11.11.

11.6 The distribution of *seepage* indicators in De Weerribben

Chapter 6 treats the distribution of the *seepage indicators* in De Weerribben in order to ascertain whether this coincides with a supposed *seepage area,* or with any area possibly distinct for its base state. As indicated in Table 11.1, eight *seepage indicators* are relatively abundant in De Weerribben, and until now no distinct distributional pattern has been assessed for them. It has appeared that these species prefer a distinct hydro-environmental zone within the quagfen parcels where they occur, however: they are usually absent from zones immediately bordering ditches and canals, and also from obviously atmotrophic zones at a greater distance from the surface water channels. For eight other species the distributional information is not considered since these species are rare, possibly absent, or easily overlooked. The five remaining *seepage indicators* appear to have a distinct distributional pattern within De Weerribben as a whole. They more-over show the same preference for an ‘intermediate’ hydro-environmental zone as reported for the eight abundant indicators. It is usually believed that their absence near the surface water channels is due to too high a nutrient state at such places.

The distribution of the five *seepage indicators* with a distinct distributional pattern in the whole area includes recently occupied sites and has no correlation with any predisposition for groundwater discharge in the last five decades. The occurrence of *Menyanthes trifoliata, Utricularia intermedia*, and *Parnassia palustris* is almost restricted to the inundation zone of a disappeared rivulet. The local presence of old *Carex, Phragmites,* and *Alnus* peats and scattered clay deposits indeed suggests a relatively high base state and certain other favourable factors associated with the former land use. All five are almost absent from the central part of De Weerribben, where the old peat remains consist of bog peat and clay was never deposited.

At present, *Liparis loeselii* and *Scorpidium scorpioides* are fairly common in the south-western part of De Weerribben (Schut- en Grafkampen). A comparison of the data about the distribution of *Scorpidium scorpioides* between 1969 and 1985, and the supposed *seepage area* indicated by Kuiper & Kuiper (1958) suggests that this species has only recently expanded over that part of the area, while it is decreasing in the north-eastern part of the nature reserve. It appears that *Scirpus maritimus, S. lacustris tabernaemontani*, *Ophioglossum vulgatum,* and *Hippuris vulgaris,* all indicating possibly brackish influences, have decreased in the same area over which *Scorpidium* is presently expanding. *Liparis loeselii* was already present in that area in 1967. The expansion area also coincides with a dominance of *Salix cf. S.cinerea* in carr vegetation. In the decrease area *Alnus glutinosa* dominates in carr vegetation, and in the former bog peat area, where *seepage indicators* are anyway rare, *Betula pubescens* does so. Although this relation cannot be quantitatively confirmed with the available data, the following hypothesis is raised:

Until ca 1940 *Scorpidium scorpioides* was probably restricted to the freshwater *Carex* peat area almost coinciding with the *supposed seepage area* indicated by Kuiper & Kuiper (1958), and representing the lithotrophic end of an atmo-lithocline developed in the old mire landscape. The Schut- en Grafkampen area was probably still slightly brackish then, and in too early a stage of succession for the *seepage indicators* to settle. The peat in this area was saturated with bases, however, due to the brackish water. The central bog area had too low a base state for most of these species. Between 1920 and 1955 the improvement of the water control in the area by the installation of a large discharge pumping station, the enclosure of the former Zuyderzee, and the reclamation of several deep polders led to an increased influence of lithotrophic water rich in bases in the whole mire area, and so facilitated an expansion of the *seepage indicators*, especially *Liparis loeselii*, over those parts of the area where the stage of succession was suitable and where a high exchange capacity of the soil ‘buffered’ the local base state. In the 1973-'78 period the expansion was temporarily stopped by a dramatically increased influx of molunotrophic water. This influx was caused by a particular strategy to operate the inlet and discharge stations of the mire area and by the extreme drought of 1975-'76. Since 1978 the water quality became more lithotrophic again, and the increased interest in nature protection resulted in an increase of the area of reeds mown in summer and autumn. These factors restarted the expansion of *seepage indicators*, and the conditions apparently now became favourable for *Scorpidium scorpioides* also. *Utricularia intermedia* and *Parnassia palustris* possibly follow in this line, but the presently available data are not convincing. Their physiological and regenerative capacities possibly require that the above-mentioned influences have continued for a longer spell of time, as is suggested by the common, but not very revealing, notions that they require relatively ‘mature’ sites or, according to the Finnish indicatory system, sites with a distinct ‘inherent nutrient supply’. This hypothesis leads to a preliminary ranking of species as regards their capability of quickly invading a ‘new’ quagfen site, which can be put to the test by future observations. The retreat of *seepage indicators* from the north-eastern part of the area is explained by the fact that vegetation management is only partially continued here, and that natural succession and a strongly decreased ditch management have led to a strong atmotrophication of some traditional quagfen sites.

If the surface water composition plays such an important rôle in preparing the site quality for the settlement of *seepage indicators*, it is expected that certain aquatic macrophytes also respond to it. Indeed the distributional behaviour of *Stratiotes aloides* between ca 1940 and 1989 seems to support the hypothesis. This species formed increasingly dense stands until it almost disappeared from De Weerribben in the early 1970s. A slow come-back since ca 1978 has been noticed to accelerate in the mid-1980s, and in 1989 several extensive and healthy stands could be found.

The hydrological investigation and the study of the distribution of *seepage indicators* in De Weerribben seem sufficient to reject the original *seepage hypothesis of quagfens* as far as an artesian discharge of groundwater is considered a prerequisite condition. Although they contribute to some specification along the lines of the revised hypothesis (Section 11.2), the conditions indicated are broader than was expected.

11.7 The quagfens of De Stobbenribben and their vegetation

Chapters 7-10 of this thesis deal with a case study in De Stobbenribben, one of the few complexes of quagfen mentioned as a representative site by the authors of the *seepage theory*. De Stobbenribben was chosen for this survey for still another reason: the quagfen parcels are isolated from the surface water system at three sides, only one narrow end providing an open connexion with a ditch. This topography provides an excellent opportunity to observe a linear gradient as a result of a possible lateral inflow of water from the ditch (Fig.7.2).

The cover of vegetation indeed exhibits a linear gradient. Somewhat arbitrarily, four main types of vegetation can be distinguished in hydro-environmental zones in De Stobbenribben (Fig.7.4):

A: *Calliergonella-Phragmites* reed near the ditch;
B: *Scorpidium-Carex* fen in the central part of the parcels;
C: *Sphagnum-Carex* fen between the central parts and the far ends;
D: *Calamagrostis canescens* litter-fen at the far ends.

They can be characterized according to the indicatory information in the species list (Chapter 3, Appendix C). *Seepage indicators* are especially abundant in the zones B and C between the more swampy and eutrophic ditch side and the litter-fen at the opposite side of the quagfen parcels. Zone B is dominated by amblystegiaceous mosses and zone C by *Sphagnum* species in the bryophyte layer. Zone C can thus be considered a successional stage due to the increased influence of peat accumulation, rain water, and acidification. The micro-sites unique to zones B and C are indicated as litho- and atmotrophic, respectively, and oligotrophic in both (Fig.7.6).

The length gradient in the cover of vegetation of De Stobbenribben was rather stable in the 1950-'90 period, although some remarkable changes were recorded in the *Scorpidium-Carex* zone B. Following more frequent mowing an extensive bed of *Cladium mariscus* in one of the parcels changed into a more typical representative of zone B vegetation. In another parcel (parcel A investigated in considerable detail in Chapters 9 and 10) a similar change involved a bed of *Typha angustifolia* and *Scorpidium scorpioides*, but this change, started between 1975 and 1979, continued to the effect that *Juncus subnodulosus* and hummock synusiae with *Sphagnum subnitens* and *S.flexuosum* had become abundant in 1983-'84, thus indicating a relatively fast transition towards the zone C type.

Mowing prevents a formation of alder and sallow carr in De Stobbenribben. At some relatively dry fen sites ericaceous dwarfshrub vegetation with a moss cover of *Sphagnum* and *Polytrichum* species and many birch seedlings has developed.

11.8 Peat temperature and the estimation of vertical water flow

Although the information reported in Chapter 5 was quite decisive as regards the absence of any groundwater discharge into the Stobbenribben quagfens, the rate of vertical water flow still remained to be assessed. A precise observation of hydraulic heads in the sand bed underlying the Stobbenribben quagfens was hampered by difficulties associated with the installation of piezometers in this sand bed, the top of which lies some 3-4 m below the quagfen surface. S. Segal (pers.comm.) had observed differences in the temperature regimes between supposed *seepage* pools and non-seepage pools, and so suggested that *seepage* could be quantified by temperature measurements relevant to heat transport, and, simultaneously, that the temperature regime could be a decisive ecological factor for *seepage indicators*. A method was designed to effectuate temperature measurements and their interpretation, and to describe the temperature regime in the quagfens.

It appeared that daily fluctuations of the temperature at shallow depths can not be held to be very informative if the flow rate is less than some centimetres per day, as it is in De Stobbenribben. An analysis of the annual temperature regime at depths below 0.4 m yielded useful results, however. Two schemes were used for a quantitative interpretation, one of which was based on Stallman (1965). They gave similar results in De Stobbenribben which could not be rejected by reference to results of any other method and which were in accordance with hydro-geological considerations (Table 8.6). In both methods it is assumed that no lateral heat transport of any significance is present. This assumption is obviously violated at the observed flow rates (up to 10 mm/d), since the water loss is compensated by a lateral influx of water from the ditch at one end of the parcels. No accurate estimation of this disturbing effect could as yet be made. Since the inflow must be most important in the very transmissive layer underneath the *kragge*, as confirmed by an inspection of depth gradients in the temperature, it can be suppressed by omitting values obtained in that layer, at the cost of some statistical accuracy. In my implementation of the Stallman method I used a Fourier analysis so as to single out the effects of non-annual temperature fluctuations. This probably also suppresses the effects of lateral flow. All results indicate a downward seepage in the order of magnitude of some mm/d, but the spatial variety was considerable.

The measuring method designed has appeared suitable for reconnaissance in various other mire areas. The more detailed interpretation with the heat transportation models requires very precise and, preferably, repeated measurements throughout a full year. Accordingly, that application is attractive in more detailed investigations rather than in reconnaissance surveys.

The measurements and the heat transport models enabled an estimation of the duration of temperatures in excess of some threshold value in the *kragge*. Surprisingly large differences appeared to exist and demand future observations concerning the phenology of plant species in the vegetational gradient (Fig.8.7). It should be emphasized, however, that, other factors being the same, the actual temperature regime is determined by a combination of hydrological factors and the structure of the local vegetation itself.

11.9 Lateral flow in longitudinal transects in De Stobbenribben

The study of the temperature and the heat transport in the Stobbenribben quagfens resulted in a preliminary quantification of the vertical water exchange between the body of mire water and the underlying sand bed. According to this quantification a considerable influx of ditch water is necessary in order to compensate for water losses. In Chapter 9 the resulting longitudinal gradient in the mire water composition and temperature is investigated in detail. Hydraulic head differences in the horizontal direction were accurately measured with a water manometer. Sounding rods with sensors for the temperature and the electrical conductivity were used to assess the gradient and its changes through the seasons. The associated water composition was determined with analyses of water samples taken at a selection of sites, depths, and dates, and the similarity to litho-, atmo-, and thalassotrophic water was used as a basis for the ordination of water samples. This method proved to be very useful for the survey of mires in general and it was also applied elsewhere. The surprising vertical and horizontal differences found in the present project (*cf.* Van Wirdum 1972, 1973, 1982, 1984) appear to be key features of many Dutch mires (see, among others, Grootjans 1985, Wassen *et al.* 1989, Koerselman *et al.* 1990), and ongoing work in mires elsewhere seems to confirm a wider applicability (see also Giller 1982, Giller & Wheeler 1986).

In De Stobbenribben a clear longitudinal gradient was demonstrated to exist (Fig.9.4). This could be attributed to a different macro-ionic composition of the mire water rather than to differences in the contents of nutrients. The gradient in the water composition can be described as a gradient from litho-molunotrophic water in the ditch to atmotrophic water at a greater distance, especially in the uppermost layer of the *kragge* (Fig.9.10). The discharge of mire water towards the underlying body of groundwater in De Stobbenribben gives rise to the establishment of a 0.001-0.002 hydraulic head gradient during the summer. Even in winter an inversion of the hydraulic head gradient seldom continues for more than a few days. Ditch water penetrates the quagfen through a preferential flow channel underneath the *kragge* and it exerts an obvious influence upon the chemical composition of the water in the *kragge* even at a distance of more than 100 m from the ditch. At the closed end of the quagfen parcels the influence of rain water is predominant. The middle part of the longitudinal gradient displays strong fluctuations.

As regards De Stobbenribben this definitely proves that there exists a considerable downward seepage from the mire into the underlying sandbed, and that this discharge generates an inflow of base-rich ditch water. This inflow fades away in the closed ends of the quagfen parcels, where *seepage indicators* become far less abundant in the cover of vegetation. It is not yet clear what prevents the *seepage indicators* from occurring in the *Calliergonella-Phragmites* vegetation near the ditch, although the vigorous stand suggests that this may be due to an additional nutrient effect.

A general conclusion is that the layered and anisotropic nature of quagfen complexes as porous media is fundamental to the understanding of the inflow of water.

11.10 Environmental and vegetational processes in De Stobbenribben

In Chapter 10 some elements are presented for the construction of a mechanistic model for the understanding of the inflow of ditch water and its impact on the salinity and the base state in the quagfen and the nutrient budget available to the vegetation.

First, the estimated flow rates in De Stobbenribben are checked and found in accordance with the hydraulic conductivity in the preferential flow channel, ca 800 m/d. Near the ditch the hydraulic conductivity is only half as large, probably due to the deposition of ditch dredge, a more vigorous growth of plant roots, and a possible blocking of pores with micro-organisms and peaty material. This check yields a justification for the range of the rate of downward discharge of water from the quagfen found earlier. Precipitation and evapo-transpiration are estimated from standard weather data and from an investigation with lysimeters (reported in Appendix E), respectively.

The QUAGSOLVE model

A balance model QUAGSOLVE is constructed for the distribution of chloride in the quagfen. This is a steady-state model. State transitions were not programmed for lack of suitable data concerning the process kinetics. As regards the longitudinal relations in the flow channel this is not regarded an important shortcoming. The vertical distribution of chloride ions between the *kragge* and the underlying flow channel, however, appears to depend also on short-term water exchange. The model provides for this by an exchange term. In excess of the precipitation surplus, a downward flow **T** of water with the ambient chloride concentration in the *kragge* balances an equal upward flow with the ambient concentration in the flow channel. In reality, **T** is influenced by other factors too. A large value of **T** signifies that the *kragge* functions as an integral part of the main flow channel. The model is calibrated with observed chloride concentrations. An essential element is the fact that a boundary condition can be derived from the situation in the 'dead' end of the quagfen, which is not reached by the inflow of ditch water. A fair simulation of the conditions observed in 1980-'84 is obtained with a downward seepage of 2 m/a (Fig.10.3), which corresponds surprisingly well with the results of heat transfer calculations. The distinctly lower concentrations of chloride in the *kragge* can be explained by assuming different exchange values T. Near the ditch this value is ca 1-1.2 m/a, decreasing to 0.6, 0.15 and 0.05 at distances of 55, 135, and 170 m from the ditch, respectively. This exchange is caused by various processes, including the asynchronous incidence of evapo-transpiration and precipitation, and a forced exchange due to pressures exerted on the *kragge* during mowing and other incidences of access. The high values of **T** suggest the inclusion of lateral exchange and, near the ditch, flooding. It seems that the quantitative effect of these factors on **T** depends on such parameters as pool density, *kragge* weakness, and, if present, the extent of a *Sphagnum* cover.

The distribution of most other constituents depends not only on the processes simulated in the QUAGSOLVE model, but also on uptake and release processes intermediated by vegetational and microbiological processes, and on an exchange with the peaty matrix. The effect of such processes is assessed by comparing a faked QUAGSOLVE result with results of water analyses. Since QUAGSOLVE essentially relies on the mixing of rain water and ditch water, a faked QUAGSOLVE result is obtained by calculating the amounts of ditch water and rain water needed to produce a mixture with the actual chloride concentration found in each sample, and accordingly calculating an estimated concentration for the other constituents. Means of 21 bi-monthly analyses in the 1980-'83 period were used for the comparison. Significant differences were especially large for calcium (Table 10.5), which can be explained by the known, large exchange capacity of fen peats for bases. Apparently the inflow of ditch water increases the base state of the quagfen.

Concentrations of phosphorus and potassium in the quagfen do not differ significantly from those found in the ditch water. The variation of their concentrations in atmospheric deposition hampers an attribution of gains or losses of these constituents to any processes within the quagfen. The total stocks in the peat and the stand of vegetation are large, but locally mobilization and diffusion rates may limit the availability of these elements to vigorously growing vegetation. If the greater productivity of the *Calliergonella-Phragmites* vegetation near the ditch is to be attributed to a greater availability of phosphorus and potassium, then this must be due to occasional floodings.

Inorganic nitrogen concentrations are decidedly lower underneath the *kragge* than in the ditch. Within the flow channel, however, any significant loss appears to be restricted to the zone bordering the ditch. This might be due to an uptake by the vegetation at a 1.5-2.5 g/m^2 per year rate from the inflowing water, so that it is possible that the nitrogen content of the surface water, in combination with the high flow rate, supports an environment suitable for tall helophytes and swamp species but not for *Scorpidium-Carex* fen.

The nutrient balance

With the data now available a balance can be drafted for phosphorus, potassium, and nitrogen, and this can be compared to similar balances drafted for quagfens in another Dutch mire area by Koerselman (1989). In addition, the amounts sequestered in the vegetation are estimated

Table 11.2 The nutrient balance of quagfens (kg per ha per year)

	Stobbenribben						Westbroek						Molenpolder					
	N		P		K		N		P		K		N		P		K	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Precipitation																		
Wet	25	-	0.3	-	10	-	24	-	0.7	-	6	-	26	-	0.6	-	6	-
Dry	(20)	-	-	-	-	-	18	-	-	-	-	-	18	-	-	-	-	-
Fixation	(20)	-	-	-	-	-	13	-	-	-	-	-	2	-	-	-	-	-
Surface water	11	0	0.4	0.0	62	0	1	21	0.1	0.7	4	13	7	9	0.5	1.0	19	22
Groundwater	0	8	0.0	1.3	0	74	20	0	0.5	0.0	6	0	0	1	-	0.1	-	2
Harvest	-	57	-	3.2	-	54	-	66	-	5.6	-	44	-	38	-	3.9	-	32
Sum total	76	65	0.7	4.5	72	128	76	88	1.3	6.3	16	58	53	49	1.1	5.0	25	56
Mineralization	115	-	5.2	-	-	-	67	-	3.4	-	-	-	315	-	43.8	-	-	-

(Westbroek and Molenpolder: from Koerselman *et al.* in press)

on the basis of biomass assessments, and the release of nutrients in the *kragge* was determined (Verhoeven *et al.* 1988). The comparison is made in Table 11.2. It appears that the external inputs of nitrogen are roughly sufficient in all cases to support the production of biomass, but phosphorus and potassium are probably released from the quagfen and discharged at harvest time, provided that surface inputs have not been largely underestimated.

Mineralization has been included in the table for the sake of completeness. The error is probably large, however, since in all cases it is measured at a depth of 20 cm during the growing season and generalized for the upper 0.4 m of the *kragge* (Verhoeven & Arts 1987, Verhoeven *et al.* 1988). However, on the whole-quagfen scale the amounts of P, K, and N released in the *kragge* seem to be in excess of those incorporated in above-ground vegetation. According to data in Ellenberg (1978), Dykyjová & Květ (1978), and Van der Linden (1980, 1986) *Phragmites australis* returns significant amounts of the nutrient stock into the root system from July-August onwards. This probably also holds for the other helophytes in quagfen vegetation. Apparently the date of mowing is very important here as regards the nutrient economy of the quagfen as a whole, and it may significantly favour or disfavour the growth of singular plant species.

A comparison of the contents of phosphorus, nitrogen, and potassium in the plant biomass to standard data summarized by Kinzel (1982) reveals that these elements are represented in smaller amounts in De Stobbenribben in all vegetational zones sampled (Table 11.3). This possibly indicates a limiting availability of these elements in critical growth periods. According to data reported by Kooijman (1985), *Phragmites australis* and *Carex elata* show a decreasing relative content of potassium in the *Calliergonella-Phragmites* reed during the growing season. Her data also suggest lower potassium concentrations in more superficially rooting species in the *Scorpidium-Carex* and *Sphagnum-Carex* fen zones, possibly indicating a lower availability of these ions near the *kragge* surface. Obviously any further work in this direction should include a study of the different layers of the *kragge* in relation to the development of the root systems of various species. Moreover, the choice of potassium, nitrogen, and phosphorus, prompted by nutritional economy models of plant growth, should be extended with estimations of the

Table 11.3 Concentrations of some elements in plant tissues

	% dry weight				
	K	**Ca**	**Mg**	**N**	**P**
Dicotyledoneous herbs	3.8-3.9	1.3-1.6	0.31-0.38	2.8-3.1	0.25-0.31
Cyperaceae and Juncaceae	2.7-3.0	0.3-0.5	0.13-0.20	1.6-2.1	0.19-0.25
De Stobbenribben mosses	0.4-1.0			0.7-1.8	0.01-0.09
vascular plants	0.9-3.1			0.6-2.4	0.03-0.20

According to Duvigneaud & Denaeyer-De Smet and Höhne (cited from Kinzel 1982) and found in De Stobbenribben (Kooijman 1985)

quantities of metal cations in order to investigate the relation between the base state of the quagfen and the spontaneous presence or absence of species in more detail, possibly by some physiological effect upon nutritional economy. The present investigations were not aimed at a detection of the physical and chemical aspects of the regulation of the availability of phosphorus as a plant nutrient. The attention paid to the ionic ratio was inspired, however, on the hypothesis that the cationic composition of the mire water, by governing the exchange of cations with the binding sites on the soil complex, has relevance to the capacity of the organic soil to hold phosphorus. While I have not contributed any further data about these matters, Kemmers (pers.comm., Van Wirdum & Kemmers 1990) recently found statistical indications of such relations.

All in all the results of this analysis suggest that the water management is probably especially important as regards the supply of nitrogen in a relatively narrow zone with eutrophic swamp vegetation bordering the ditch, and as regards the maintenance of a high base state in the quagfen. The latter possibly has an influence on the local processes governing the (im)mobilization and uptake of nutrients and on the selection of species that may settle. A lowering of the base state (atmotrophication) soon leads to an extension of *Sphagnum* vegetation at the cost of *seepage indicators*. Stands of quagfen vegetation with *seepage indicators* so appear to be restricted to a zone or stage ‘sandwiched’ in-between atmotrophic and nutrient-rich ones, respectively. Harvesting of the vegetation plays its rôle in the suppression of otherwise dominant helophytes and invading shrubs, and in the overall nutrient budget of the quagfen. The importance of the latter to the vegetation cannot be demonstrated, however, as long as no quantification is available of the effect of the harvesting operation on the release of nutrients that would otherwise have remained in living plant tissues.

Non-steadiness of the environment

Analyses of water samples from De Stobbenribben in the 1960-'84 period suggest a gradual decrease of the salinity and calcium content of the water. Occasional samples also present indications of a local exchange of calcium from the water for magnesium adsorbed at the peat matrix in the deeper parts of the quagfen body. It is, therefore, possible that the hypothesis of a gradual replacement of slightly thalassotrophic influences for lithotrophic ones also applies to De Stobbenribben. Presently an atmotrophication seems to be ongoing.

Next to the studies in De Stobbenribben also some other, less detailed case studies of shorter duration were carried out in this investigation (Raeymaekers 1978), but not yet reported in full here. It appeared that the areas involved (De Provincie, Het Maatje, and De Vlakte, in the neighbouring mire reserve De Wieden) are subject to similar hydrological influences as De Stobbenribben. An inflow of water from surface water channels penetrates the quagfens underneath the *kragge* up to a point were the influence of rain water becomes dominant. The same has been found for De Wobberibben (Ruitenberg, unpublished data, Calis & Van Wetten 1983), a complex of quagfens close to De Stobbenribben. These complexes constitute the majority of classic *seepage sites* in North-West Overijssel. An atmotrophication that has led to a changed cover of vegetation is well documented for De Wobberibben, where extensive carpets of *Scorpidium* have been replaced by *Sphagnum* vegetation. The atmotrophication in De Wobberibben can be attributed to ditches becoming clogged, this reducing the access of base-rich water to the quagfen parcels. Similar phenomena have also been observed in the other investigated quagfen complexes, and they have recently been documented for the complex De Bollemaat in De Wieden (Molenaar *et al.* 1990). The eco-hydrological system described for De Stobbenribben is, therefore, held to be representative for *seepage sites* in North-West Overijssel.

11.11 Management and the rich-fen environment in zoned mires

Clearly, the water composition in the larger mire area, as dictated by the water management, weather conditions, and the availability of resources for water supply, has an appreciable effect upon the quagfens by providing regulating conditions for their base state. Although the present investigation has not yielded any definitive conclusion as regards what determines the unique environment required by *seepage indicators*, it has appeared that the old hypothesis must be rejected.

Support is provided for the specification of an alternative hypothesis. In North-West Overijssel water management, and especially water quality control, may be of primary importance maintaining quagfen environment. As stated before this type of environment is not unique to quagfen: quagfens just provide favourable conditions for the establishment of an extreme rich-fen environment. While such an environment may be due elsewhere to discharging lithotrophic groundwater it is also generated in landscape zones where atmotrophic and lithotrophic water interact laterally, as in De Stobbenribben. Van Wirdum (1979) presents a qualitative scheme of such a zoned mire landscape (Fig.11.2) according to the botanical composition of old peats in North-West Overijssel reported by Veenenbos (1950). He explains that the natural tendency of atmotrophication at hummock sites is balanced by base-rich water in hollows in a zone intermediate between bog and areas that are occasionally entirely flooded by base-rich water.

In our climate, and at the present state of eutrophication of the environment the flooded areas are usually eutrophic and unsuitable for typical *seepage fen* vegetation. The analysis of water composition in the intermediate zone (the *poikilotrophic* zone, Van Wirdum 1979) reveals a similarity to water mixtures comprising a relatively large volume of atmotrophic, and a smaller amount of lithotrophic water. The present study indicates that a very small amount of thalassotrophic water may also contribute to the establishment of typical *seepage mire* environments. Since atmotrophic and thalassotrophic water are widely available in The Netherlands the maintenance of this species-rich mire zone is only possible if lithotrophic influences can be guaranteed. In our climate this leads to site heterogeneity in a litho- atmocline and to OR-association of species.

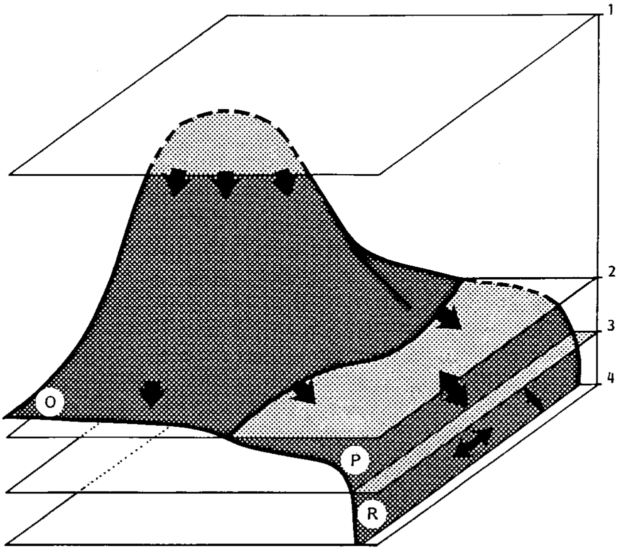


Fig.11.2 Water composition (vertical) in a zoned mire (horizontal)
1 Atmotrophic water; 1-2 Atmotrophic zone (ombrotrophic mire, O); 2 Ca 80% rain water, admixed with 20% groundwater (lithotrophic); 2-3 Poikilotrophic zone (P); 3 Ca 40% groundwater, admixed with rain water; 3-4 Flooding or seepage zone (rheo-eutrophic, R); 4 100% groundwater
From Van Wirdum (1979)

A similar zonation appears to exist in grasslands, where the central atmotrophic area is represented by heathlands (Van Wirdum 1981).

Where the underlying strata are relatively impermeable to water, as in Nieuwkoopse Plassen and in various mires in the province of North-Holland, the inflow of lithotrophic water underneath the *kragge* is insufficient to maintain the rich-fen environment in the long run. In North-Holland and in Norfolk (see Section 11.5) a resident body of brackish mire water may prevent a deep atmotrophication.

In quagfens the deep-rooting *kragge* synusia usually become dominant if this is not prevented by grazing or mowing. Natural succession therefore leads to carr and, ultimately, bog vegetation, with the exception of small patches grazed by the natural fauna. This probably also applies to non-quaking fens at our latitude. Human influences so extend the influence of the natural fauna in establishing and maintaining a type of environment otherwise limited in occurrence to more northern areas and, in The Netherlands, to earlier geologic periods. It is a matter of policy to what extent the fundamental ecological variety should be maintained, so as to allow for biological variety, and to what extent vegetation management should replace former faunal and agricultural activities, so as to maximize the actual biological variety in selected nature reserves. The present abundance of species threatened elsewhere indicates the potential success of such measures.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX A

Explanation of some specific terms

A.1 Specific terms related to the mire type concerned

The present study concerns a well defined type of *mire*, called *trilveen* in Dutch. Even this word *trilveen* has different local meanings in The Netherlands and the translations found in English writings may be confusing. I here define the type of *mire* studied in close agreement with recent works on *mire* terminology (Stanek & Worley 1983, Int. Peat Soc. 1984, Bick *et al.* 1976, Gore 1983). The main concern is to explain in general terms what a *trilveen* (*quagfen*), a *drijftil* (*flotant*), a *kragge*, and a *petgat* are. Meanwhile some related terms are defined. Note, especially, that a rather broad definition is being used for the word "*mire*".

Wetland
Land which has the water table at, near, or above the land surface, or which is saturated for long enough periods to promote *wetland* or aquatic processes as indicated by poorly drained soils, hydrophilic vegetation, and various kinds of biological activity which are adapted to the wet environment. *Wetlands* include *peatlands* and areas that are influenced by excess water but which, for climatic, edaphic, or biotic reasons, produce little or no peat. Shallow open water, generally less than 2 m deep, is also included in *wetlands* (Stanek & Worley 1983). Often, the emphasis is on *wetlands* comprising a considerable area of such bodies of open water. For this reason I have not taken "*wetland*" as an appropriate term to indicate what is defined as *mire* below.

Mire
"Land" with a more or less permanently water-logged substratum, excluding open waters. *Mires* are usually peat-producing ecosystems, but not necessarily so (Wheeler 1980a). Note that I have preferred this definition over those that confine the *mire* concept to peat-producing ecosystems (Stanek & Worley 1983, Gore 1983a). In doing so, the natural relatedness of all kinds of "morass" (*cf* Rijksinstituut voor Natuurbeheer 1979, p.99-101, 107-109) is preserved in a technical term. There are two main types of *mire*: undrained *peatlands* and *marshes*, respectively.

Peatland
Any *mire*, or former *mire*, where peat has been produced to such an extent that the uppermost layers of the profile, say 0.3 m, consists of soil materials comprising more than 50 %, by volume, of peat. Undrained ("virgin") *peatlands* are *mires*.

Marsh
Mire with predominantly inorganic soil materials, little peat accumulation, and, usually, a grassy vegetation cover (for a more complete treatment see: Stanek & Worley 1983).

Swamp
Mire with an average summer water table more than 0.15 m above the surface of the substratum (Tansley, modified by Wheeler 1980). Note that the Americans usually define *swamps* as forested *wetlands* on mainly inorganic soils (though rich in humus; Gore 1983). *Swamps* may be either *marshes* or undrained *peatlands*.

Bog
Undrained *peatland* with an influx of rainwater only ("ombrotrophic")

Fen
Undrained *peatland* with an influx of groundwater or surface water ("minerotrophic", *i.e.*, supplied with (nutrient) minerals from neighbouring areas)

Carr
Fen with scrub or woodland (Gore 1983a)

Quagmire
Related terms: **quaking bog**, **quivering bog**, **quagfen**
Equivalents: *Schwingmoor* (D); *trilveen* (NL)
Floating (quaking) *mire*, being a stage in hydrarch (hydroseral) succession resulting in pond-filling; yields underfoot (Stanek & Worley 1983). Ombrotrophic types of *quagmire* may be called *quaking bog* (*quivering bog*). Minerotrophic types can be named with the new term *quagfen*. According to the botanical tradition in The Netherlands, *trilveen* is usually preserved for *quagfen* with a cover of vegetation belonging to the *Parvocaricetea* class, to its associations *Sphagno-Caricetum lasiocarpae* and *Scorpidio-Caricetum diandrae* in particular (Westhoff & Den Held 1969). Compare also: *Peucedano-Phragmitetum caricetosum* and *Acrocladio (gigantei)-Caricetum diandrae*, especially in the Norfolk Broads (U.K., Wheeler (1980); moderately calcitrophic brown moss fen (Rybníček in Moore 1984, p.182), rich fen (Moore & Bellamy 1973, p.55). Note that this

particular type of *quagfen* has been called, among other things, "*quaking bog*" and "*quivering bog*" by some Dutch authors (e.g., Segal 1966). According to Moore & Bellamy (p.10) *quagmires* should be considered a primary, i.e., basin-filling, *mire* type, in spite of the fact that even *bog* vegetation may occur within such a *mire* (Van Wirdum 1979, p.9-10).

Kragge (*plur.***kraggen**)
Related terms: scragh, scraw (E, GB), hove(r) (Norfolk), *plaur*, *plav?* (R); *Schwingrasen* (D); *heve*, *zodde*, *zudde* (NL)
(Dutch; no equivalent term found in technical English)
A more or less solid raft held together by the intertwining root systems of rhizomatous plants, such as *Phragmites australis*, *Typha angustifolia*,
Carex lasiocarpa, *Equisetum fluviatile*, and *Menyanthes trifoliata*. Although pieces of *kragge* may become detached to form floating islets, typical *kragge* is a sedentary formation, often attached to firm land and formed by species invading more or less eutrophic water from a riparian station. The terms *plaur* and *plav* are quoted for the reedbeds along the Danube (Gore 1983, p.28; Van der Toorn 1972, p.33; Pallis 1916, Sculthorpe 1967, p.423). A *Phragmites* reed *kragge* is nicely demonstrated by Van der Toorn (1972, p.37), a *Carex* one (as *Schwingrasen*) by Schmidt (1969, p.240).

Flotant
Related terms: *drijftil* (NL); *sudd*, *sadd* (Sudan); *embalsado* (Argentina); *batume* (Paraguay); *calamotale* (?)
Free floating mass of plants, drifted together into sometimes extensive mats by wind and current action. Often originating from mats of more or less free-floating aquatic macrophytes, such as *Eichhornia crassipes* and *Stratiotes aloides*, invaded by certain herbs (in The Netherlands *Cicuta virosa*, *Menyanthes trifoliata*, and other ones) and graminoids (*Carex pseudocyperus*, in the Sudan *Cyperus papyrus*; Sculthorpe 1967, p.423, 479-483), but sometimes even bearing trees (in The Netherlands *Alnus glutinosa*, *Salix cinerea*, and other ones). A description of the Southern American *flotants* was provided by Bonetto (1975, p.184, 192). In excellent photography, *flotants* or *sudds* are demonstrated by Sculthorpe (1967, p.468).

Petgat (*plur.***petgaten**)
Synonym: *trekgat* (NL)
(Dutch; no equivalent term found in technical English)
A pond, originated by excavation of peat from below the water level with dredging tools. Typical dimensions are 30-50 m width, 1.5-3.0 m depth, and a few hundreds of meters length. The name *petgat* is also used for the already overgrown *kragge* stage. "Peat hole", "dredging lake", "peat pond", or "peat working" might be used as English equivalents, although neither of these terms seems to be as specific as the Dutch words *petgat* and *trekgat*. "*Pet*" has probably common ethymological roots with the English "pit", while "*gat*" literally means "hole". The word *petgat* might thus be a pleonasm; it is commonly used in several peat working areas, especially in the Northern part of The Netherlands.

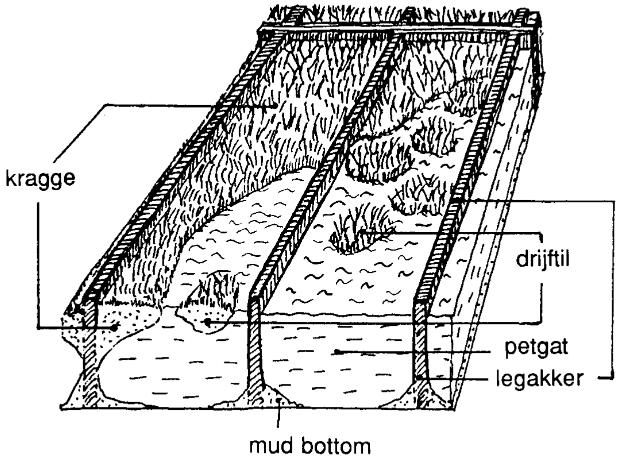


Fig. A.1 Diagram showing baulks and *petgaten*, and also *kragge* and flotants formed in *petgaten*

(Standing) balk, baulk
Equivalent: *legakker* (NL)
A strip of land, in The Netherlands typically 2-5 m wide, between *petgaten*. The Dutch *legakkers* may be composed of untouched peat, or they may have been constructed by filling earlier drainage grubs or ditches with otherwise less useful materials, mostly a peaty clay. In technical Dutch, especially in soil science, the untouched *legakkers* are mostly called "*ribben*", while the other type of *baulks* is called "*zetwal(len)*". The English term seems to be more or less indigenous in the Norfolk *Broads* area (cf Lambert et al. 1960).

Broad
Equivalent: *wiede*, *wijde* (NL)
Typically a lake that came into being by wind- and water-erosion of the *baulks* between *petgaten*. Also applied to natural widenings of rivers. "*Broad*" and "*wiede*" ("*wijde*") have the same ethymological range of meanings. *Baulks*, *petgaten*, *kraggen*, and *flotants* have been illustrated in Fig.A.1

A.2 Specific terms related to the water management system

The water management system in North-West Overijssel is of a type very common in The Netherlands. It also occurs in other parts of the world. Recently, TNO Committee on Hydrological Research (CHO-TNO 1986) published a concise introduction to "Water in The Netherlands", which well covers this subject. Some of the most common terms related to the water control system, including *boezems* and polders, are explained below.

The average soil surface level in North-West Overijssel is slightly below sea level, but some parts of the area are more low-lying, or at least drained to a lower level, and may have groundwater levels

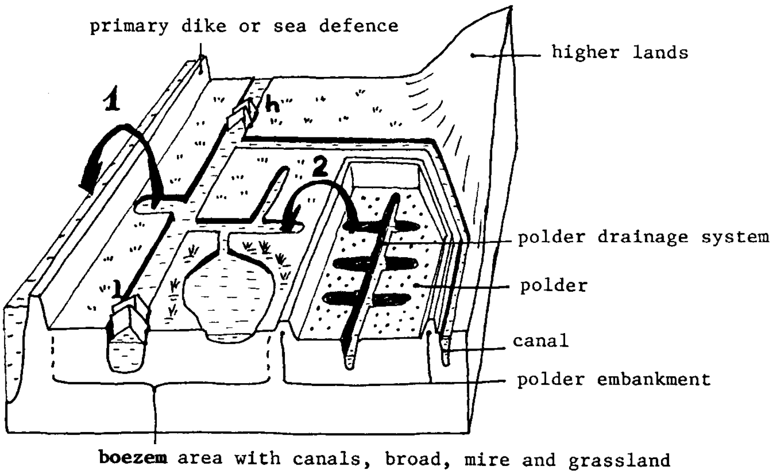


Fig. A.2 Diagram showing lay-out of *boezem* and polder, for the situation in NorthWest Overijssel, with surface in- and outlets
1 primary pumping station; 2 secundary pumping station; l discharges sluices (low end); h inlet sluices (high end)

maintained a few meters below sea level. (The present reference level for heights in The Netherlands, Normaal Amsterdams Peil (*NAP*), almost coincides with the average sea level.) Formerly, the area was bordered at one side by somewhat higher land and at the other side by the Zuyderzee (Fig.A.2), with a separating dike acting as a defence against high seas. During low tides, sluices could be opened for the discharge of surplus water. This became increasingly annoying by the end of the last century, when the dredging of peat had left large areas of economically nearly useless wetland with human settlements very susceptible to flooding and storm damage. Since 1920 the primary pumping station "Stroink" maintains a nearly constant water level by discharging excess water into the Zuyderzee.

Since the Zuyderzee became separated from the North Sea by a dam in 1932, the freshwater lake IJsselmeer thus formed has a somewhat lower water level and it is not subject to tides. The water level in the IJsselmeer is maintained by discharge of the surplus into the North Sea through sluices and by control of the influx of water through the river IJssel. All this has furthered the poldering of wetlands, in order to increase the agricultural production in the area.

The polders are the most low-lying parts of the area, separated from the main area by embankments, or polder dams (dikes). There drainage levels are controlled by a number of secundary pumping stations discharging into a network of canals and lakes which, together with the mire and land areas freely draining into it, form the main water reservoir or basin, called *boezem* in Dutch. Shallow polders, *i.e.*, those which are not very deeply drained, also use the *boezem* as a water supply during dry periods, whereas the *boezem* itself is replenished by intakes through the sluices separating it from systems with a higher water-level, as diagrammatically shown in Fig.A.2. The *boezem* with its in- and outlets must have a certain minimum capacity related to the amounts of water to be retained, without causing unacceptable flooding, in the worst possible case. In this way the water-level can be accurately regulated, so that it rarely deviates more than ca. 0.1 m from the prescribed target value.

The local regulation of the water management is mainly in the hands of two institutional bodies: the water board "Waterschap Vollenhove", which is in charge of the water-level control, and the water-quality board "Zuiveringschap West-Overijssel". The name Waterschap Vollenhove is frequently also applied to the area which is controlled by the water board, including the *boezem*, several polders, and some freely draining land.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX B

Classification of quagfen vegetation

The syntaxonomical treatment of the "*Scorpidio-Caricetum diandrae* (W.Koch 1926) Westhoff nom. nov." (Westhoff & Den Held 1969), according to Zijlstra (1981) synonymous with the *Caricetum lasiocarpae* Koch 1926, varies considerably from author to author. A summary is presented below.

Westhoff & Den Held (1969)

Association:	*Scorpidio-Caricetum diandrae* (W.Koch 1926) Westhoff 1969
Alliance:	*Caricion davallianae* Klika 1934
Order:	*Tofieldietalia* Preising apud Oberdorfer 1949
Class:	*Parvocaricetea* (Westhoff 1961 mscr.) Den Held & Westhoff 1969

The class *Parvocaricetea* is placed in the rankless group of "Vegetation of Fens and Bogs", together with the classes *Scheuchzerietea* Den Held, Barkman & Westhoff 1969 and *Oxycocco-Sphagnetea* Br.Bl. et R.Tx. 1943. The *Parvocaricetea* Class comprises fen vegetation in minerotrophic environments. The herb layer is dominated by graminoids, and the moss layer by pleurocarpic mosses, especially *Amblystegiaceae*, and by *Sphagnum* species. The environment is described as meso- to eutrophic, with a low nitrogen status, and as weakly acid to alkaline. Other authors have classified the pertaining communities, together with the Order *Scheuchzerietalia palustris*, in a Class *Scheuchzerio-Caricetea nigrae* (compare Ellenberg, Dierssen, below).

Within the *Parvocaricetea* Class the Orders *Tofieldietalia* and *Caricetalia nigrae* W.Koch 1926 *em.* Nordh. 1936 *denuo em.* R.Tx. 1937 (*sub nom. Caricetalia fuscae*) are distinguished. The Association *Sphagno-Caricetum lasiocarpae* (Gadeceau 1909) Steffen 1931 *em.* Westhoff 1969 is placed in the *Caricetalia nigrae*, which, in The Netherlands, is considered to be calciphobe. The *Sphagno-Caricetum lasiocarpae* is commonly considered to be a stage of succession following upon the *Scorpidio-Caricetum diandrae*, which is, in turn, usually preceded by vegetation of the *Phragmitetea* Class.

The differential species of both Associations, with respect to each other, are listed in Table B.1. The list of the *Scorpidio-Caricetum diandrae* comprises all character species of the *Tofieldietalia* Order and of the *Caricion davallianae* Alliance, although several of these species, especially those which have not been found in North-West Overijssel, are more characteristic of other Associations of the *Caricion davallianae*, such as the *Parnassio-Caricetum pulicaris*. The character species of the *Scorpidio-Caricetum diandrae*, *Eriophorum gracile* and *Juncus subnodulosus*, could be added to this list, and so might *Utricularia intermedia* and, perhaps, *Utricularia minor*. These two *Utricularia* species are characteristic of the Association *Scorpidio-Utricularietum* (Ilscher 1959 mscr.) Th.Müll. *et* Görs 1960 *em.* Den Hartog *et* Segal 1964 *denuo em.*Den Held *et* Westhoff 1969, which is characteristically found in, often small, hollows in the meshes of stands of the *Scorpidio-Caricetum diandrae*. According to the OR-assumption (Chapter 3) the *Scorpidio-Utricularietum* may be considered a part of the *Scorpidio-Caricetum diandrae*, although they are not singularly, nor necessarily, associated.

It is evident from Table B.1 that the difference between the *Sphagno-Caricetum lasiocarpae* and the *Scorpidio-Caricetum diandrae*, according to Westhoff & Den Held, is especially expressed by bryophytes. The vascular plants that would indicate that a stand belongs to the *Scorpidio-Caricetum diandrae* also present problems: *Eriophorum gracile*, *Carex pulicaris*, *Sagina nodosa*, *Epipactis palustris*, *Parnassia palustris*, and *Utricularia intermedia* are by no means found in all stands of the Association. With the exception of *Eriophorum gracile* and *Utricularia intermedia*, they appear to be more characteristic of certain Associations of the Alliance *Molinion*, which is placed in the *Molinio-Arrhenateretea* Class, or of transitional vegetation between quagmire and *Molinion*. *Carex curta*, *C. echinata*, *Drosera rotundifolia*, and, to some extent, *Oxycoccus palustris*, which would characterize the *Sphagno-Caricetum lasiocarpae*, on the other hand, are often found locally in stands which would otherwise be indicated as *Scorpidio-Caricetum diandrae*.

This can simply be explained from the fact that both Associations are linked in the supposed successional sere. It remains to be seen whether such a situation is entirely different from the one that brought Rybníček (1964) to the preliminary proposal of an Alliance *Caricion demissae* with *Carex tumidicarpa*, *C. dioica*, *C. pulicaris*, *Triglochin palustre*, *Riccardia pinguis*, *Fissidens adianthoides*, *Scorpidium scorpioides* and, but unknown from quagfens in The Netherlands, *Trichophorum alpinum*, *Scirpus cespitosus ssp. cespitosus*, and *Calliergon trifarium* as character species (see also Chapter 2). The differential species with regard to the *Caricion davallianae* are *Drosera rotundifolia*, *Oxycoccus palustris*, *Sphagnum contortum*, and *Sphagnum subsecundum*.

Juncus subnodulosus often occurs in a *facies*, as dense stands with few, if any, other vascular plants, which is considered a *Scorpidio-Caricetum diandraefacies* by Westhoff & Den Held. In North-West Overijssel *Juncus subnodulosus* is frequently found, without contributing to any easier

Table B.1 Differential species of the associations *Sphagno-Caricetum lasiocarpae* (LAS) and *Scorpidio-Caricetum diandrae* (DIA) according to Westhoff & Den Held (1969)

Vascular plants	**LAS**	**DIA**	**Not in the study area**	**LAS**	**DIA**
Carex pulicaris		+	*Carex lepidocarpa*		+
Sagina nodosa		+	*Carex flava s.s.*		+
Dactylorhiza incarnata		+	*Juncus alpino-articulatus*		
Epipactis palustris		+	*ssp. arthrophyllus*		+
Liparis loeselii		+	*Taraxacum limnanthes*		+
Parnassia palustris		+	*Eleocharis quinqueflora*[1]		+
Carex curta	+		*Equisetum variegatum*		+
Carex echinata	+		*Eriophorum latifolium*		+
Oxycoccus palustris	+		*Pinguicula vulgaris*		+
Drosera rotundifolia	+				

Bryophytes	**LAS**	**DIA**	**Not in the study area**	**LAS**	**DIA**
Calliergon giganteum		+	*Drepanocladus vernicosus*		+
Scorpidium scorpioides		+	*Fissidens osmundoides*		+
Drepanocladus lycopodioides		+	*Camptothecium nitens*		+
Drepanocladus revolvens[2] *s.l.*		+	*Bryum ovatum*		+
Campylium elodes		+	*Bryum marratii*		+
Campylium polygamum		+	*Mnium cinclidioides*		+
Campylium stellatum		+	*Cinclidium stygium*		+
Fissidens adianthoides		+	*Catoscopium nigritum*		+
Bryum pseudotriquetrum		+	*Riccardia chamaedryfolia*		+
Plagiomnium affine		+	*Sphagnum platyphyllum*		+
Rhizomnium pseudopunctatum		+	*Sphagnum cuspidatum*	+	
Riccardia multifida		+			
Pellia endiviaefolia		+			
Pellia neesiana		+			
Sphagnum contortum		+			
Polytrichum commune					
var. uliginosum	+				
Sphagnum subsecundum	+				
Sphagnum nemoreum					
var. subnitens	+				
Sphagnum flexuosum					
var. flexuosum	+				
Sphagnum fimbriatum	+				
Sphagnum palustre	+				
Aulacomnium palustre	+				
Calypogeia fissa	+				

1) Recently found at one location in the study area (Piek et al., pers. comm.).,; 2) = *Scorpidium revolvens + cossoni*
(The species in the right-hand column have not, or not with certainty, been recorded from North-West Overijssel)

discrimination between the *Sphagno-Caricetum lasiocarpae* and the *Scorpidio-Caricetum diandrae*.

Although the list of differential bryophytes seems impressive, it does not really clarify the problem. In The Netherlands especially *Calliergon giganteum* and *Scorpidium scorpioides* form dense stands which are in practice considered to belong to the *Scorpidio-Caricetum diandrae*, especially when the *Scorpidio-Utricularietum* is present in the hollows. Many of the other species seem to be more characteristic of particular microrelief elements in both Associations, and also in certain other ones, especially in the Alliances *Magnocaricion* and *Molinion*. Dierssen obviously treated the moss *synusiae* as ones that may occur in different Associations, and he made them decisive for the presence of particular Subassociations (see below).

On the whole, the Associations *Sphagno-Caricetum lasiocarpae* and *Scorpidio-Caricetum diandrae* seem to be closely interwoven in The Netherlands, and it is difficult to find pure stands.

Ellenberg (1978) and Oberdorfer (1979)

The classification schemes by Ellenberg and Oberdorfer are similar in outline. Ellenberg's scheme is followed here down to the Alliance level. The Associations are cited from Oberdorfer. No attention is paid to bryophytes in these schemes.

Associations:	*Caricetum lasiocarpae* W.Koch 1926
	Caricetum diandrae Jon. 1932 *em.* Oberd.1957
Alliance:	*Caricion lasiocarpae* Vanden Bergh. in Lebr. *et al.* 1949 (synonymous with *Eriophorion gracilis* Preising *apud* Oberd.1957)
Order:	*Scheuchzerietalia palustris* Nordh.1937
Class:	*Scheuchzerio-Caricetea nigrae* (Nordh.1936) Tx.1937

The Order *Tofieldietalia* is also recognized, with, among other Alliances, the Alliance *Caricion davallianae*. The Associations placed within that Alliance, however, are usually characterized by the presence of *Schoenus nigricans*, *S. ferrugineus*, or *Carex davalliana*. *Triglochin palustre*, as a character species of the *Tofieldietalia*, and *Liparis loeselii*, characteristic of the *Caricion davallianae*, are frequently met with in Dutch quagmires. *Epipactis palustris* and *Taraxacum palustre*, both listed for the *Caricion davallianae*, might be added, although they are by no means common. Possibly they do not especially occur in Westhoff's *Scorpidio-Caricetum diandrae*. The pertaining stands comprise several species which, in the sense of Ellenberg and Oberdorfer, justify a classification under the *Scheuchzerietalia* rather than the *Tofieldietalia*, however, and some of these are even more characteristic of the Alliance *Caricion fuscae* than of the *Caricion lasiocarpae* (Table B.2).

It is of some interest that certain communities with *Carex buxbaumii*, *Juncus subnodulosus*, and *Carex lasiocarpa*, respectively, are placed under the *Magnocaricion* Alliance of the *Phragmitetalia* Order in the Class *Phragmitetea* (Oberdorfer 1979, p.36). The similarity with certain *Magnocaricion* Associations is especially obvious from Braun's (1968) phytosociological study of calcareous fens in the Alpine foothills of Southern Bavaria. As described by Braun, the Associations in the *Magnocaricion* and *Caricion lasiocarpae* (*syn. Eriophorion gracilis*) are each primarily characterized by differential species groups that play a similar role in several Associations. Examples of species of such groups are *Utricularia intermedia* and *Scorpidium scorpioides*, which

Table B.2 Character species of certain *Scheuchzerio-Caricetea nigrae* communities according to Ellenberg (1978, p. 902, 568).

Class:		***Scheuchzerio-Caricetea nigrae***	
		Carex dioica	
		Carex hostiana	
		Carex panicea	
		Carex pulicaris	
		(*Dactylorhiza traunsteineri*)	
		Eriophorum angustifolium	
		Menyanthes trifoliata	
		Parnassia palustris	
		Pedicularis palustris	
		Potentilla palustris	
Order:	***Scheuchzerietalia***	***Tofieldietalia***	
	Calamagrostis stricta	*Triglochin palustre*	
	Hydrocotyle vulgaris		
Alliances:			
Caricion nigrae	***Eriophorion gracilis***	***Caricion davallianae***	***(Caricion juncifoliae)***
Agrostis canina	*Carex diandra*	*Liparis loeselii*	*Carex tumidicarpa*
Hierochloë odorata	*Carex lasiocarpa*	*Epipactis palustris*	
Ranunculus flammula	*Eriophorum gracile*	*Taraxacum palustre*	
(Additional species mentioned on p.568:)			
	Carex curta	*Campylium stellatum*	
	Carex echinata	*Scorpidium cossoni*	
	Carex nigra		
	Calliergon stramineum		
	Viola palustris		

Only species found in Dutch quagmires have been included here.

are thus no longer characteristic of any singular Association, but rather of similar Subassociations or Varieties in different Associations.

The *Scorpidio-Caricetum dissolutae* Braun 1961 in the *Magnocaricion* is of particular interest. It was named after a loose, not so pronouncedly tussocky modification of *Carex elata, mod. dissoluta sensu* Braun, which is probably the modification found in quagmires in North-West Overijssel also. The wetter stands of the mentioned Association are distinguished as Subassociation *utricularietosum*, which has a variety with *Campylium stellatum*, *Drepanocladus revolvens var. intermedius* (= *Scorpidium cossoni*), *Carex panicea*, and *Carex lepidocarpa*. The drier stands, Subassociation *molinietosum*, lack the *Utricularia* synusia, but, in addition to the species in the *Campylium stellatum* group, are characerized by several species that are strongly reminiscent of the *Scorpidio-Caricetum diandrae sensu* Westhoff: *Fissidens adianthoides*, *Parnassia palustris*, and certain *Molinion* species. The affinity to the *Phragmitetea* Class is shown by the presence of such species as *Phragmites australis*, *Equisetum fluviatile*, *Lycopus europaeus*, *Peucedanum palustre*, *Galium palustre*, *Scutellaria galericulata*, and *Lysimachia thyrsiflora*.

The Associations *Caricetum lasiocarpae* and *Caricetum diandrae*, as they occur in Braun's tables, are both subdivided in a *scorpidietosum*, a *drepanocladetosum vernicosi*, and a *polytrichetosum stricti*. Apart from the "wet" *scorpidietosum* Subassociations, they all contain several *Magnocaricion* and *Molinion* species, such as *Galium palustre*, *Peucedanum palustre*, and *Molinia caerulea*, which are also present in the *Scorpidio-Caricetum dissolutae molinietosum*. The *drepanocladetosum vernicosi* Subassociations are characterized by a group of differential species of which only *Drepanocladus vernicosus* is, at least at present, absent from the quagmires in North-West Overijssel, but the other taxa are not especially typical of *Parvocaricetea* quagmires: *Cardamine pratensis*, *Anthoxanthum odoratum*, *Calliergonella cuspidata*, *Juncus articulatus*, *Ranunculus flammula*, and *Climacium dendroides*. The *polytrichetosum stricti* of both Associations is somewhat poorly documented, but it notably includes *Drosera rotundifolia* and *Polytrichum strictum*.

In summary, it appears that few dominant species are decisive for the classification into Associations and larger units in these schemes of classification, although they all share a core of *Scorpidio-Caricetum diandrae* species, *sensu* Westhoff & Den Held.

Dierssen (1982)

At the higher levels of classification, Dierssen's scheme resembles Ellenberg's, although several character species have been evaluated in a somewhat different way (Table B.3). Below the Association level Dierssen has systematically distinguished Subassociations according to the prevailing moss synusiae. A *scorpidietosum* Subassociation is recognized for each of the following seventeen Associations in five Alliances and three different Orders:

Order:	*Scheuchzerietalia palustris*
Alliance:	*Rhynchosporion albae*
Associations:	*Caricetum limosae*
	Sphagno tenelli-Rhynchosporetum albae
	Caricetum rotundatae
Alliance:	*Caricion lasiocarpae*
Associations:	*Caricetum lasiocarpae*
	Caricetum rostratae
	Calamagrostio-Caricetum lyngbyei
	Drepanoclado exannulati-Caricetum aquatilis
	Caricetum diandrae
	Drepanoclado revolventis-Caricetum chordorrhizae
Order:	*Caricetalia nigrae*
Alliance:	*Caricion nigrae*
Associations:	*Caricetum magellanicae* (as a rankless variety)
	Calliergono sarmentosi-Caricetum saxatilis
Order:	*Tofieldietalia*
Alliance:	*Caricion davallianae*
Associations:	*Schoenetum nigricantis*
	Campylio-Caricetum dioicae
	Drepanoclado revolventis-Trichophoretum cespitosi
	Eleocharitetum quinqueflorae
	Drepanoclado revolventis-Caricetum adelostomae
Alliance:	*Caricion bicolori-atrofuscae*
Association:	*Caricetum microglochinis*

Table B.3 Character species of certain *Scheuchzerio-Caricetea nigrae* communities according to Dierssen (1982, various places).

Class:	***Scheuchzerio-Caricetea nigrae***	
	Eriophorum angustifolium	
	Potentilla palustris	
	Menyanthes trifoliata	
	Carex nigra	
	Carex panicea	
	Carex rostrata (locally only?)	
	Carex lasiocarpa	
	Sphagnum flexuosum var. fallax	
	Sphagnum riparium	
	Sphagnum subsecundum s.l.	
	Polytrichum commune	
	Drepanocladus revolvens	
	Bryum pseudotriquetrum	
(Additional from Fig.33:)	*Scorpidium scorpioides*	
	Aulacomnium palustre	
	Equisetum palustre	
Orders:		
Scheuchzerietalia palustris	***Caricetalia nigrae***	***Tofieldietalia***
Sphagnum subsecundum s.l.	*Carex curta*	*Parnassia palustris*
	Carex echinata	*Drepanocladus revolvens*[1]
(Additional from Fig. 33:)	*Epilobium palustre*	*Fissidens adianthoides*
	Viola palustris	*Campylium stellatum*
Sphagnum riparium	*Juncus filiformis*	*Campylium polygamum*
Carex rostrata	*Polytrichum commune*	*Fissidens adianthoides*
Menyanthes trifoliata	*var. uliginosum*	
	Sphagnum teres	(Additional from Fig.33:)
	Sphagnum palustre	
	Sphagnum flexuosum s.l.	*Carex flava* agg.
	Calliergon stramineum	*Carex dioica*
	Rhizomnium pseudopunctatum	
	Ranunculus flammula	

Alliances (*Rhynchosporion albae* and *Caricion bicolori-atrofuscae* disregarded):

Caricion lasiocarpae	***Caricion nigrae***	***Caricion davallianae***
Carex rostrata	(as for the Order)	*Carex hostiana*
Carex lasiocarpa		*Carex tumidicarpa*
Menyanthes trifoliata		*Carex pulicaris*
Potentilla palustris		*Dactylorhiza incarnata*
Equisetum fluviatile		*Epipactis palustris*
Eriophorum gracile		*Liparis loeselii*
Calliergon giganteum		*Campylium elodes*
Pedicularis palustris		*Triglochin palustre*
		(Juncus subnodulosus)
Differential in respect to		*(Carex buxbaumii)*
Rhynchosporion albae:		*Taraxacum palustre*
Lysimachia thyrsiflora		
Peucedanum palustre		

Only species which occur in Dutch quagmires have been included here. Some additional species have been mentioned by Dierssen in his Fig.33 (p.94); these have been included here as indicated in the table. 1) *Scorpidum revolvens + S. cossoni*

Although several of these Associations do not occur in The Netherlands, it is at once demonstrable that the presence of *Scorpidium scorpioides* is only diagnostic at the Class and Subassociation levels in Dierssen's scheme. *Carex elata* is, according to Dierssen's records, especially characteristic of the *Caricetum elatae*, in the Alliance *Magnocaricion*, Order *Phragmitetalia*. This Alliance has been narrowed somewhat by excluding the *Caricetum rostratae*, which is now placed in the *Caricion lasiocarpae*, Order *Scheuchzerietalia palustris*. *Menyanthes trifoliata*, *Potentilla palustris*, *Carex rostrata*, and *Equisetum fluviatile* thus become slightly more characteristic of the *Caricion lasiocarpae*, especially in comparison to the *Magnocaricion*.

The stands of quagmire vegetation in North-West Overijssel would, according to this proposal, also become more strongly related to the *Caricion lasiocarpae*. The affinity to *Magnocaricion* vegetation is nonetheless retained, since all but one of the character species of the *Magnocaricion sensu* Dierssen, *Scutellaria galericulata*, *Galium palustre ssp. elongatum*, *Carex acutiformis, Lysimachia thyrsiflora, Carex disticha*, and *Peucedanum palustre*, belong to the most constant associate species in these stands of quagmire vegetation. *Lysimachia thyrsiflora* and *Peucedanum palustre* are also recognized by Dierssen as differential species of the *Caricion lasiocarpae* with regard to the *Rhynchosporion albae*.

The *Caricetum dissolutae sensu* Braun is not mentioned by Dierssen, but, on p.110, he refers to Balátová-Tuláčková (1972), who includes both the *Caricetum lasiocarpae* and the *Caricetum diandrae*, together with the *Caricetum rostratae* and certain other Associations in the *Magnocaricion*, especially referring to the vigirous growth of *Menyanthes trifoliata*, *Potentilla palustris*, *Carex rostrata*, and other species. Records from North-West Overijssel contain several species which prove a relation with the *Caricion nigrae* and *Caricion davallianae* (Table B.3). It is noteworthy that Dierssen might have overcome this problem (or: missed this resemblance) through the use of much smaller quadrats in his records.

The *Juncetum subnodulosi* is placed in the *Caricion davallianae* by Dierssen. In conclusion there is strong evidence that the stands of vegetation characterized by the abundance of *Carex lasiocarpa*, *C. diandra*, and *Juncus subnodulosus* cannot be easily classified in the schemes of the Zürich-Montpellier school, regardless of the attention paid to the moss layer by different authors.

Wheeler (1975, 1980, 1984)

Wheeler's scheme is probably not of the same kind as the other Zürich-Montpellier classification systems. Although Wheeler (1980) refers to a comparison of Zürich-Montpellier tabulations with statistical clustering techniques, his ultimate scheme reflects the results of the latter approach. Formally, therefore, the characteristic species mentioned in this scheme are not character and differential species in the Zürich-Montpellier sense. The Dutch quagmire vegetation can probably be classed under two Associations in Wheeler's system. Down to the level of Alliances the scheme largely coincides with that of Westhoff & Den Held (see before).

Association 1:	*Peucedano-Phragmitetum* Wheeler 1978
Alliance:	*Magnocaricion elatae* Koch 1926
Order:	*Magnocaricetalia* Pignatti 1953
Class:	*Phragmitetea* Tüxen et Preising 1942

Association 2: *Acrocladio-Caricetum diandrae* Klika 1934
Alliance: *Caricion davallianae* Klika 1934
Order: *Tofieldietalia* Preising *apud* Oberdorfer 1949
Class: *Parvocaricetea* Den Held *et* Westhoff 1969

Several Subassociations and Varieties have been distinguished by Wheeler, such as the *Carex lasiocarpa* variety of the *Peucedano-Phragmitetum cicutetosum*. His work is of special interest since it is based upon, among others, many vegetation records from The Broads in Norfolk, an area which has much in common with North-West Overijssel. From his descriptions, it is obvious that *Carex lasiocarpa* and *Carex diandra*, and, less typically so, the amblystegiaceous mosses, are especially present in Norfolk in stands of vegetation somewhat intermediary between the *Phragmitetea* and *Parvocaricetea* Classes. The *Peucedano-Phragmitetum* typically includes *Carex elata*, *Juncus subnodulosus*, *Lysimachia vulgaris*, *Peucedanum palustre*, *Thelypteris palustris*, and other taxa, and it is usually dominated by *Phragmites australis*, *Cladium mariscus*, or, less often, *Calamagrostis canescens*.

Very similar stands are present in North-West Overijssel, but in most typical quagfens, that can be classed under Wheeler's *Acrocladio-Caricetum diandrae*, regular hay-making prevents the dominance of these tall helophytes. The *Acrocladio-Caricetum diandrae* is, according to Wheeler, typically characterized by mixed stands of *Carex diandra*, *C. lasiocarpa*, and *C. rostrata*, usually with much *Menyanthes trifoliata* and *Potentilla palustris*, and sometimes *Carex limosa*. *Carex limosa* is absent from the quagfens in North-West Overijssel, but it was formerly associated with similar types of quagmire elsewhere in The Netherlands. Brown mosses are frequently abundant in the *Acrocladio-Caricetum* (notably *Calliergon giganteum*), but *Sphagnum* is also present, especially in less base-rich examples.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX C

Indicator list of fen-mire species

In this appendix the species have been listed according to their scientific name (Van der Meijden *et al.* 1983, Dirkse *et al.* 1989) with the indications attached to them (Chapter 3). A short explanation of abbreviations is given below. For any details, reference should be made to Chapter 3. The list is an extract of a larger database.

T	**('threatened')**		
!	Especially occurring in protected areas		
#	Especially occurring in protected areas, also a 'seepage' indicator		

R	**(Red Data List, Weeda et al. 1990)**		
0	Extinct and presumed extinct	4	Rare
1	Endangered	5	Strongly declining, but not yet 1-4
2	Most vulnerable	6	Legal protection proposed, but not 1-5
3	Vulnerable		(not considered 'threatened' in Chapter 3)

Typ	**(Phytosociological group)**		
AQU	Communities of aquatic macrophytes	LIT	Litter fen
BOG	Oxycocco-Sphagnetea, Nardo-Callunetea	MOL	Molinion
DAV	Caricion davallianae	SMA	Salt-marsh, brackish fen communities
FEN	Other Parvocaricetea, Caricion fuscae	SMP	Various swamp communities
LAS	Caricion lasiocarpae		

Wat	**(Water type, acidity)**				
ATM	Atmotrophic	CIR	Circumneutral	LTH	Lithotrophic

Nut	**(Trophic state)**				
EUT	Eutrophic	MES	Mesotrophic	OLI	Oligotrophic

Indications according to the Finnish tradition (Eurola et al. 1984):

Bas	**Base state, as found in the following milieus:**				
OMB	Ombrotrophic (very low)	POR	Poor (low base state)	TRL	Transitional
WMS	Wide-range mesotrophic	XRC	Extreme rich-fen		

Lev	**Groundwater level as in:**				
HUM	Hummocks	INT	Intermediate mire parts	FLK	Flarks (hollows)

Ext	**Supplementary nutrient effect associated with:**				
SEP	Seepage in general	FLD	Flooding	ANY	Either or both
NO	No supplementary nutrient effect				

Inh	**Inherent nutrient effect associated with:**				
MOS	Moss (bog) peat	NVA	Neva (intermediate mire)	RFN	Rich-fen peat
NO	No inherent nutrient effects				

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Achillea ptarmica	L.			MOL		OLI				
Acorus calamus	L.			SMP	CIR	EUT				
Agrostis canina	L.			LIT	ATM	OLI	TRL	INT	FLD	NO
Agrostis stolonifera	L.			LIT		MES				
Ajuga reptans	L.			MOL	LTH	MES				
Alisma lanceolatum	Withering			SMP	CIR	MES				
Alisma plantago-aquatica	L.			SMP	CIR	EUT	TRL	FLK	FLD	NO
Alnus glutinosa	(L.) Gärtner			LIT	CIR	EUT	WMS	HUM	FLD	NO
Althaea officinalis	L.	!	3	LIT						
Amblystegium riparium	(Hedw.) Schimp.			SMP	CIR	EUT				
Amblystegium serpens	(Hedw.) Schimp.			LIT	CIR	EUT				
Amblystegium varium	(Hedw.) Mitt.			LIT	LTH	EUT				
Andromeda polifolia	L.	!	5	BOG	ATM	OLI	OMB	INT	NO	NVA
Aneura pinguis	(L.) Dum.	#		LAS	LTH	OLI	WMS	FLK	SEP	RFN
Angelica sylvestris	L.			LIT	LTH	OLI	WMS	HUM	SEP	RFN
Anthoxanthum odoratum	L.			BOG		OLI	TRL	INT	ANY	NO
Aronia x prunifolia	(Marshall) Rehder									
Aster tripolium	L.			SMA		EUT				
Atrichum undulatum	(Hedw.) P.Beauv.			FEN	ATM	EUT				
Atriplex prostrata	Boucher ex DC.			SMA		EUT				
Aulacomnium palustre	(Hedw.) Schwägr.			FEN	ATM	MES	OMB	HUM	NO	MOS
Azolla filiculoides	Lamk.			AQU		EUT				
Berula erecta	(Hudson) Coville			SMP	CIR	EUT				
Betula pubescens	Ehrhart			DAV	ATM	OLI	POR	HUM	ANY	NVA
Bidens cernua	L.			SMP		EUT				
Bidens connata	Mühlenb. ex Willdenow			SMP		EUT				
Bidens frondosa	L.			SMP		EUT				
Bidens tripartita	L.			SMP		EUT				
Brachythecium rutabulum	(Hedw.) Schimp.			LIT		EUT	TRL	HUM	ANY	NO
Briza media	L.	!	3	MOL		OLI				
Bryum pseudotriquetrum	(Hedw.)Gärtn., Meyer et Scherb.	#		LAS	LTH	MES	WMS	FLK	ANY	RFN
Calamagrostis canescens	(Weber) Roth			LIT	ATM	OLI	TRL	FLK	FLD	NO
Calamagrostis stricta	(Timm) Koeler	#	4	LAS	CIR	OLI	TRL	FLK	FLD	NO
Calla palustris	L.	!	6	SMP	CIR	MES	TRL	FLK	FLDNO	
Calliergon cordifolium	(Hedw.) Kindb.			SMP	CIR	EUT	TRL	FLK	ANY	NO
Calliergon giganteum	(Schimp.) Kindb.	!		LAS	LTH	MES	WMS	FLK	ANY	NO
Calliergon stramineum	(Brid.) Kindb.			FEN	ATM	OLI	POR	FLK	ANY	NVA
Calliergonella cuspidata	(Hedw.) Loeske			LIT		MES	WMS	FLK	ANY	NO
Callitriche platycarpa	Kützing			SMP						
Calluna vulgaris	(L.) Hull			BOG	ATM	OLI	OMB	HUM	NO	MOS
Caltha palustris	L.			MOL	CIR	MES	TRL	FLK	FLD	NO
Calypogeia fissa	(L.) Raddi			FEN		MES	OMB	HUM	NO	MOS
Calystegia sepium	(L.) R.Br.			LIT	CIR	EUT				
Campylium elodes	(Lindb.) Kindb.	#		MOL		MES				
Campylium polygamum	(Schimp.) J.Lange et C.Jens.			LIT	CIR	MES				
Campylium stellatum	(Hedw.) J.Lange et C.Jens.	#		DAV	LTH	OLI	XRC	INT	SEP	RFN
Campylopus pyriformis	(K.F.Schultz) Brid.			LIT	ATM	OLI				
Cardamine pratensis	L.			MOL	CIR	MES	WMS	FLK	ANY	NO
Carex acuta	L.			SMP	CIR	MES				
Carex acutiformis	Ehrhart			SMP	CIR	MES	WMS	FLK	SEP	NO
Carex appropinquata	Schumacher	!	3	SMP	LTH	OLI	XRC	INT	SEP	NO
Carex buxbaumii	Wahlenberg	#	4	MOL	CIR	OLI	WMS	FLK	FLD	RFN
Carex curta	Goodenough			FEN	ATM	OLI	POR	FLK	FLD	NO
Carex diandra	Schrank	#	5	LAS	CIR	OLI	WMS	FLK	ANY	RFN

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Carex dioica	L.	!	1	DAV		OLI	WMS	HUM	NO	RFN
Carex disticha	Hudson			LIT	CIR	MES				
Carex echinata	Murray	!	6	FEN	ATM	OLI	TRL	FLK	SEP	NO
Carex elata	Allioni			FEN	CIR	MES	WMS	FLK	FLD	NO
Carex hostiana	DC.	!	2	BOL	ATM	OLI				
Carex lasiocarpa	Ehrhart	#	5	FEN	CIR	OLI	POR	FLK	FLD	
NVA										
Carex nigra	(L.) Reichard			FEN	ATM	OLI	TRL	INT	FLD	NO
Carex panicea	L.	!	6	MOL	ATM	OLI	XRC	INT	NO	RFN
Carex paniculata	L.			SMP	LTH	EUT	XRC	FLK	SEP	NO
Carex pseudocyperus	L.			SMP	LTH	EUT	WMS	FLK	FLD	NO
Carex pulicaris	L.	!	2	MOL	ATM	OLI				
Carex riparia	Curtis			SMP		MES	WMS	FLK	FLD	NO
Carex rostrata	Stokes	!		FEN	ATM	OLI	POR	FLK	FLD	NVA
Carex tumidicarpa	N.J.Anderson	!		MOL	LTH	MES				
Carex vesicaria	L.	!	6	FEN	ATM	MES	TRL	FLK	FLD	NO
Centaurea jacea	L.			LIT						
Cephalozia bicuspidata										
var. lammersiana	(Hüb.) Breidl.	!		FEN	CIR	MES				
Cephalozia connivens	(Dicks.) Lindb.	!		FEN	ATM	OLI				
Cephaloziella hampeana	(Nees) Schiffn.	!		LAS	ATM	MES				
Cephaloziella spinigera	(Lindb.) Jørg.	!		BOG	ATM	OLI				
Chiloscyphus pallescens	(Ehrh.) Dum.			LIT	CIR	MES	TRL	FLK	SEP	NO
Cicuta virosa	L.			SMP	LTH	EUT	WMS	FLK	FLD	NO
Cirsium dissectum	(l.) Hill	!	2	MOL	ATM	OLI				
Cirsium palustre	(L.) Scopoli			MOL		OLI	WMS	INT	ANY	NO
Cladium mariscus	(L.) Pohl	!	3	SMP	LTH	OLI				
Climacium dendroides	(Hedw.) Web. et Mohr			MOL		MES	TRL	INT	FLD	NO
Cochlearia officinalis	L.		3	SMA						
Cratoneuron filicinum	(Hedw.) Spruce	!		DAV	LTH	MES	XRC	FLK	SEP	NO
Dactylorhiza incarnata	(L.) Soo	#	3	DAV	CIR	OLI	WMS	INT	NO	RFN
Dactylorhiza maculata	(L.) Soo	!	3	BOG	ATM	OLI	TRL	INT	SEP	RFN
Dactylorhiza majalis	(Reichenb.)Hunt & Summerhayes	!		MOL	CIR	OLI				
Danthonia decumbens	(L.) DC.			BOG	ATM	OLI				
Deschampsia cespitosa	(L.) Beauv.			LIT	ATM	MES	TRL	INT	ANY	NO
Deschampsia flexuosa	(L.) Trinius			BOG	ATM	OLI	TRL	HUM	SEP	NO
Dicranella cerviculata	(Hedw.) Schimp.			LIT	ATM	OLI	OMB	HUM	NO	NO
Dicranella heteromalla	(Hedw.) Schimp.			BOG	ATM	OLI				
Dicranum bonjeanii	De Not.			FEN	ATM	MES	WMS	INT	SEP	RFN
Dicranum scoparium	Hedw.			MOL		MES	OMB	HUM	SEP	MOS
Drepanocladus aduncus	(Hedw.) Warnst.			SMP	LTH	EUT	WMS	FLK	FLD	NO
Drepanocladus fluitans	(Hedw.) Warnst.			BOG	ATM	MES	OMB	FLK	NO	NVA
Drepanocladus lycopodioides	(Brid.) Warnst.	#		LAS	LTH	MES				
Drepanocladus sendtneri	(H.Müll.) Warnst.	!		DAV	LTH	OLI				
Drosera rotundifolia	L.	!	5	FEN	ATM	OLI	OMB	HUM	NO	MOS
Dryopteris carthusiana	(Villars) H.P.Fuchs			FEN	ATM	OLI	TRL	HUM	SEP	NO
Dryopteris cristata	(L.) A.Gray	!		FEN		OLI	TRL	INT	FLD	NO
Dryopteris dilatata	(Hoffmann) A.Gray			LIT	CIR	EUT				
Echinodorus ranunculoides	(L.) Engelmann ex Ascherson	!	2	SMP						
Eleocharis palustris										
ssp. palustris				SMP	CIR		TRL	FLK	FLD	NO
ssp. uniglumis	(Link) Hartman			SMP	CIR		TRL	FLK	FLD	NO
Eleocharis quinqueflora	(Hartmann) Schwarz	!	2	DAV	LTH	OLI	XRC	FLK	SEP	RFN

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Empetrum nigrum	L.			BOG		OLI	OMB	HUM	NO	MOS
Epilobium hirsutum	L.			LIT	LTH	EUT				
Epilobium palustre	L.	!		FEN	LTH	MES	TRL	FLK	ANY	NO
Epilobium parviflorum	Schreber			LIT	LTH	MES				
Epipactis palustris	(L.) Crantz	!	3	DAV	LTH	OLI	XRC	INT	SEP	NO
Equisetum arvense	L.			LIT	LTH	OLI	TRL	HUM	ANY	NO
Equisetum fluviatile	L.			FEN	CIR	MES	TRL	FLK	FLD	NVA
Equisetum palustre	L.			SMP		OLI	WMS	INT	ANY	NO
Erica tetralix	L.		5	BOG	ATM	OLI				
Eriophorum angustifolium	Honckeny		5	FEN	ATM	OLI	POR	FLK	FLD	NVA
Eriophorum gracile	Roth	#	1	LAS	LTH	OLI	WMS	FLK	FLD	NVA
Eriophorum vaginatum	L.	!	3	BOG	ATM	OLI	OMB	HUM	NO	MOS
Eupatorium cannabinum	L.			LIT	LTH	EUT				
Euphrasia stricta	Wolff ex J.F.Lehmann	!		BOG						
Eurhynchium praelongum	(Hedw.) Schimp.			SMP		EUT				
Eurhynchium striatum	(Hedw.) Schimp.			MOL	CIR	MES				
Festuca arundinacea	Schreber			LIT	CIR	MES				
Festuca ovina	L.			LIT	ATM		WMS	HUM	SEP	RFN
Festuca rubra	L.			MOL	CIR	MES	WMS	INT	FLD	RFN
Filipendula ulmaria	(L.) Maximowicz			LIT	LTH	MES	WMS	INT	ANY	NO
Fissidens adianthoides	Hedw.	#		DAV		MES	XRC	FLK	ANY	RFN
Fontinalis antipyretica	Hedw.	!		AQU	LTH	MES	TRL	FLK	SEP	NO
Frangula alnus	Miller			FEN	LTH		WMS	HUM	ANY	NO
Fraxinus excelsior	L.			SMP	CIR	EUT	XRC	HUM	ANY	NO
Funaria hygrometrica	Hedw.			LIT	CIR	EUT				
Galeopsis bifida	Bönninghausen			LIT						
Galium palustre	L.			SMP	CIR		TRL	FLK	ANY	NO
Galium uliginosum	L.		6	MOL	CIR	OLI	TRL	INT	FLD	NO
Gentiana pneumonanthe	L.	!	5	MOL	ATM	OLI				
Glyceria maxima	(Hartman) Holmberg			SMP	LTH	EUT				
Hammarbya paludosa	(L.) O.Kuntze	!	1	FEN	CIR	OLI	WMS	FLK	FLD	RFN
Heracleum sphondylium	L.			LIT	LTH	MES				
Hierochloë odorata	(L.) Beauv.	!	6	LIT	CIR	OLI	WMS	INT	FLD	I
Holcus lanatus	L.			MOL	CIR	MES				
Humulus lupulus	L.			SMP	CIR	EUT				
Hydrocharis morsus-ranae	L.			AQU	CIR	EUT				
Hydrocotyle vulgaris	L.			LIT	ATM	OLI				
Hypericum tetrapterum	Fries			MOL	CIR	OLI				
Hypnum jutlandicum	Holmen et Warncke			BOG	ATM	OLI				
Impatiens noli-tangere	L.	!		SMP	CIR	MES	WMS	FLK	SEP	NO
Iris pseudacorus	L.			SMP	CIR	EUT	WMS	FLK	FLD	NO
Juncus acutiflorus	Ehrhart ex Hoffmann	!		MOL	CIR	OLI				
Juncus articulatus	L.			LIT	CIR	OLI				
Juncus bulbosus	L.	!		SMP	ATM	OLI				
Juncus conglomeratus	L.			LIT	ATM	OLI				
Juncus effusus	L.			LIT	ATM	OLI				
Juncus filiformis	L.	!	6	MOL	CIR	OLI	TRL	FLK	FLD	NO
Juncus gerardii	Loisel.			SMA		MES				
Juncus subnodulosus	Schrank	!		LIT	LTH					
Kurzia pauciflora	(Dicks.) Grolle	!		BOG	ATM	OLI				
Lathyrus palustris	L.	!	6	LIT	LTH	OLI	WMS	INT	FLD	NO
Lemna gibba + Lemna minor	L.			AQU						
Lemna trisulca	L.			AQU	LTH	EUT				
Leontodon autumnalis	L.			LIT						
Leucobryum glaucum	(Hedw.) Ångstr.			BOG	ATM	OLI				

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Linum catharticum	L.	!	3	MOL	LTH	OLI				
Liparis loeselii	(L.) Richard	#	2	LAS	LTH	OLI				
Lonicera periclymenum	L.			FEN	ATM	MES				
Lophocolea bidentata	(L.) Dum.			LIT		EUT				
Lophocolea heterophylla	(Schrad.) Dum.			LIT	CIR	MES				
Lotus uliginosus	Schkuhr			MOL	CIR	MES				
Luzula campestris	(L.) DC.			BOG	ATM	OLI				
Luzula multiflora ssp. multiflora				MOL	CIR	OLI				
Lychnis flos-cuculi	L.		5	MOL	CIR	MES	WMS	INT	SEP	NO
Lycopus europaeus	L.			SMP	LTH	MES	WMS	FLK	FLD	NO
Lysimachia thyrsiflora	L.		6	SMP	CIR	OLI	TRL	FLK	FLD	NO
Lysimachia vulgaris	L.			LIT	CIR	OLI	TRL	FLK	FLD	NO
Lythrum salicaria	L.			LIT	CIR	MES	TRL	FLK	FLD	NO
Marchantia polymorpha	L.			SMP	LTH	EUT				
Mentha aquatica	L.			SMP	CIR	MES				
Menyanthes trifoliata	L.	#	5	FEN		OLI	POR	FLK	FLD	NVA
Mnium hornum	Hedw.			LIT	ATM	OLI	TRL	HUM	FLD	NO
Moehringia trinervia	(L.) Clairville			SMP	CIR	EUT				
Molinia caerulea	(L.) Mönch			MOL	ATM	OLI	WMS	INT	ANY	RFN
Myosotis laxa	Lehmann			SMP		MES				
Myosotis palustris	(L.) L.			MOL	ATM	MES				
Myrica gale	L.	!		FEN	CIR	MES	TRL	HUM	FLD	NO
Nardus stricta	L.			BOG	ATM	OLI	WMS	INT	SEP	NO
Nasturtium microphyllum	(Bönninghausen) Airy Shaw			SMP	CIR	EUT				
Nuphar lutea	(L.) J.E.Smith			AQU	CIR		TRL	FLK	FLD	NO
Nymphaea alba	L.			AQU	CIR	EUT	TRL	FLK	FLD	NO
Oenanthe aquatica	(L.) Poiret			SMP	LTH	MES				
Oenanthe fistulosa	L.			SMP	CIR	MES				
Ophioglossum vulgatum	L.	!	6	MOL						
Osmunda regalis	L.	!		LIT	CIR	MES				
Oxycoccus macrocarpos	(Aiton) Pursh	!		BOG		OLI				
Oxycoccus palustris	Persoon	!	5	BOG	ATM	OLI	OMB	FLK	FLD	NVA
Pallavicinia lyellii	(Hook.) S.F.Gray	!		FEN	ATM	MES				
Parnassia palustris	L.	#	3	DAV	LTH	OLI	WMS	INT	ANY	NO
Pedicularis palustris	L.	!	3	LAS	CIR	OLI	WMS	FLK	FLD	NVA
Pellia endiviifolia	(Dicks.) Dum.	!		DAV	LTH	OLI	TRL	INT	ANY	NO
Pellia epiphylla	(L.) Corda			LIT	ATM	EUT	TRL	INT	ANY	NO
Pellia neesiana	(Gottsche) Limpr.	!		LAS	CIR	MES	TRL	INT	ANY	NO
Peucedanum palustre	(L.) Mönch	!		FEN	CIR	OLI	TRL	FLK	FLD	NO
Phalaris arundinacea	L.			SMP	CIR	MES	TRL	INT	FLD	NO
Philonotis marchica	(Hedw.) Brid.	#		DAV	LTH	OLI	WMS	FLK	SEP	NO
Phragmites australis	(Cavanilles) Trinius ex Steudel			SMP	LTH	MES	WMS	FLK	FLD	RFN
Pinus sylvestris	L.			BOG	ATM		OMB	HUM	NO	MOS
Plagiomnium affine	(Bland.) T.Kop.			LIT	CIR	EUT	WMS	FLK	ANY	NO
Plagiomnium elatum	(Bruch et Schimp.) T.Kop.	!		DAV	LTH	MES	XRC	FLK	SEP	NO
Plagiomnium ellipticum	(Brid.) T.Kop.			SMP	CIR	EUT	WMS	FLK	ANY	NO
Plagiothecium denticulatum var. undulatum	Ruthe ex Geh.			LIT	CIR	EUT	TRL	HUM	SEP	NO
Plantago lanceolata	L.			LIT						
Platanthera bifolia	(L.) Richard	!		MOL	CIR					
Pleurozium schreberi	(Brid.) Mitt.			MOL	ATM	OLI	OMB	HUM	NO	MOS
Poa palustris	L.			SMP	CIR	MES	TRL	INT	FLD	NO
Poa pratensis	L.			LIT		MES				

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Poa trivialis	L.			SMP	LTH	EUT	WMS	FLK	SEP	NO
Pohlia nutans	(Hedw.) Lindb.			LIT	ATM	MES	OMB	HUM	NO	MOS
Polygonum amphibium	L.			SMP		EUT				
Polygonum hydropiper	L.			SMP	ATM	EUT				
Polytrichum commune	Hedw.			FEN	ATM	OLI	POR	HUM	SEP	NO
Polytrichum juniperine	Hedw.	!		BOG	ATM	OLI	OMB	HUM	NO	MOS
Polytrichum longisetum	Swartz ex Brid.			LIT		MES	TRL	INT	FLD	NO
Populus tremula	L.			BOG			TRL	HUM	SEP	NO
Potentilla anglica	Laicharding			LIT						
Potentilla anserina	L.			LIT		EUT				
Potentilla erecta	(L.) Räuschel	!		MOL	ATM	OLI	WMS	INT	SEP	RFN
Potentilla palustris	(L.) Scopoli			FEN	ATM	OLI	TRL	FLK	FLD	NVA
Potentilla reptans	L.			LIT	CIR	MES				
Prunella vulgaris	L.			MOL		OLI				
Pseudoscleropodium purum	(Hedw.) Fleisch. ex Broth.			BOG		MES				
Quercus robur	L.			BOG						
Ranunculus acris	L.			MOL	CIR	MES	WMS	HUM	SEP	NO
Ranunculus ficaria	L.			LIT	LTH	EUT				
Ranunculus flammula	L.			LIT	CIR	OLI				
Ranunculus lingua	L.	!	5	SMP	LTH	MES				
Ranunculus repens	L.			LIT		EUT	TRL	FLK	ANY	NO
Ranunculus sceleratus	L.			SMP	CIR	EUT				
Rhinanthus angustifolius	C.C.Gmelin	!	5	MOL	CIR	OLI				
Rhizomnium pseudopunctatum	(Bruch et Schimp.) T.Kop.	!		DAV	CIR	MES	WMS	FLK	SEP	RFN
Rhizomnium punctatum	(Hedw.) T.Kop.	!		DAV	ATM	MES	TRL	INT	SEP	NO
Rhytidiadelphus squarrosus	(Hedw.) Warnst.			MOL		MES				
Riccardia multifida	(L.) S.F.Gray	#		LAS	CIR	OLI				
Riccia fluitans	L.	!		SMP	CIR	MES				
Ricciocarpos natans	(L.) Corda	!		SMP	LTH	MES				
Rorippa amphibia	(L.) Besser			SMP	CIR	EUT				
Rubus fruticosus	L.			LIT		EUT				
Rumex acetosa	L.			MOL	CIR	MES	WMS	INT	SEP	NO
Rumex hydrolapathum	Hudson			SMP	CIR	EUT				
Rumex palustris	J.E.Smith			SMP						
Sagina nodosa	(L.) Fenzl	#	3	LAS	LTH	MES				
Sagina procumbens	L.			LIT	CIR	MES				
Salix aurita	L.	!		FEN	CIR	OLI	POR	HUM	ANY	NO
Salix cinerea	L.			FEN	CIR	OLI	TRL	HUM	FLD	NO
Salix pentandra	L.	!		FEN	LTH	MES	WMS	INT	FLD	NO
Salix repens	L.	!		MOL	CIR	OLI	TRL	HUM	ANY	NO
Samolus valerandi	L.	!		SMA		MES				
Sanguisorba officinalis	L.	!	6	MOL	CIR	OLI				
Scirpus lacustris										
ssp. lacustris		!		SMP	LTH	MES	WMS	FLK	FLD	NO
ssp. tabernaemontani	(C.C.Gmelin) Syme	!		SMP	LTH		WMS	FLK	FLD	NO
Scirpus maritimus	L.			SMA	LTH	MES				
Scorpidium cossoni	(Schimp.) Hedenäs	#		DAV	LTH	OLI	XRC	INT	NO	RFN
Scorpidium lycopodioides	(Brid.) Paul	see Drepanocladus l.								
Scorpidium revolvens (pro parte)	(Swartz) Rubers	see S. cossoni								
Scorpidium scorpioides	(Hedw.) Limpr.	#		LAS	LTH	OLI	XRC	FLK	FLD	RFN
Scutellaria galericulata	L.			SMP	CIR	MES	TRL	INT	FLD	NO
Senecio paludosus	L.			SMP		MES				
Sium latifolium	L.			SMP	LTH	EUT				

Species Name	Author	T	R	Typ	Wat	Nut	Bas	Lev	Ext	Inh
Solanum dulcamara	L.			SMP		EUT	XRC	FLK	FLD	NO
Sonchus palustris	L.		6	LIT	CIR	EUT				
Sorbus aucuparia	L.			LIT			TRL	HUM	SEP	NO
Sparganium emersum	Rehmann			SMP	CIR	MES				
Sparganium erectum	L.			SMP	CIR	MES				
Sparganium minimum	Wallroth	!	3	SMP	CIR	OLI				
Sphagnum contortum	K.F.Schultz	!		LAS	CIR	MES	XRC	FLK	ANY	RFN
Sphagnum fimbriatum	Wils.			FEN		MES	TRL	INT	FLD	NO
Sphagnum flexuosum	Dozy & Molk.			FEN	ATM	MES	OMB	HUM	NO	MOS
Sphagnum fuscum	(Schimp.) Klinggr.	!		BOG	ATM	OLI	OMB	HUM	NO	MOS
Sphagnum magellanicum	Brid.	!		BOG	ATM	OLI	OMB	HUM	NO	MOS
Sphagnum palustre	L.			FEN						
Sphagnum papillosum	Lindb.	!		BOG	ATM	OLI	OMB	HUM	NO	NVA
Sphagnum riparium	Ångstr.	!		FEN	ATM	MES	TRL	FLK	FLD	NO
Sphagnum rubellum	Wils.	!		BOG	ATM	OLI	OMB	HUM	NO	NVA
Sphagnum russowii	Warnst.	!		BOG	ATM	MES	OMB	HUM	SEP	MOS
Sphagnum squarrosum	Crome in Hoppe			LIT	CIR	EUT	TRL	INT	FLD	NO
Sphagnum subnitens	Russ. & Warnst.	!		LAS	CIR	MES	WMS	INT	NO	RFN
Sphagnum subsecundum ssp. subsecundum	Nees	!		LAS	CIR	OLI	WMS	FLK	FLD	RFN
Sphagnum teres	(Schimp.) Ångstr.	!		FEN	CIR	OLI	WMS	INT	ANY	NO
Spirodela polyrhiza	(L.) Schleiden			AQU		EUT				
Stachys palustris	L.			LIT	CIR	MES				
Stellaria palustris	Retzius		6	FEN	CIR	MES	TRL	INT	FLD	NO
Succisa pratensis	Mönch	!	5	MOL	ATM	OLI				
Symphytum officinale	L.			SMP		EUT				
Thalictrum flavum	L.			LIT	CIR	OLI				
Thelypteris palustris	Schott	!		FEN	CIR	MES	WMS	FLK	FLD	NO
Trifolium dubium	Sibthorp			MOL	CIR	MES				
Trifolium pratense	L.			MOL	LTH	MES				
Trifolium repens	L.			LIT	CIR	EUT				
Triglochin maritima	L.			SMA			XRC	INT	NO	NO
Triglochin palustris	L.			LIT	LTH	OLI	WMS	FLK	SEP	RFN
Typha angustifolia	L.			SMP	LTH	MES	WMS	FLK	FLD	NO
Typha latifolia	L.			SMP		EUT	WMS	FLK	FLD	NO
Urtica dioica	L.			SMP	CIR	EUT	WMS	INT	SEP	NO
Utricularia intermedia	Hayne	#	1	LAS	LTH	OLI	TRL	FLK	FLD	NVA
Utricularia minor	L.	!		FEN	CIR	MES	TRL	FLK	FLD	NVA
Utricularia vulgaris	L.			SMP	CIR	MES	TRL	FLK	FLD	NO
Vaccinium vitis-idaea	L.			BOG	ATM	OLI	OMB	HUM	NO	MOS
Valeriana dioica	L.	!	5	MOL	CIR	OLI				
Valeriana officinalis	L.			LIT	LTH	MES				
Veronica anagallis-aquatica	L.		6	SMP		MES				
Veronica beccabunga	L.			SMP	CIR	MES				
Veronica scutellata	L.		6	LIT						
Viburnum opulus	L.			SMP	CIR	MES	WMS	HUM	ANY	NO
Vicia cracca	L.			MOL	CIR	OLI				
Viola palustris	L.	!	6	FEN	ATM	MES	TRL	INT	FLD	NO

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX D

Evaluation of the major-ionic composition of **natural waters**

D.1 Processing of water quality data

General introduction

The ionic composition of natural waters plays an important role in ecological studies for the protection of nature. A method for the mutual comparison of water analyses on the basis of their similarity to certain chosen reference waters was developed for use in such studies. The calculations involved in this method can be done with a computer program called MAION, and this name MAION was also chosen for the method as a whole. The MAION method was specially developed during the present study of the hydrological ecology of quagfen vegetation in North-West Overijssel. It is separately dealt with in this appendix, together with several auxiliary functions of the MAION program.

The MAION method combines several well-known procedures from the literature with some new ideas. The main additions to be discussed are: (1) the EC-IR diagram with the LAT framework and the MIX model, and (2) the development of a similarity formula for water analyses. Moreover, existing solutions for common problems were re-formulated in order to facilitate their application: (3) a new recipe for the construction of Maucha diagrams, (4) an activity-based procedure for the calculation of electrical conductivity, with some alternative formulae for the activity coefficients, and (5) the introduction of pHsat as an indicator of the carbonate equilibrium state.

The analysis of a water sample yields a list of numerical data, most of which represent the amount of a chemical species present in a unit volume of the sample. Some other numbers apply to physical features of the sample, such as its electrical conductivity, or its pH. In order to supply a reliable picture of the water quality, the analysis should at least comprise all major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, $SO_4^{=}$, HCO_3^{-}) and the other most important plant nutrients (P, N). The MAION method is suitable for the processing of data concerned with the major ions, pH, and electrical conductivity. It will be shown that analyses comprising only some of these parameters can still be profitably used in connexion with a limited number of more elaborate analyses and even without such a framework.
The first section of this appendix (D.1) comments on current notational conventions and introduces various aspects of data processing in MAION, among which a new recipe for the construction of Maucha diagrams. The formulae used in MAION are presented and dicussed in detail in Section D.2, including a discussion of activity coefficients, the derivation of similarity coefficients, and the introduction of pH as a practical indicator of the carbonate equilibrium state. Section D.3 deals with the interpretation of MAION results in the light of differences in water chemistry observed in North-West Overijssel and supposed to be significant also for ecological studies elsewhere. Section D.3 includes an account of the use of the EC-IR diagram in connexion with the LAT benchmark analyses and the MIX model for an ecological interpretation of hydro-analytical data.
Since this appendix deals especially with the MAION method, no attention will be paid here to several other important aspects of processing and interpretation of water analyses, such as the presence of N and P compounds and toxic substances, and the dissolution and precipitation of minerals, with the exception of the calcite equilibrium.

It must be emphasized that several of the major ions are quite often deliberately disregarded in water studies (*e.g.*, in most of the official water-quality monitoring programs in The Netherlands). Often correlations are sought between concentrations of single constituents and other phenomena. Especially in biological ecology this correlative approach is often followed, with the intention of constructing "response models" and "indicator lists", as in Segal (1966b), De Lange (1972), Seddon (1967), and Hutchinson (1975, Chapter 30). This type of correlative studies served as the basis for water-quality standards, as in the Dutch "IMP" policy program for water-quality management. This train of thought will not be followed in this appendix.

To improve the readability of this appendix,some sample analyses have been used to exemplify the various aspects of data processing discussed. These analyses are presented in Table D.1 together with the outcome of the MAION calculations to be discussed later on. The sample analyses used represent types of water regarded as very diverse from the ecological point of view. LI-ANG is a relatively calcium-rich groundwater; AT-W80 is precipitation caught in a relatively unpolluted inland area of The Netherlands,

Table D.1 The water analyses of the samples spanning the LAT framework LI-ANG, AT-W80, and TH-N70, and the composition of Rhine water at Lobith in 1975 (RH-LOB)

Sample code		**LI(ANG)**	**AT(W80)**	**TH(N70)**	**RH(LOB)**
Date of sampling	801208	1980	820727	1975	
Analytical data:					
pH		7.3	4.22	8.3	7.8
Ca^{2+}	mg/l	115	0.42	420	82
Mg^{2+}	mg/l	8	0.20	1400	10
Na^{+}	mg/l	12	1.60	10480	96
K^{+}	mg/l	2	0.23	390	7
alkalinity	mmol(c)/l	6.6	0.00	2.0	2.6
Cl^{-}	mg/l	11	2.97	19100	178
$SO_4^{=}$	mg/l	13	5.79	2640	80
EC_{25}	mS/m	65.1	5.01	5200	99.6
Ionic balance and partial molar(c) fractions:					
x= (cat-an)/(cat+an) (%)		-1.2	-8.4	0.5	-0.1
$f(c)H^{+}$	%	0.0	34.7	0.0	0.0
$f(c)½Ca^{2+}$	%	82.3	12.1	3.5	44.1
$f(c)½Mg^{2+}$	%	9.4	9.5	19.1	8.9
$f(c)Na^{+}$	%	7.5	40.3	75.7	45.1
$f(c)K^{+}$	%	0.7	3.4	1.7	1.9
$f(c)HCO_3^{-}$	%	91.9	0.0	0.3	28.0
$f(c)Cl^{-}$	%	4.3	41.0	90.4	54.1
$f(c)½SO_4^{=}$	%	3.8	59.0	9.2	17.9
Ionic strength and calculated EC_{25}:					
Ionic Strength	mol(c)/l	0.010	0.00027	0.70	0.013
ECc	mS/m	65.8	4.27	4782	101
y= (ECm-ECc)/ECm (%)		-1.0	14.8	8.0	-1.7
Special ratios:					
IR	%	94.9	20.0	3.7	44.9
ECaR	%	52.4	2.5	2.4	24.4
EClR	%	3.6	12.8	79.1	38.5
Coefficients of similarity:					
rLI	%	100.0	-55.6	30.1	43.8
rAT	%	-55.6	100.0	-17.0	-1.0
rTH	%	30.1	-17.0	100.0	82.1
rRH	%	43.8	-1.0	82.1	100.0
Additional data:					
N in NH_4^{+}	mg/l		1.32		
N in NO_3^{-}	mg/l		0.77		

Analytical data and results of the application of MAION (Section D.2). Further details about these samples are given in Section D.3.

acquired a particular meaning in the MAION method, since they constitute the so-called LAT framework introduced and discussed in Section D.3. RH-LOB represents water of the river Rhine at Lobith. This water is badly polluted by human activities. Rhine water is the main source of water in many parts of The Netherlands during periods of drought.

Notational and conceptual conventions

Electrical conductivity

The electrical conductivity (EC) will be expressed in the SI unit mS/m and always refers to the standard temperature of 25 °C (EC_{25}, see Section D.2). For a comparison with the earlier current unit µS/cm (or µmho/cm) it may be noted that 1 mS/m = 10 µS/cm. No reduction was applied for the contribution of $[H^+]$.

Concentration units

Most of the analyses used in the present publication have been reported as mass per unit volume of the pure ionic form of the constituents (1 mg/l = 1 g/m^3). For calculations such as those used in MAION, the concentrations have been expressed as moles of charge per unit volume (1 mmol(c)/l = 1 mol(c)/m^3). Ionic strength, however, is used as a dimensionless number, which is always calculated on the basis of mol/l (see below: 1 mol(c)/l = 1000 mmol(c)/l).

The mole concept

A few words on the "mole" concept may be appropriate here. In older writings the concept is often restricted to atoms, molecules, or ions. Thus, in a solution of $CaCl_2$, twice as many moles of Cl^- will be present as there are moles of Ca^{2+}. For solutions of ionizing substances, the "equivalent" concept was introduced to facilitate charge-related computations. Each mole of an ion was now defined to comprise as many equivalents as to equal its charge number. One mole of Ca^{2+} ions in an aqueous solution thus equalled two equivalents of Ca^{2+}. This concept is no longer recognized in the SI (Système International d'Unités, International System of Units), and it will not be used here.

The SI defines a mole of a substance as the amount of that substance which contains Avogadro's number of elementary entities (atoms, molecules, ions, charges, etc.), *i.e.*, 6.02 x 10^{23}. This definition requires a precise statement of the elementary entities the moles refer to (Schurer & Rigg 1980, p.6). In line with this recommendation the following notations will be used:

- mol(c) for moles of charge, *i.e.*, the earlier equivalents. Molar concentrations in mol(c)/m^3 are symbolically indicated by the specification of the elementary entities involved, which indication is surrounded by square brackets:

  $$[Na^+], [½Ca^{2+}], ..., [1/nX^{n+}], [1/nY^{n-}] \text{ mol(c)/m}^3$$

  Throughout this publication, moles of charge will be used whenever applicable; '½Ca^{2+}' ('halfCalcium') so is a symbol, not an arithmetical formula;

- mol(a) for atomic, molecular or ionic moles, *i.e.*, the "old" moles. Molar concentrations in $mol(a)/m^3$ are symbolically indicated by the specification of the elementary entities involved, which indication is surrounded by square brackets:

$$[Na^+], [Ca^{2+}], [CaCl_2], ..., [X^{n+}], [Y^{m-}], [X_mY_n] \text{ mol(a)/m}^3$$

Quantitatively, the relation between concentrations in mol(c) and mol(a) per unit volume is:

$$[_{1/n}X^{n+}] \text{ mol(c)/m}^3 = n[X^{n+}] \text{ mol(a)/m}^3$$

Note that formally the parameter "ionic strength" (Section D.2) is also a molar concentration (mol/l). The ionic strength moles are neither straightforward moles(a), nor moles(c). In formulae used in this publication, the ionic strength will be treated as a dimensionless number. The form of the formula for the computation of ionic strength as presented in Section D.2 requires mol(c)/l input values for the ionic concentrations.

Partial molar(c) fractions
The ionic composition of a water sample can be expressed by calculating the share of individual ionic species as a percentage of the total concentration of moles of the same type. These shares will be called partial molar fractions here. For partial molar fractions, the mol(c) scale has been used throughout this publication. For cationic species the sum of cations has been used as a total, and for anionic species the sum of anions, and each fraction is expressed as a percentage:

$$f(c)½Ca^{2+} = 100\ [½Ca^{2+}]/[cat] \text{ and } f(c)Cl^- = 100\ [Cl^-]/[an]\ (\%)$$

where:

$f(c)_{1/n}X^{n+/-}$	is the partial molar(c) fraction of X in %
[cat]	is the sum of cations in $mol(c)/m^3$
[an]	is the sum of anions in $mol(c)/m^3$
$[½Ca^{2+}]$	is the concentration of $½Ca^{2+}$ in $mol(c)/m^3$
$[Cl^-]$	is the concentration of Cl^- in $mol(c)/m^3$

Partial molar fractions are used in several types of diagrams, such as triangular diagrams according to Piper and radial diagrams according to Maucha.

Special ratios and similarity coefficients
The special ratios introduced in this appendix are expressed as percentages with numerical values between 0 and approximately 100. The numerical value of the similarity coefficient defined in Section D.2 ranges from -1.00 to +1.00. Similarity coefficients have often been expressed as percentages also.

Reliability of analytical data

One must bear in mind that the analytical concentrations found in a water sample may well differ from the representative, "real" concentrations in the water sampled. The following arguments may account for possible discrepancies:

- The sample may be not representative. Cost factors commonly prevent statistically "safe" numbers of samples to be collected and analysed;

- Not all constituents present in the sampled solution are determined. Especially the concentrations of naturally occurring organic solutes, such as humic acids, are not specifically assessed;
- Changes during transport and storage of samples sometimes considerably alter their physico-chemical and biological properties. Improved filtering procedures, specific preservatives and careful planning of storage can diminish such changes, but they still modify the solution (Hem 1970, p.86-88);
- Errors may still occur in spite of careful procedures;
- Results of chemical analyses are given as concentrations of a chemical entity. Several elements may occur in different forms, however, and it is not always easy to infer the concentrations of each of them (compare Hem 1970, p.234).

A first stage in data processing, therefore, should involve checks for consistency. MAION incorporates checks of electroneutrality and of electrical conductivity (Section D.2). When these checks do not reveal major discrepancies, it is generally assumed that:
- No major errors have been made;
- A solution prepared with the analytical results as a recipe would, in the same reactive environment of nature, act in the same way as does the sampled solution.

Of course, the checks do not permit any conclusion regarding the sample being representative of the body of water studied.

The use of partial molar(c) fractions as measures of ionic composition

When a number of water analyses is available, it is possible to compare the analyses and to infer their possible relationships. Such relationships may exist when the samples reflect different stages in processes which alter bodies of water with initially equal concentrations, or when individual portions of such bodies of water come into contact with different environments. Water samples may also be related when they originate from mixing of the same water types. Several of these processes may well occur simultaneously and some concentrations may be more strongly altered by any such process than other ones. Exact calculations may become fairly complex, and graphical representations can help to arrive at valuable hypotheses. The computation of partial molar fractions provides the input parameters for the graphical representation in triangular diagrams according to Piper and in radial diagrams according to Maucha. These are shortly discussed below.

Triangular diagrams according to Piper

A triangular diagram according to Piper (Hem 1970, p.264-270) comprises three parts: the cations triangle, the anions triangle, and a quadrangle combining both (Fig.D.1). The overall concentration of the samples is not reflected in the diagram, although this may be achieved by choosing symbols with a different surface area to represent different overall concentrations. An advantage of the Piper diagram is that it enables a quick comparison of many samples in one diagram. When the surface area of the symbols is made proportional to the overall concentrations of the water samples, the readibility of the diagram becomes poorer, however. Each of the three parts of the Piper diagram may be used separately.

In Fig.D.1, the points representing the three "extreme" samples LI-ANG, AT-WTV, and TH-N70 have been connected to form a contour which encloses the plotting area of all possible, simple mixtures of the waters represented by these analyses. RH-LOB was added as a fourth point.

Note:

The original graph (upper left corner) showed At-W80 in a wrong position.

It should be noted that, in Piper diagrams, the partial molar fraction of f(c)H^+ is not included in the sum of cation concentrations.

The symbols L, A, T, M are used for LI-ANG, AT-W80, TH-N70 and RH-LOB, respectively.

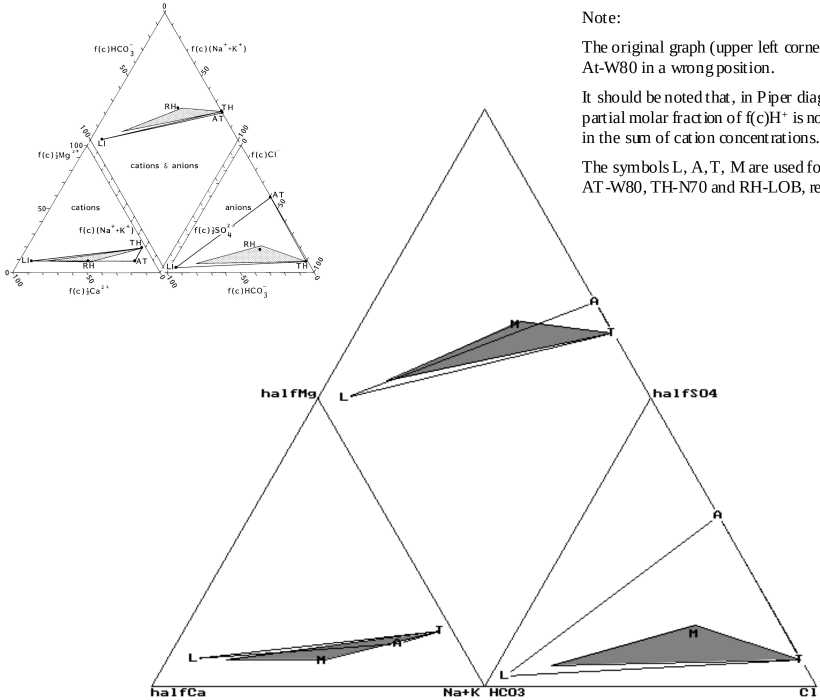


Fig.D.1 Piper diagram, showing the LAT analyses (LI-ANG, AT-W80, TH-N70), the analysis of RH-LOB, and certain mixtures

The triangular contours LI-AT-TH-LI delineate the plotting fields for mixtures of LI, AT, and TH. The dotted triangular areas represent the plotting fields for mixtures of 20% by volume of RH with 80% of the other samples.

The dotted plotting field represents samples which are composed of 20% by volume of RH-LOB and 80% of any combination of the three other waters. Note that in the quadrangle and in the left-hand triangle the very different samples TH an AT plot at nearly the same positions since the overall concentrations are not involved in the Piper diagram.

Radial diagrams according to Maucha

The radial diagram according to Maucha (1932, p.87-89) is illustrated in Fig.D.2. Maucha refers to this diagram as a modification of an unpublished suggestion by I. Telkessy, and Schoeller (1962, p.321-322) calls it the "Telkessy diagram". I will follow Hutchinson (1975, p.557-559), Moore & Bellamy (1973, p.60), and other authors calling it a Maucha diagram.

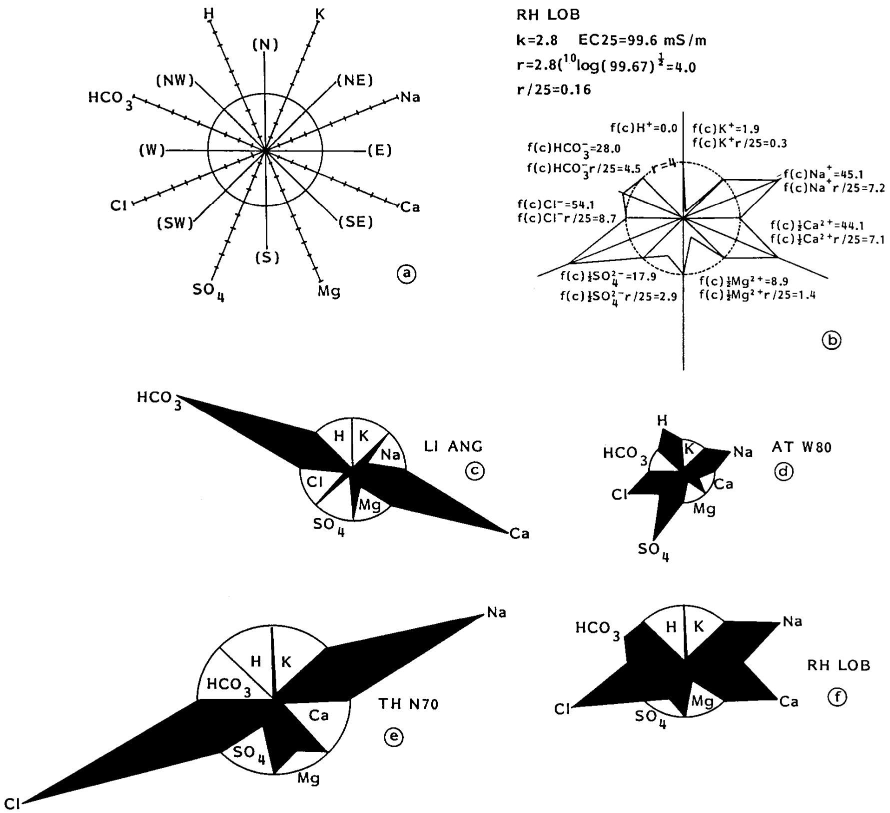


Fig.D.2 Maucha diagrams for the analyses LI-ANG (c), AT-W80 (d), TH-N70 (e), and RH-LOB (f), including illustrations of the construction of a Maucha diagram (a,b)
The radius of each diagram is proportonal to the square root of $^{10}\log EC_{25}$

Each water sample is represented by one individual diagram, thus enabling the visual comparison of features of the waters concerned. One may either use different radial lengths to represent different overall concentrations, or use equal radial lengths for all diagrams. Maucha diagrams are very distinct and suitable for use as map symbols. Fig.D.2 shows the Maucha diagrams for the four analyses LI-ANG, AT-W80, TH-N70, and RH-LOB, and also demonstrates the construction of such diagrams, as explained below. This method has generally been regarded as computationally cumbersome, which has probably held up its wide application. To overcome this problem, the recipe has been modified, so as to enable manual drawing. This recipe has been implemented for computer application also.

Recipe for Maucha diagrams:

- If the concentration is not to be reflected, choose an arbitrary radius length r;
- Otherwise, define the radius length r of a circle, in such a way that the area will be proportional to a measure of overall ionic concentration C:

$$r=kC^{½}$$

where k is a constant. Ionic strength, electrical conductivity, or total moles(c)/m^3 may be used for C. When the overall concentrations are very different, as for the samples represented in Fig.D.2, it is often more convenient to use the logarithm of the overall concentration, *i.e.*,

$$r=k(^{10}\log C)^{½}$$

This has been done in Fig.D.2 and elsewhere in this publication. For one set of diagrams, the same rule should be used for the choice of r;
- Draw the 16 radii of a "compass card", as in Fig.D.2a, and draw the circle with radius r; Reserve the NNE, ENE, ..., NNW radii for fX= f(c)K^+, f(c)Na^+, f(c)½Ca^{2+}, f(c)½Mg^{2+}, f(c)½$SO_4^=$, f(c)Cl^-, f(c)HCO_3^-, and f(c)H^+, respectively;
- Using 1%=r/25, plot the values of fX on the respective radii at the distance

$$d=(fX)(r/25)$$

from the centre;
- Connect the marks on the radii with the points where the intervening radii (N, NE, ..., NW) intersect the circle with the radius r (Fig.D.2b) and fill the obtained symbol in with black;
- Since different authors may define the radial axes differenty, it is necessary to add indicators for the meaning of the axes. Especially the NNW compass point is often deliberately used for different parameters, but not so in this publication.

In the symbol obtained, the area of each black sector is proportional to the respective fX value, whereas the total black area in different symbols is either a constant, or proportional to the overall concentration, or proportional to the logarithm of the overall concentration (as in Fig.D.2), depending on the choice of r. The total black area also equals the area of the inscribed regular 16-angle in the circle.

The use of special ratios for the comparison of water analyses

The graphical methods described until now can only be used if all major ions have been analysed. Cost factors often prevent this from being done. Moreover, until about 1965 it was common practice to determine several major ion concentrations by computation, rather than by analysis, according to the following procedure:

The anionic concentrations were determined separately. Total hardness in German degrees (°D), and Ca^{2+} concentration were the only measures of cationic concentration determined analytically. Since the total hardness (HD) is almost completely attributable to the Ca^{2+} and Mg^{2+} ions, and since 1 °D refers to the same amount of moles(c) as there are moles(c) of ½Ca^{2+} in a solution of 10 mg/l of CaO,

$$[\tfrac{1}{2}Ca^{2+}]+[\tfrac{1}{2}Mg^{2+}] = 0.356\ HD\ \text{(concentrations in mol(c)/m}^3\text{, HD in °D)}$$

This formula enables the computation of the Mg^{2+} content from the total hardness and the Ca^{2+} content.

The Na^+ and K^+ contents in mol(c)/m^3 will often approximately equal the apparent surplus of anions:

$$[Na^+]+[K^+] = [\tfrac{1}{2}SO_4^{=}]+[Cl^-]+[HCO_3^-]-[\tfrac{1}{2}Ca^{2+}]-[\tfrac{1}{2}Mg^{2+}]$$

(concentrations in mol(c)/m^3)

Because Na^+ is present in much larger concentration than K^+ in most natural waters, the sum of the Na^+ and K^+ contents is reported as mg/l of Na^+ in this procedure.

Since it was thought desirable to have a means for the comparison of analyses of unequal completeness, some special ratios were developed, which summarize the supposedly most important features of water quality with respect to their concentrations of major ions. These ratios, called IR, IR*, EClR, and ECaR, will be discussed in detail in Section D.2. They are well correlated with f(c)½Ca^{2+} or with its complement. Especially the ionic ratio IR, defined as

$$IR = 100[\tfrac{1}{2}Ca^{2+}]/\{[\tfrac{1}{2}Ca^{2+}]+[Cl^-]\}\ \text{(concentrations in mol(c)/m}^3\text{, IR in \%)}$$

is often used in this publication, in combination with EC_{25} as a measure of the overall concentration. A graphical representation was adopted which has $^{10}\log(EC_{25})$ as abscissae and IR as ordinates. This EC-IR diagram (Van Wirdum 1978, 1980) enables a quick comparison of many water samples on the basis of both ionic composition (for which IR is a measure) and overall concentration (logEC). Fig.D.3 examplifies the EC-IR diagram. As in the Piper diagram (Fig.D.1), contours have been added which enclose the plotting area of all possible, simple mixtures of LI-ANG, AT-W80, and TH-N70. Also RH-LOB has been added for comparison. It may be seen that the EC-IR diagram plots these mixed samples in a much wider area than does the Piper diagram. This permits the addition of some further characteristic mixing isopleths as will be discussed in detail in Section D.3.

The use of coefficients of similarity in relation to chosen analyses

Sets of water analytical data are multidimensional data sets. Some of the graphical procedures discussed before are aimed at selecting representative combinations of parameters enabling the use of a two-dimensional diagram to represent supposed (dis)similarities between water samples by the distance between points in the diagram. The MAION similarity coefficients (Section D.2) were developed to obtain numerical data which reflect such similarities.

Water analyses from a particular region often do not show any appreciable difference, the less so when the types of water from which they possibly derive their quality are not native to the region, and thus may have escaped from being sampled. In such cases it is advisable to include analyses from elsewhere which represent these water types. When available, analyses

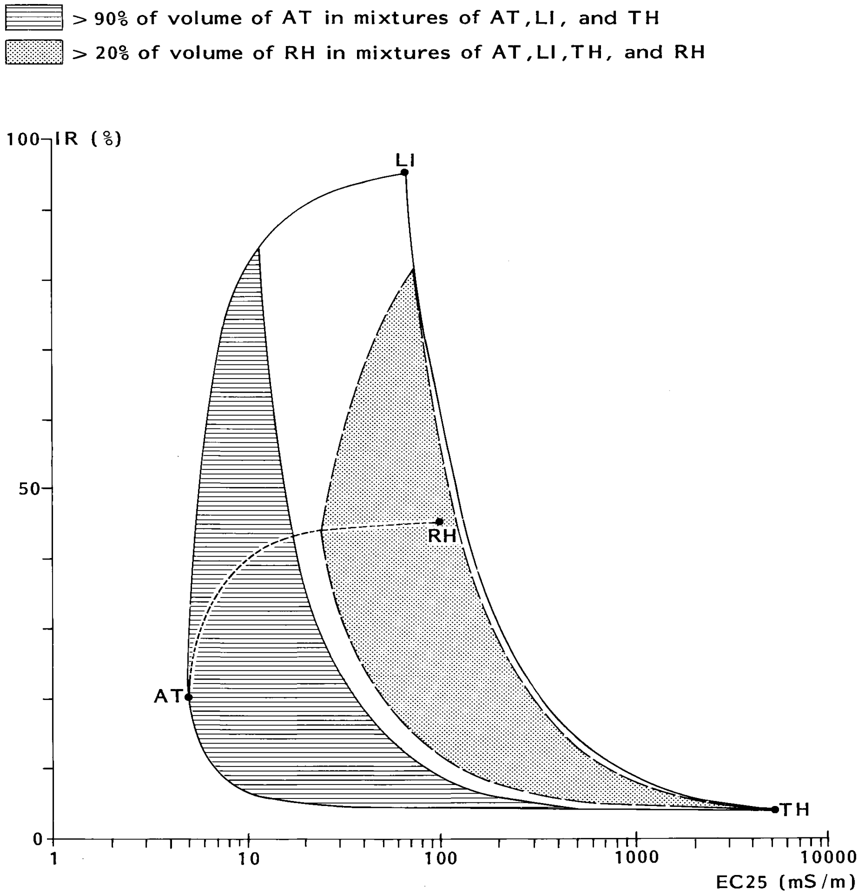


Fig.D.3 EC-IR diagram, showing the LAT-samples
The connecting lines represent simple mixtures (see also Fig.D.9)

should be taken from the source areas. It has appeared to be more convenient, however, to use a few typical analyses for reference. If carefully chosen, the similarity to two or three of such benchmark samples will efficiently summarize most of the features of the sample under study, as will be explained later. The samples LI-ANG, AT-W80, and TH-N70, none of which represents water native to North-West Overijssel, have been chosen as such benchmarks. They constitute the so-called LAT framework explained in Section D.3.

The similarity to these selected analyses can be used in a graphical representation, *e.g.*, a rTH-rLI diagram, of which Fig.D.4 is an example. This diagram will be explained in detail in

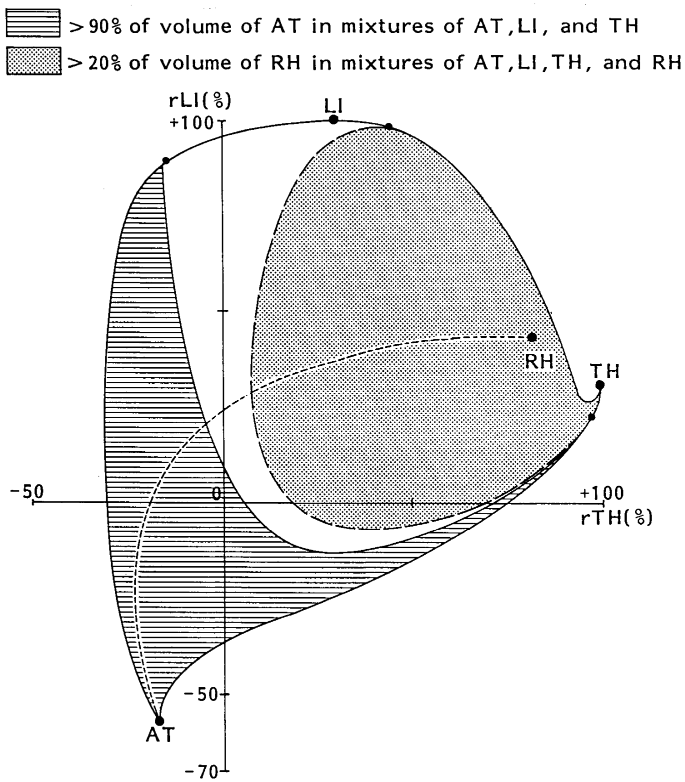


Fig.D.4 rTH-rLI diagram, showing the LAT analyses
The connecting lines represent simple mixtures (see Fig.D.12)

Section D.3, after the MAION similarity coefficient has been treated in Section D.2. The abscissa of any point in the diagram gives rTH, the similarity to TH-N70, while the ordinate represents rLI, the similarity to LI-ANG. Since, according to the MAION calculations (Table D.1), LI-ANG and TH-N70 have 30% similarity to each other, TH itself is plotted at the location (+100, +30) in the diagram, while LI is at (+30, +100). AT-W80 has rTH=-17% and rLI=-50%. The same contours and admixtures have been indicated as in the examples of the Piper diagram (Fig.D.1) and the EC-IR diagram (Fig.D.3). The LAT framework has proved to be useful for water-quality studies in different regions. Values of similarity coefficients can be easily shown on maps.

D.2 Definition of MAION functions and related procedures

The MAION program

The MAION program is the result of a development from manual calculations and graphical representations towards the use of programmable calculators and computers. At present, the program is available in the programming code for Hewlett-Packard series 41 programmable calculators (MAION41), and in the FORTRAN 77 (MAIONF) and Turbo-Pascal 3 (MAIONTP) source codes for microcomputers. The core functions of the MAION programs are treated in detail in this section.

The core functions of MAION are:
- Computation of the ionic balance, electroneutrality test;
- Computation of the electrical conductivity, conductivity test;
- Computation of the special ratio IR;
- Computation of the coefficients of similarity rLI, rAT, rTH, and rRH;
- Computation of the pH of saturation with respect to calcium carbonate;

The ionic balance and the electroneutrality test

The most frequently used check on the reliability of water analytical results is the electroneutrality test, based on the calculation of the ionic balance (Golterman *et al.* 1978, p.91; Hem 1970, p.233-234). In MAION, the ions H^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, $SO_4^=$, and HCO_3^- (or alkalinity) are taken into account, and it is tacitly assumed that no other ions are present in any appreciable amounts. According to Golterman *et al.*, this is justified when pH<9.5. $[H^+]$ is inferred from the pH. Some versions of MAION can take account of other ions. The notation H^+ will be used in this publication, rather than H_3O^+ or still different notations.

The basic concept of the electroneutrality test is that of equivalence of cations to anions. MAION presents the result of the test by the ratio

$$x= (cat-an)/(cat+an)$$

where:

cat	is the sum total of the cations in mol(c)/m^3
an	is the sum total of the anions in mol(c)/m^3
x	is usually reported as a percentage.

One of the reasons for a deviation of the electroneutrality may be the presence of other ions, such as NO_3^-, NH_4^+, and forms of Fe and Al. As it is often difficult to establish the formulae and charges of such constituents, their inclusion is not always unbiased. This especially holds true for solutions containing partly dissociated or complex-forming organic substances and micro-organisms, some of which may pass through micropore (0.45 µm) filters. In this study, a somewhat conservative procedure was followed, by using only the quantities of the above-mentioned eight ions. If no near-equivalence (-8% <x< 8%) was found, the possible presence of other ions was investigated, using analytical results (if available), or the measured conductivity as a criterion. No analyses were discarded if a sound reason was found for the deviation from the balance. In Table D.1, AT-W80 has x= -8.4%. In this analysis, inclusion of NH_4^+ and NO_3^- would yield the more satisfactory value x= 1.5%.

The conductivity test

Methods provided by the pertaining literature

Several authors dealing with aquatic chemistry have suggested procedures for the calculation of the electrical conductivity. Some of these procedures are entirely empirical, whereas other methods are based on physico-chemical theories. Several procedures of both types are comprised in a method proposed by Stuyfzand (1983). Stuyfzand selected a best fitting procedure for each of many types of water, and added regression constants in order to obtain an even better fit. A more theoretical approach has been maintained in MAION, however.

The theory for the calculation of electrical conductivity is reasonably well developed, especially for very dilute solutions. At conductivities below 10 mS/m, the electrical conductivity (EC) at a given temperature can be expressed as:

$$EC = \Sigma_i(C_i \lambda^{\infty}{}_i)$$

where:

EC	is the electrical conductivity of the solution in mS/m
C_i	is the molar concentration of ionic species i in mol(c)/m^3
$\lambda^{\infty}{}_i$	is the molar conductivity of ionic species i at infinite dilution in mS/m per mol(c)/m^3
Σ_i	is the sum total over all ionic species in solution

Consequently, Golterman *et al.* (1978, p.91-92) advise dilution of water samples with a known amount of demineralized water (with a known, but very low conductivity) until the electrical conductivity falls below 10 mS/m. This method is computationally simple, but it has the disadvantage of an extra manipulation of the sample in the laboratory, introducing at least three additional numerical data with inherent uncertainties: the volume and the conductivity of the water added, and the volume of the sample. Certain samples will, moreover, change in composition upon dilution.

The activity-based method used in MAION

The electrical conductivity of less diluted solutions is influenced by interactions among the ions in solution, which may vary for different ionic species. Although this is theoretically not quite permissible, earlier versions of MAION used the stoichiometric Debije-Hückel-Güntelberg activity coefficients (Stumm & Morgan 1970, p.83-84) to correct for these effects, which results in the following formulae, which can be used at 25°C and when $I < 0.1$:

$$I = 0.5\ 10^{-3} \Sigma_i(C_i |z_i|)$$

$$^{10}\log(f_i) = -0.5\ z_i^2\ I^{½} / \{1+(0.33\ a_i\ I^{½})\} \text{ with } a_i=3|z_i|$$

$$EC = \Sigma_i(f_i\ C_i \lambda^{\infty}{}_i)$$

where:

I	is the ionic strength (mol/l) of the solution, treated as a dimensionless number
C_i	is the concentration of ionic species i in mol(c)/m^3
f_i	is the activity coefficient applicable to ionic solute species i
a_i	is a constant which depends on the effective diameter of ions of species i
EC	is the electrical conductivity of the solution in mS/m
z_i	is the signed charge number of ionic solute species i
$\lambda^{\infty}{}_i$	is the molar(c) conductivity of ionic species i at infinite dilution in mS/m per mol(c)/m^3
Σ_i	is the sum total over all ionic constituents

The values for $\lambda^{\infty}{}_i$ at 25°C used in the actual calculations in the computer program MAION have been expressed as an array of constants (MolConduct[H..halfSO4]) in mS/m per mol(c)/m^3 in the program source code.

The non-extended form of the Debije-Hückel formula for log(f) differs from the one presented here in the absence of the denominator, *i.e.*, a_i=0. The extended formula expands the applicability to solutions with a greater ionic strength. Güntelberg's formula substitutes 1 for 0.33a_i in the extended formula, *i.e.*, a_i=3. In more precise applications of the Debije-Hückel theory published values of a_i are used, although they must be regarded as calibration constants. Most often the values listed by Kielland (1937, see Hem 1970) are used, but slightly different values are also found in the literature (see Table D.2). Since the errors in single values for a_i will rarely reinforce each other in solutions of mixed salts, a simple and nearly as accurate method is to substitute $|z_i|$ for 0.33a_i, *i.e.*, $a_i=|z_i|/0.33$, or $a_i=3|z_i|$. In doing so, no new parameters are introduced, while the accuracy is greater than in case a_i=3 is assumed. This enables a comparison of formulae on the basis of the charge number of ions. The assumption is seriously in error only for H+. In nature, that ion is important only in very dilute solutions, so that the term in which a_i occurs has no significant influence.

Conductometric activity coefficients

The stoichiometric activity coefficients apply to co-ordinate chemistry. Onsager (see Levine 1978, p.465-466) applied the Debije-Hückel theory to conductivity problems. The application of the theory to solutions of mixed salts is difficult, however. Onsager's formula was derived for very dilute solutions of single salts. No activity coefficients are used, but it is possible to rewrite the formula in order to have explicit conductometric activity coefficients. This enables a comparison of the effects of ionic strength on the activity coefficients for stoichiometric and conductometric problems, respectively. The derived conductometric activity coefficients for conductivity (f') can be calculated as follows:

$$f'_i = 1 + (\log f_i)\{2B_1 + B_2/(|z_i|\lambda^{\infty}{}_i)\} \text{ with } B_1=0.23,\ B_2=6065$$

where f_i is the stoichiometric activity coefficient from the earlier formula with a_i=0. The values B are derived from physical constants relating to the solvent. Since, on average, $\lambda^{\infty}{}_i$=6250 mS/m per mol/l (note that I is based on mol/l, not mol/m^3!), $B_2/(|z_i|\lambda^{\infty}{}_i) \cong 1/|z_i|$, and the formula can be simplified into:

$$f'_i = 1 + (\log f_i)(0.46 + 1/|z_i|)$$

Table D.2 Numerical values of a_i in the Debije-Hückel theory

Solute species	**K^+ Cl^- NO_3^- NO_2^-**	**Na^+ HCO_3^-**	**$SO_4^=$ Mn^{2+}**	**Ca^{2+} Fe^{2+}**	**Mg^{2+}**	**Al^{3+} Fe^{3+}**	**H^+**
Formula, author							
Debije-Hückel:	0	0	0	0	0	0	0
Extended Debije-Hückel,							
Güntelberg:	3	3	3	3	3	3	3
Kielland:	3	4	4	6	8	9	9
various authors:	3-4	3-4.5	4	5-8	8	9	-
proposed here:	3	3	6	6	6	9	3

Some species not considered in standard MAION have been included for reference

Robinson & Stokes (1970) suggest the following solution:

$$\lambda_i = \lambda^\infty{}_i - \{(B_1 z_i^2 \lambda^\infty{}_i + ½B_2|z_i|)(I^{½})/(1+0.33a_i I^{½})\}$$

and $$EC = \Sigma_i(\lambda_i C_i)$$

where λ_i is the actual molar(c) conductivity of species i in the solution involved, (mS/m per mol(c)/l).

It appears that this formula complies with the conductometric activity coefficients if the stoichiometric activity coefficients are determined according to the extended Debije-Hückel formula with tabular values (Table D.2) for a_i. It is assumed that the extended formulations for f_i, specifying the effect of solute interactions, may be applied here as well, since f_i is the only place in the formula where such interactions are considered. Fig.D.5 shows the effects of some alternative formulations.

From Fig.D.5 it appears that the application of stoichiometric activity coefficients suggests a stronger concentration effect than appears from the use of conductometric ones, the difference being significant for ionic species with charge number 2 and higher. In recent versions of MAION conductometric activity coefficients are used for the calculation of electrical conductivity, while stoichiometric activity coefficients are maintained for the computation of the carbonate equilibrium state.

Compensation for temperature differences
The electrical conductivity varies with the temperature. A useful formulation (Levine 1978, p.468) is:

$$EC_{25} = (EC_t)\, e^{b(25-t)}$$

where:
EC_{25} is the electrical conductivity at 25°C in mS/m
EC_t is the electrical conductivity at t°C in mS/m
b is a temperature coefficient in K^{-1}

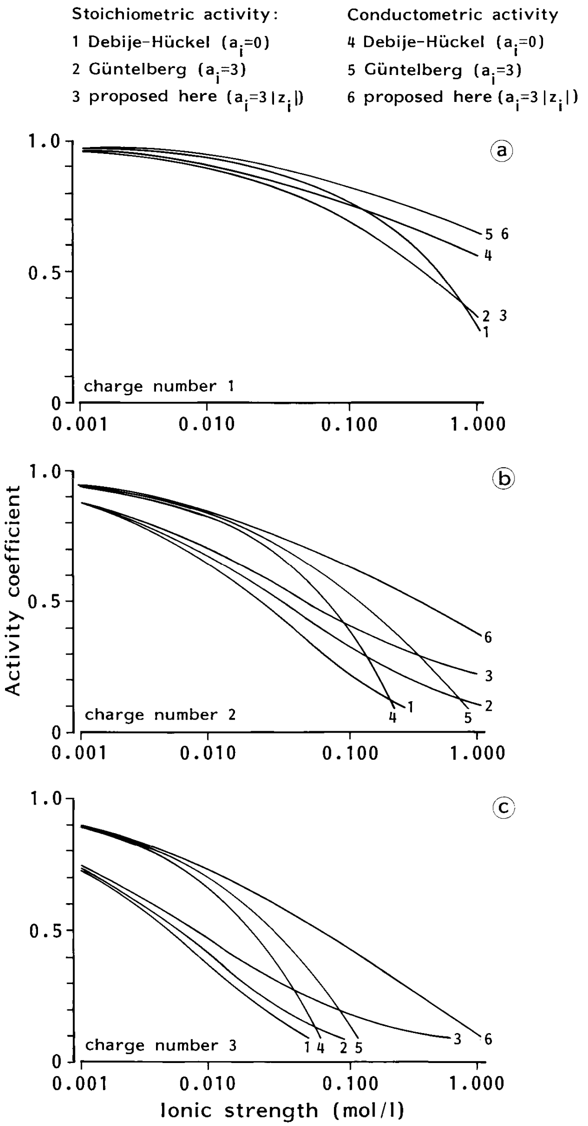


Fig.D.5a-c Activity coefficients for ions with charge numbers 1-3

The value b= 0.02 K^{-1} is correct for most ionic compositions. Laboratory experiments not reported here suggest that this value is also sufficiently accurate for very dilute and acid samples.

Method of evaluation
As a standard procedure, the eight ions involved in the electroneutrality test were included in the calculation of electrical conductivity. Calculations on the basis of the above-mentioned ions allow for a reasonable check on the substantial presence of other ions. A formula is used in MAION for the evaluation of the conductivity test by a quantity

$$y= (ECm-ECc) /ECm$$

where:
ECm is the measured EC_{25} (mS/m)
ECc is the calculated EC_{25} (mS/m)

For ECm, laboratory values are preferred to field measurements, since the ionic concentrations are also determined in the laboratory. Due attention is paid to possible causes of large values for y. If y is positive, other possibly determined ions may be taken into account. Allowing for NH_4^+ and NO_3^- would reduce y for AT-W80 in Table D.1 from 14.8% to –6.0%. Even for TH-N70 (I=0.7!), which is at the high end of the range of applicability of the Debije-Hückel theory, the use of the conductometric activity coefficients results in a relatively small y=8%. (*P.S.: In this paragraph, the original publication suggested big values for y, not corresponding with those given in Table D.1. That text had been falsely retained from the 1987 prepublication, which did not yet use the conductometric coefficients of activity.*)

The Ionic Ratio and related quantities

A special function of MAION is the calculation of the Ionic Ratio (IR), defined by (Van Wirdum 1980):

$$IR= 100[½Ca^{2+}] /\{[½Ca^{2+}]+[Cl^-]\}$$

(concentrations in mol(c)/m^3, IR in %)

As shown before (Fig.D.3), IR together with $^{10}\log(EC_{25})$ provides a useful coordinate system for the arrangement of water samples. The IR concept was developed as a composite parameter to characterize the ionic composition of the type of water concerned. The purpose was to obtain a parameter, preferably well-correlated with f(c)½Ca^{2+}, and computable on the basis of a minimum number of parameters. Especially Cl^- was taken into account, as it can be easily determined and it is hardly influenced by *in situ* processes. Further considerations (Van Wirdum 1978) were that, in The Netherlands:

- Both f(c)H^+ and f(c)K^+ are usually small;
- f(c)½Mg^{2+} is fairly constant (17 ±5%);
- f(c)½$SO_4^=$ and f(c)HCO_3^+ may be strongly affected by the action of biochemical processes and by sampling conditions, so that their concentrations are less readily interpretable;
- Variation of [Na^+] is strongly correlated with variation of [Cl^-];
- In older analyses, [Na^+] and [K^+] have often not been individually determined (see Section D.1). Their sum often more or less equals [Cl^-].

The partial molar(c) fraction of $½Ca^{2+}$,

$$f(c)½Ca^{2+} = 100[½Ca^{2+}] /\{[½Ca^{2+}]+[½Mg^{2+}]+[Na^{+}]+[K^{+}]\} \text{ (all concentrations in mol(c)/m}^3\text{)}$$

is approximately equalled by the following expression:

$$f(c)½Ca^{2+} \cong (100-a)[½Ca^{2+}] /\{[½Ca^{2+}]+[Cl^{-}]\} \text{ with } a=17$$

or: $$f(c)½Ca^{2+} \cong 0.83 \text{ IR and IR} \cong 1.2 \ f(c)½Ca^{2+}$$

Fig.D.6a shows the nearly linear relationship between the partial mole(c) fraction of $½Ca^{2+}$ and IR for a variety of water samples from different Dutch localities. These samples will be used further in Section D.3, where they are listed in Table D.3. It appears that the value used for **a** does not exactly describe the relation in this limited example. A RIN archive, comprising ca 5000 water analyses, yields the result shown in Fig.D.6e.

The use of total hardness to approximate IR, yielding IR and IR_{ha}*
Although Cl^- is almost always included as a parameter in water analyses in The Netherlands, Ca^{2+} is not. There remain some possibilities to approximate IR by means of other data. Two different cases will be considered. The first especially applies to most of the older water analyses, where Ca^{2+} and Mg^{2+} have been determined together as "total hardness" (HD), expressed in The Netherlands in German degrees (°D). As stated in Section D.1,

$$[½Ca^{2+}]+[½Mg^{2+}] = 0.356 \text{ HD (concentrations in mol(c)/m}^3\text{, HD in °D)}$$

By accepting that the partial mole fraction of $½Mg^{2+}$ is rather constant and approximately 17%, a ratio IR* can be defined as follows:

$$IR^* = 35.6 \text{ HD} /\{0.356 \text{ HD} + [Cl^{-}]\} \cong 100a + (1-a)IR \text{ with } a=0.17$$

or: $$IR^* \cong 17 + 0.83 \text{ IR and IR} \cong IR_{ha} = 43 \text{ HD} /\{0.36 \text{ HD} + [Cl^{-}]\} -20$$

The relationship between IR* and IR is illustrated in Fig.D.6b and Fig.D.6f.

The Cl^-- and Ca^{2+}-based conductivity ratios EClR and ECaR, yielding IR_{Cl} and IR_{Ca}
The second case to be considered is a real poor man's approach for cases where only Cl^- or Ca^{2+}, and electrical conductivity have been determined. A ratio EClR is defined as:

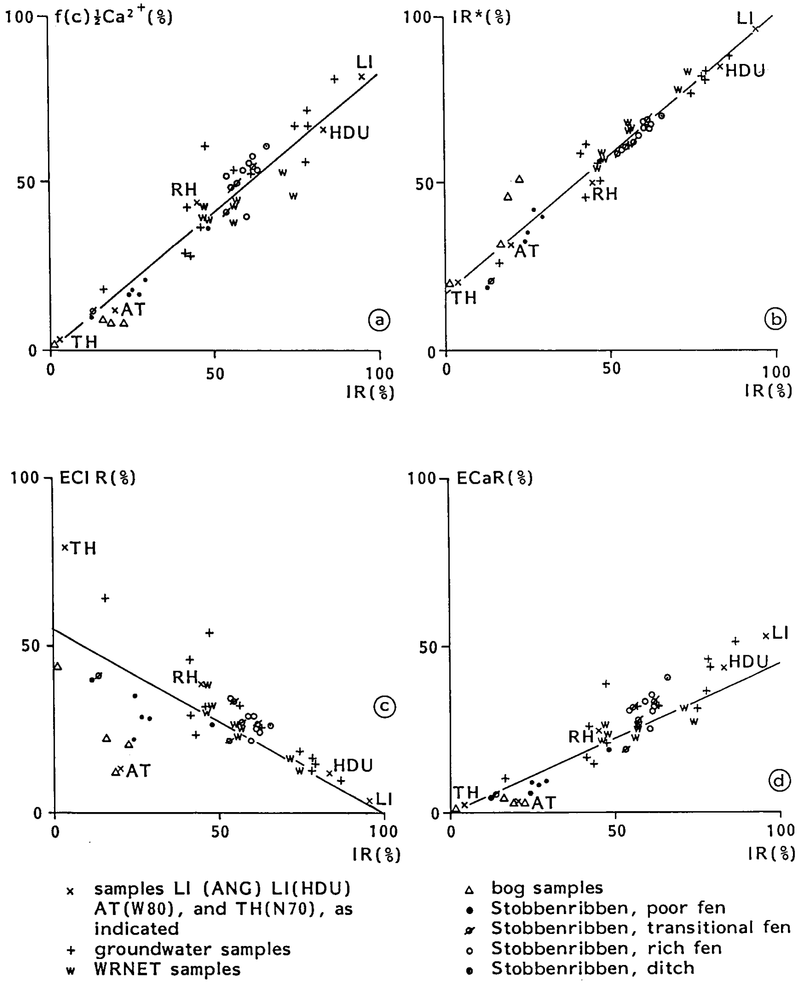


Fig.D.6a-d Diagrams, showing the correlation between IR and f(c)½Ca^{2+} (a), IR* (b), EClR (c), and ECaR (d), respectively

The samples used for these diagrams are documented in Table D.3. The relations shown with straight lines are the ones derived in the text, rather than regression lines. Note that, in the IR-EClR diagram (c), acid samples of low concentration (bog, poor fen) have lower EClR than described by the "theoretical" relation, because of the contribution of $[H^+]$ to EC_{25}; rather concentrated samples show higher EClR, since the "theoretical" relation does not take the effects of concentration into account.

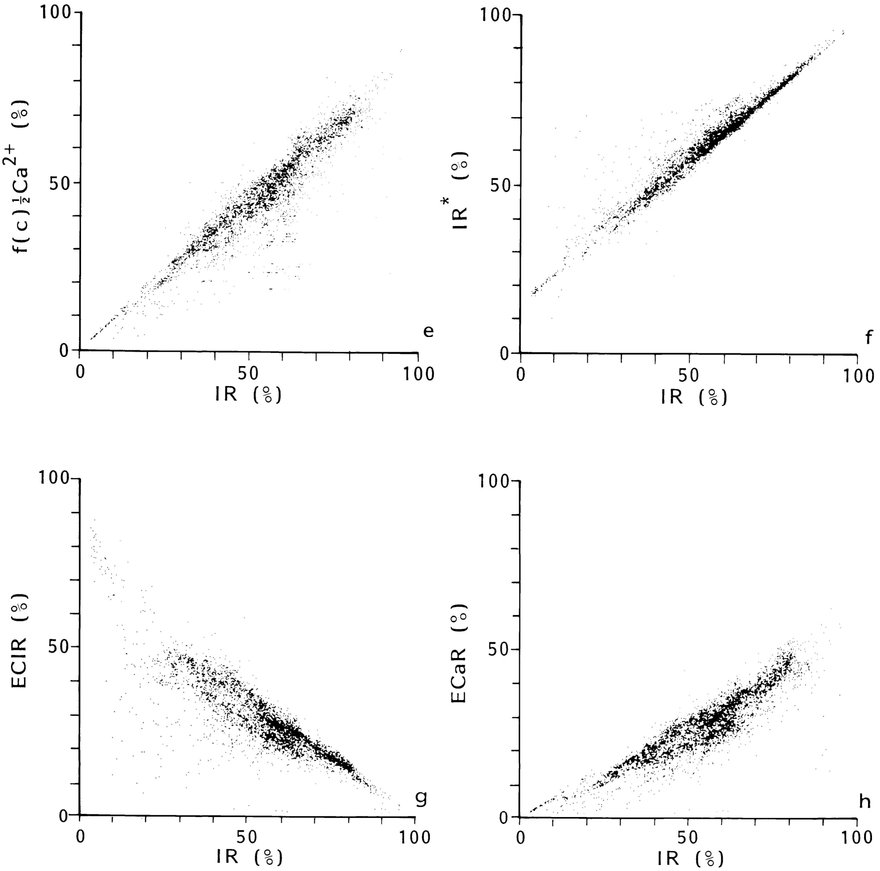


Fig.D.6e-h Diagrams, showing the correlation between IR and f(c)½Ca^{2+} (e), IR* (f), EClR (g), and ECaR (h), respectively

More than 5000 samples from archives of the Research Institute for Nature Management are represented in these diagrams. Most of these samples were taken from surface waters, many of which are influenced by Rhine water (see Fig.D.10, D.14), so that they do not represent an unbiased group. The diagrams strongly indicate, however, that there is no reason to reject the relations derived in the text.

$$ECIR = 100[Cl^-]\,\lambda^\infty / EC_{25}$$

where

ECIR	is a dimensionless ratio, expressed as a percentage
EC_{25}	is the measured electrical conductivity at 25°C (mS/m)
$[Cl^-]$	is the concentration of Cl^- (mol(c)/m^3)
λ^∞	is the molar(c) conductivity of Cl^- at infinite dilution and at 25°C (7.6 mS/m per mol(c)/m^3)

In dilute solutions, this ratio is approximately the share of Cl^- ions in the total conductivity. It is expressed as %. ECIR is less precisely correlated with IR than is IR*. As a rough approximation

$$ECIR \cong c(100\text{-}IR) \text{ with } c=0.55, \text{ and } IR \cong IR_{Cl} = 100\text{- } 1380\,[Cl^-]/EC_{25}$$

The relation between IR and ECIR has been illustrated in Fig.D.6c and Fig.D.6g.

ECIR has a Ca-based counterpart:

$$ECaR = 100[½Ca^{2+}]\,\lambda^\infty / EC_{25}$$

where

λ^∞	is the molar(c) conductivity of $½Ca^{2+}$ at infinite dilution and at 25°C (5.95 mS/m per mol(c)/m^3)

For ECaR the approximate relations

$$ECaR \cong p\ IR \text{ with } p=0.45, \text{ and } IR \cong IR_{Ca} = 1320\,[½Ca^{2+}]/EC_{25}$$

can be derived. The relation between IR and ECaR has been illustrated in Fig.D.6d and Fig.D.6h.

It must be emphasized that IR and related parameters are especially informative in combination with a measure of the total concentration, for which the electrical conductivity (EC_{25}) is recommended.

The MAION similarity coefficient

The MAION similarity coefficient is aimed at a simple numerical comparison of analyses, very much like a visual comparison of graphical representations.

In MAION, each analysis is represented by a set of numerical values. Let X and Y be two water analyses, and x_i and y_i the numerical values associated with the i-th of n features in samples X and Y, respectively. The general correspondence between both samples is expressed by a quantity r(X,Y) which is similar to the product-moment coefficient of correlation as produced by the computational formula (Spiegel 1972, p.245)

$$r(X,Y) = (n\Sigma_i x_i y_i - \Sigma_i x_i \Sigma_i y_i) / \{(n\Sigma_i x_i^2 - (\Sigma_i x_i)^2)\,(n\Sigma_i y_i^2 - (\Sigma_i y_i)^2)\}^{½}$$

The different features should be scaled in such a way that none of them dominates the others. In MAION, the concentrations of the eight ions mentioned before are used in mol(c)/m^3. To this set of data, the square of the electrical conductivity in mS/m at 25°C is added, divided by 1000, as a scaled measure of the total concentration. Hence n=9. Note that r(X,Y) does not change when every x_i is replaced by k_1x_i and every y_i by k_2y_i, k_1 and k_2 being non-zero constants. As a consequence, the nine above-mentioned features may be divided by a constant k, which is different for each analysis, and proportional to EC_{25}:

$$k= \{(EC_{25})^2 /1000\}^{½} = EC_{25} /32$$

This leaves an array of features comprising eight different ionic concentrations, each relative to the measure of overall concentration k, and k itself. This array, or feature vector, is discussed further in Section D.3.

One must bear in mind that the similarity coefficient (r(x,y), as defined here, differs from the correlation coefficient in statistics in requiring that the n observations (features) relate to the same parameters for all computations. Each of these parameters has its own chemical meaning.

The use of this similarity coefficient in connexion with the pre-selected analyses LI-ANG, AT-W80, and TH-N70, the LAT framework, will be explored in the next section, where this use is introduced on the basis of the EC-IR diagram and on the basis of statistical and theoretical considerations.

Saturation with respect to calcium carbonate

The carbonate equilibrium is an important factor as a pH-buffer system in natural waters, determining the availability of carbon as CO_2 and HCO_3^-. Moreover, there is some evidence that the state of the carbonate system is indicative of the availability of various forms of phosphate in the solution. The formulation in MAION was derived from the treatment by Kelts & Hsü (1978) and it is consistent with Kleijn (1986).

Calcite is considered to be the most important calcium carbonate mineral in the present context. The saturation of an aqueous solution with respect to calcite can be determined by the temperature, the pH, and the activity of Ca^{2+} and HCO_3^- ions. The activity of Ca^{2+} and HCO_3^- ions is computed from the analytical concentrations and the ionic strength of the solution with the Debije-Hückel-Güntelberg activity coefficients applicable to chemical equilibria, as discussed earlier in relation to the MAION conductivity test. The state of the solution can be characterized in several ways. A saturation quotient, or its logarithm, relating the saturated concentration of calcium ions to the actual one, is often used for this purpose. Also, the equilibrium temperature is a good candidate, since then it is possible to see whether saturation conditions might apply during a day-and-night cycle. Usually, however, pH is the factor that varies most and that, according to its logarithmic nature and serious problems for field determination, is the weakest point in the formulation. For this reason the saturation pH at T°C is reported, where, in MAION, T=10:

$$pHsatT= K-\log\{f_2[½Ca^{2+}]\}-\log\{f_1[HCO_3^-]\}-0.015(T-10)$$

where

T	is the temperature of the solution in °C
K	is a constant defined below; its numerical value is 8.43
f_1	is the activity coefficient for ions with charge number 1
f_2	is the activity coefficient for ions with charge number 2

[X] is the molar(c) concentration of X in mol(c)/m^3

The constant K combines some conversion factors to accomodate the formula for mol(c)/m^3 units, with the equilibrium constant for calcium carbonate and the dissociation constant for the bicarbonate ion, according to values cited by Kelts & Hsü (1978, p.300). For an increase of the temperature with 1°C, in the range from 0 to 30°C, the value of pHsat decreases 0.015. The pH is understood as the negative logarithm of the hydrogen ion activity, rather than of the concentration.

D.3 The LAT framework

Introduction

The purpose of this section is to explain the LAT framework, which has been mentioned in the foregoing sections and which consists of the benchmark analyses LI-ANG, AT-W80, and TH-N70, introduced in Table D.1, and graphically depicted in various figures in this chapter. For illustrative purposes, several further analyses are used in this section (Table D.3). These analyses were selected to show a wide variety of chemical compositions of natural waters, mainly from North-West Overijssel. The LAT reference analyses have been included. It was only while using and further developing the MAION method that the need for a single set of well-defined benchmark analyses arose. The choice of such benchmarks, of cause, relies on the definition of similarity and dissimilarity between water analyses and the weight given to the various physico-chemical parameters. Although the illustrations in the Sections D.1 and D.2 empirically show some of the decisions made, more detailed arguments in favour of the EC-IR and similarity methods are given below.

Statistical evidence for the importance of EC and IR

The fundamental question is here whether there is any statistical evidence for EC and IR to be chosen as representative parameters for the characterization of water analyses. This question has been investigated with a variety of statistical means, such as, among others, principal component analysis (Van Wirdum 1981). For the present purpose, a simpler approach is followed, which leads to the same conclusions. This is the approach by means of determinant analysis.

Determinant analysis
Sheffield (1985) has shown that selection of two or three parameters which explain most of the statistical variation in multivariate data sets, can be done by determinant analysis of sub-sets of elements of either the matrix of covariances, or the matrix of correlations. Such selection will only be successful when there is much redundancy in the numerical data. This method provides a formalized and quantitative supplement to the method of manually rearranging the relevant matrices in order to group correlated parameters (McIntosch in Whittaker 1973, p.157-191), although it is only practicable for relatively small submatrices.

The formulae for the computation of the determinant of a 2x2 covariance matrix, and a 2x2 correlation matrix, respectively, are simple:

$$\text{Detcov} = \text{var}(x)\text{var}(y) - (\text{covar}(x,y))^2 \quad \text{and} \quad \text{detcor} = 1 - (\text{cor}(x,y))^2$$

Table D.3 Analytical data and MAION results for several water samples, mainly from North-West Overijssel

			Concentrations of ions												Similarities				fractions		
Sample	date yymmdd	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	EC_{25} mS/m	IR %	x %	y %	pHsat	LI r%	AT r%	TH r%	RH r%	Ca %	Mg %	Cl %
LI-ANG	801208	7.3	115.0	8.0	12.0	2.0	11.0	400.0	13.0	65.2	95	-1	-1	7.07	100	-56	30	44	82	10	4
LI-HDU	1969	8.3	33.0	4.1	11.5	1.0	12.0	119.0	10.9	22.5	83	0	-13	8.06	92	-46	-6	22	66	14	13
AT-W80	80mean	4.2	0.4	0.2	1.6	0.2	3.0	0.0	5.8	5.0	19	-8	13	?.??	-56	100	-17	-2	11	10	41
TH-N70	820727	8.3	420.0	1400.0	10480.0	390.0	19100.0	122.0	2640.0	5200.0	4	1	8	7.66	30	-17	100	82	3	19	90
RH-LOB	75mean	7.8	82.0	10.0	96.0	7.0	178.0	158.6	80.0	99.6	45	0	-2	7.64	44	-1	82	100	44	9	54
B1a	801119	5.9	13.0	9.0	16.0	8.0	30.0	19.0	60.0	27.6	43	-2	-3	9.26	-8	58	16	38	28	33	35
B1b	801119	6.2	20.0	12.0	25.0	13.0	50.0	34.0	68.0	37.5	42	1	-6	8.84	6	43	38	66	29	29	42
B2a	800918	7.2	105.0	18.0	24.0	2.0	49.0	374.0	4.0	71.8	79	2	-2	7.14	98	-56	43	58	67	19	18
B2b	800918	8.0	105.0	11.0	26.0	1.0	51.0	352.0	3.0	68.5	79	0	-2	7.16	98	-53	40	59	72	13	20
B5a	801119	7.5	63.0	17.0	75.0	25.0	130.0	290.0	30.0	87.2	46	-3	-4	7.48	66	-29	75	92	37	17	41
B5b	801119	7.0	155.0	28.0	85.0	4.0	78.0	332.0	350.0	127.0	78	-4	-14	7.10	58	-5	83	83	56	17	15
B5c	801119	6.9	130.0	16.0	94.0	3.0	180.0	442.0	30.0	121.4	56	-4	-3	7.02	70	-30	82	93	54	11	39
B5d	801119	6.9	305.0	140.0	1350.0	42.0	2750.0	380.0	300.0	913.1	16	-2	4	6.97	29	-14	100	86	18	13	86
*B4a	821026	6.9	122.0	8.7	51.0	1.5	74.0	435.0	5.0	88.3	75	-1	-0	7.03	93	-47	57	73	67	8	22
*B4b	821026	7.0	106.0	8.0	12.5	1.3	28.0	350.0	7.0	61.8	87	-1	-2	7.16	100	-55	30	47	81	10	12
13.13	741107	7.6	32.0	10.0	35.0	4.0	64.0	103.7	27.0	45.5	47	-0	3	8.16	63	-12	47	85	39	21	44
26.10	780309	7.0	39.0	14.0	42.0	5.0	75.0	91.5	76.0	51.0	48	-1	-12	8.15	46	16	51	87	38	23	41
30.12	790412	6.7	39.0	11.0	30.0	7.0	53.0	67.1	79.0	45.0	57	1	-8	8.28	49	20	45	77	45	21	35
30.14	790412	6.4	44.0	18.0	41.0	11.0	62.0	54.9	125.0	59.0	56	5	-5	8.33	29	27	64	79	38	26	33
30.9	790412	6.7	38.0	11.0	32.0	7.0	52.0	79.3	72.0	45.0	56	1	-7	8.21	56	13	46	80	43	21	34
39.9	810313	6.6	31.0	7.0	15.0	6.0	22.0	42.7	76.0	30.0	71	1	-12	8.55	42	30	10	35	53	20	21
4.14	721130	7.0	60.0	24.0	31.0	7.0	37.0	42.7	220.0	67.2	74	2	-7	8.33	24	29	56	56	46	31	16
46.13	821021	7.9	56.0	12.0	58.0	7.0	114.0	134.2	51.0	64.0	47	0	-11	7.84	54	-3	60	94	43	15	50
LM187a	801119	6.7	108.0	13.5	83.0	3.0	115.0	440.0	9.0	97.2	63	-2	-5	7.08	82	-40	67	84	53	11	30
LM187b	801119	6.7	137.0	11.5	180.0	4.1	330.0	415.0	13.0	154.6	42	-2	-7	7.04	48	-16	88	98	44	6	57
LM187c	801119	6.7	275.0	20.0	165.0	4.1	540.0	455.0	15.0	215.3	47	-1	-9	6.75	46	-17	92	96	61	7	66
M02-04	811021	3.4	1.5	2.3	4.5	1.2	9.0	0.0	23.0	19.3	23	10	-14	?.??	-45	75	34	17	8	22	35
M05-04	811021	3.6	1.0	1.6	4.0	1.1	7.5	0.0	15.0	13.3	19	10	-11	?.??	-60	89	11	6	8	21	40
M09-16	811021	4.6	0.2	3.0	18.5	6.1	37.0	4.0	11.0	18.2	1	-4	7	11.70	-40	47	3	39	1	20	78
M18-04	811021	3.8	1.0	0.8	5.5	0.8	9.0	0.0	8.0	8.6	16	12	-24	?.??	-60	84	-14	12	9	12	60
STOB-a	820617	7.7	81.0	9.9	39.0	2.7	74.0	220.0	39.0	60.7	66	1	-12	7.47	90	-33	43	73	61	12	32
STOB-b	800620	7.4	48.9	7.7	34.0	5.8	73.1	125.0	28.0	46.5	54	0	-10	7.91	74	-18	35	77	52	14	44
STOB-b	800821	7.0	42.4	6.2	27.0	3.2	52.1	105.0	27.0	38.2	59	2	-8	8.03	79	-18	23	67	54	13	39
STOB-b	801016	6.5	67.9	10.4	38.0	3.7	77.1	200.0	21.0	57.4	61	1	-8	7.58	87	-35	43	75	56	14	37
STOB-b	801215	6.5	30.9	3.9	16.5	3.5	33.1	82.0	13.0	28.7	62	2	1	8.25	84	-29	11	54	58	12	37
STOB-b	810217	6.5	28.9	4.2	19.0	2.4	31.0	69.0	35.0	28.1	62	-1	-7	8.36	74	-2	8	54	54	13	32
STOB-c	800620	4.7	3.5	1.3	21.0	15.0	40.0	2.0	30.0	21.1	13	-5	-6	10.78	-43	63	4	38	11	7	63
STOB-c	800821	6.5	26.9	4.6	14.5	2.8	29.0	76.0	19.0	23.9	62	-1	-12	8.34	81	-23	-3	42	55	16	33
STOB-c	801016	6.0	20.5	3.5	16.5	1.8	30.0	36.0	30.0	19.3	55	1	-24	8.77	42	26	-13	42	49	14	41
STOB-c	801215	6.7	6.0	1.1	6.0	2.7	9.5	18.0	9.0	9.6	53	-2	10	9.56	49	10	-26	28	42	13	36
STOB-c	810217	6.0	14.0	2.2	10.5	1.9	19.0	34.0	14.0	15.5	57	0	-2	8.94	61	1	-14	40	50	13	39
STOB-d	800620	4.1	2.0	0.8	14.0	5.1	25.0	0.1	14.0	13.5	12	-1	-11	12.30	-45	65	-7	32	10	7	71
STOB-d	800821	4.4	2.5	1.0	5.0	4.9	11.0	0.1	13.0	8.4	29	1	-5	12.19	-51	78	-22	11	21	14	53
STOB-d	801016	4.5	3.0	1.1	11.0	4.0	16.0	1.0	18.0	9.9	25	1	-18	11.12	-44	76	-19	20	18	11	54
STOB-d	801215	5.4	1.0	0.3	4.0	1.6	5.5	1.0	5.0	5.3	24	3	29	11.56	-39	66	-21	22	17	9	56
STOB-d	810217	5.5	5.5	1.4	6.0	3.6	10.5	8.0	19.0	8.8	48	-5	-12	9.95	-6	65	-30	11	37	16	36
STOB-d	820617	4.0	3.0	1.8	9.5	2.6	14.5	0.0	18.0	11.0	27	6	-22	?.??	-51	84	-17	18	17	17	52
STOBdd	820617	5.7	13.5	3.5	15.0	2.5	16.0	62.0	7.0	16.0	60	2	-10	8.70	72	-30	-15	26	40	17	28

Coding of samples: Chapter 5 (groundwater samples, WRNET samples), Chapter 9 (Stobbenribben), the present chapter (benchmarks); M-codes are from the Meerstalblok bog area

The selection of the 2x2 submatrix with the largest determinant, *i.e.*, of the two "best" parameters can be done by a visual inspection of the matrices. Determinant analysis and manual matrix rearrangement in most cases provide a sound basis for a reasonable decision with regard to the selection of especially informative parameters. Both methods suffer less from statistical uncertainties than such alternatives as are principal component analysis and factor analysis.

The application of these methods is not reported in detail here. EC, or Cl^-, and Ca^{2+} do not always form the statistically most informative combination. If such factors as pH and K^+, which vary within a small range, and $SO_4^=$ and alkalinity, which are often less representative for the body of water sampled (Section D.2), are disregarded, Ca^{2+} and Cl^- are always indicated as one of the most powerful pairs of parameters, however. When IR is used instead of Ca, the indication is still stronger.

As a result of increasing interest in the method described, also Hoogendoorn (1983, part 4) discussed several aspects of the EC-IR method and its applicability to some 3000 analyses of ground waters from the eastern part of The Netherlands. Judging from information obtained through a factor model, Hoogendoorn concludes that the choice of Ca^{2+} and Cl^- would have been a very good one for the characterization of his analyses.

The LAT framework

From the use of the EC-IR diagrams, it appeared that most water analyses plot within the area bounded by the curved lines LI-AT-TH-LI in Fig.D.7 (after Van Wirdum 1980). This result suggested not only that certain combinations of EC and IR are rare or absent in The Netherlands, but also that the cluster of analyses can be described by three more or less extreme points. The locations of these points have EC and IR values which, in the diagrams, appear to be characteristic of rain water (both EC and IR low), sea water (EC high, IR low), and a certain type of groundwater (IR high, EC 50-100 mS/m). If these points are accepted as a framework, it would be possible to characterize water analyses with respect to EC and IR as more or less resembling atmotrophic rain water (AT), lithotrophic high-IR groundwater (LI), or thalassotrophic sea water (TH).

The first two characters of the codes of these analyses represent the type of water:
- LI: Lithotrophic, *i.e.*, borrowing its chemical character from an intensive contact with the lithosphere;
- AT: Atmotrophic, *i.e.*, borrowing its chemical character from atmospheric water;
- TH: Thalassotrophic, *i.e.*, borrowing its chemical character from oceanic water (Gr. **θαλασσα** (thalassa): ocean, sea).

After some try-outs, a first set of reference points was chosen which was later replaced by the analyses LI-ANG, AT-W80, and TH-N70.

LI-ANG was selected from the analyses for the groundwater monitoring program by the National Institute of Public Health and Environmental Hygiene (R.I.V.M.) as an example of an accurate analysis of water without any manifest sign of pollution, and with a very high IR value, combined with an average EC_{25}. LI-ANG was sampled at Angeren (Gelderland), station nr. 272 in the groundwater monitoring program, 24 m below soil surface (date: December, 8, 1980). It replaced LI-HDU which is less extreme with regard to IR. This analysis has been included in several illustrations in the present chapter.

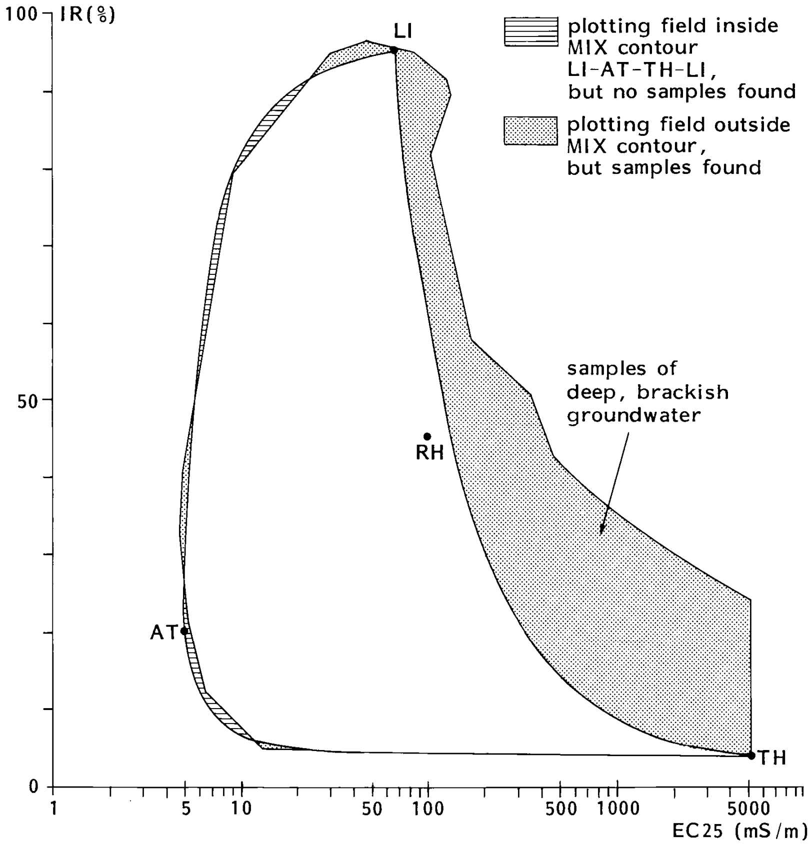


Fig.D.7 A first reconnaissance of the area of interest in EC-IR diagrams: contour of the plotting field for all samples in Van Wirdum (1980), as compared with the MIX contour

AT-W80 is the weighted mean composition of rain water collected at Witteveen (Drenthe) during 1980. It was chosen as a representative example after the chemical characteristics of rain water at this station had been investigated over the period 1972-'80, as reported by the Royal Netherlands Meteorological Institute (K.N.M.I.). The earlier benchmark AT-WTV represented the weighted mean rain water composition at Witteveen during 1973-'74, but in those years certain factors could only be assessed less accurately.

The analytical data of TH-N70 were kindly supplied by Rijkswaterstaat, North Sea Directorate, as a representative analysis from the North Sea monitoring program, 70 km from the coast at Noordwijk, station nr. N-70 (date: July, 27, 1982). Several parameters were especially analysed for the present purpose. Its predecessor in MAION, TH-XXX was derived from various data in the literature.

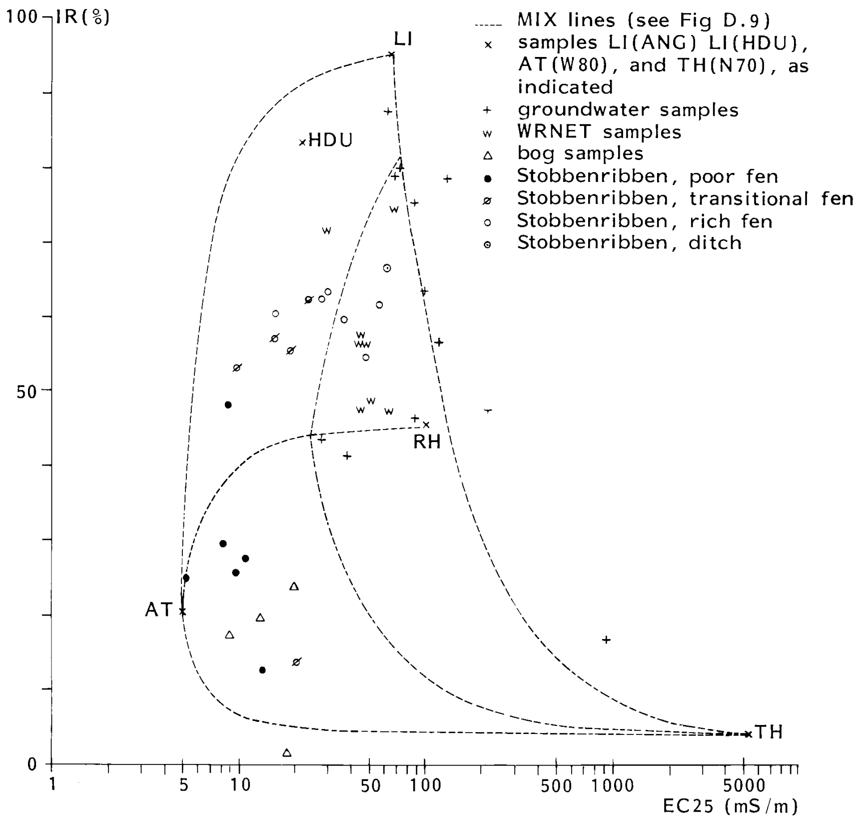


Fig.D.8 EC-IR diagram for the samples documented in Table D3

Note that the WRNET samples (w) depicted were selected to fill in some of the otherwise open space in the diagram, rather than to represent the composition of the *boezem* water in "De Weerribben"

A fourth analysis often used in connexion with the LAT framework is RH-LOB, the mean composition of Rhine water at Lobith during 1975. This analysis was included since it is representative of the river water which is distributed over a large area in The Netherlands during periods of drought. This water also reaches the *boezem* waters of North-West Overijssel in many summers.

Both atmospheric and lithospheric water may be quite different from AT-W80 and LI-ANG, but up to now, such different types of water have appeared to fall more or less in between the LAT reference points in EC-IR diagrams. The analyses presented in Table D.3, which include the LAT analyses, have been plotted in an EC-IR diagram in Fig.D.8.

The LAT framework and the hydrological cycle

The LAT framework can be related to a model describing the changes in water chemistry during the hydrological cycle. Two very simple models were introduced by Van Wirdum (1980, p.135-137) which lump several processes and parameters. Of these, the mixing model (MIX) was used already in Fig.D.1, D.3, and D.4. This model will be considered in somewhat greater detail here.

Due to coastal effects and very varying atmospheric pollution rain water samples differ in composition according to the location of the measuring station. The composition of groundwater depends on the properties of soils and substrata. Groundwater samples differ considerably in total hardness, and may be influenced by such processes as dissolution or precipitation of $CaCO_3$, ion exchange, diffusion of connate salt from deeper marine formations, *etc.* In general, the three benchmarks LI-ANG, AT-W80, and TH-N70, and their combinations, embrace almost all water samples from North-West Overijssel and from elsewhere in The Netherlands (Fig.D.10). An exception are deep brackish waters from Tertiary and older formations, which are influenced by remnants of their original (connate) salinity and by the dissolution of solid gypsum present in these formations (Fig.D.7). Moreover, some water samples have somewhat higher EC_{25} than the mixtures of LI-ANG and TH-N70 with the same IR. Most of these samples originate from places which have been under the influence of brackish waters in historical times. These samples may have higher Cl^-, SO_4^{2-} or Mg^{2+} concentrations than a "typical" fresh groundwater with similar IR.

Series formed by actual water analyses
It may be concluded that the LAT framework can be used to delineate the plotting area for actual water analyses from The Netherlands in the EC-IR diagram. Repeated sampling at the same locations, or sampling of different bodies of water at different locations in an interconnected hydrological system, may yield more or less linearly extended clusters of points in the EC-IR diagram, as shown in Van Wirdum (1980). By reference to the LAT framework, such clusters may suggest developmental or mixing relations, which can be studied further with a more complete set of analytical data and with models of water chemistry. As proposed by Van Wirdum (1981, p.115), the clusters can be indicated as:

- Atmocline for clusters of samples that only slightly differ from AT;
- Atmo-lithocline for clusters of samples which stretch along the AT-LI contour line in the diagram;
- Various other clines of this kind.

If one wants to distinguish between the influence of thalassotrophic water and the influence of pollution, as traced in the MIX model by the mixing with RH-LOB, the clusters which are supposed to have RH-LOB as an end point or as a centre of gravity, can be named molunoclines (Gr. **μολυνω** (moluno): to defile, pollute, become vile). A cluster with the line AIR (Fig.D.9) as a main axis would thus be named an atmo-molunocline. The dotted area in Fig.D.9 may represent a molunocline.

Applicability at the global scale
An interested reader of earlier publications about the EC-IR method has drawn my attention to a paper by Gibbs (1970), who considered the mechanisms controlling world water chemistry. Gibbs plotted the weight of total dissolved salts (logarithmic scale) in various rain, river, lake,

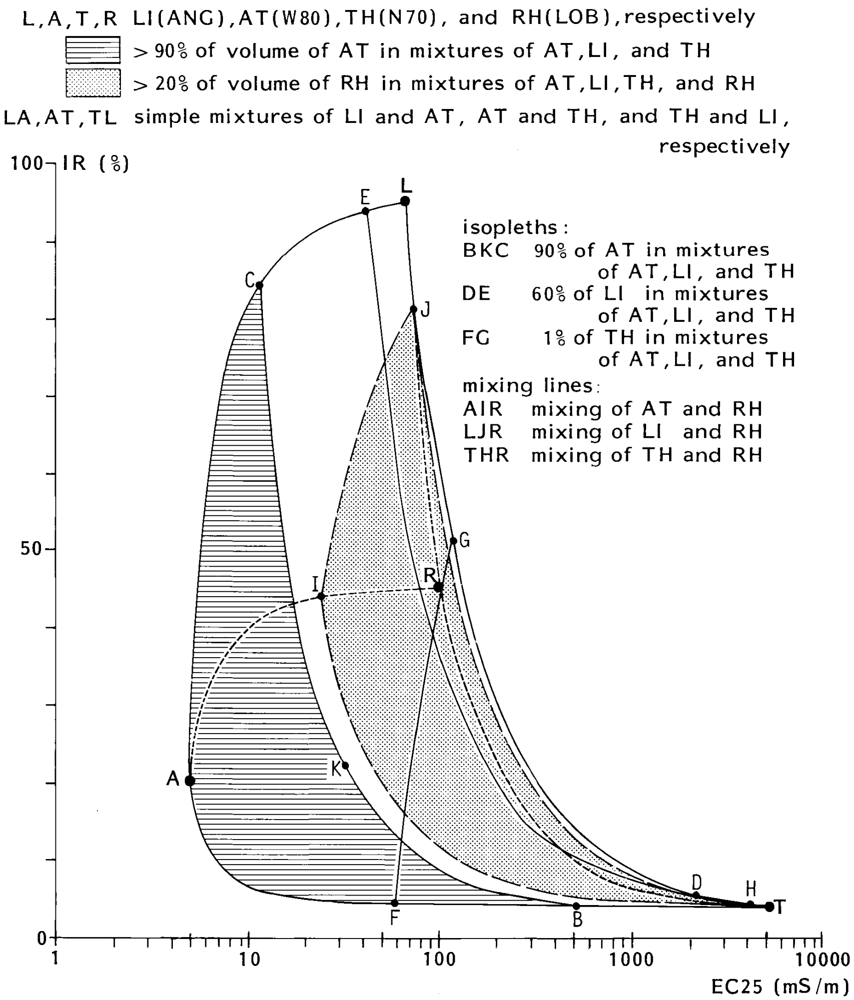


Fig.D.9 EC-IR diagram, showing the results of application of the MIX model
Explanation in the text

and ocean samples from all over the world, against the weight ratio [Na]/{[Na]+[Ca]}, and, as an alternative, against the weight ratio [Cl]/{[Cl]+[HCO_3]}. This method yields results which are very similar to the ones obtained with the EC-IR method, as can be easily understood from the description of the ionic ratio and related quantities in Section D.2. The LAT framework would fit Gibbs' analyses quite well, although LI-ANG is somewhat more concentrated than his "lithotrophic" river waters. It is also apparent, from Gibbs' paper, that most samples of surface waters, at the global scale, fit in either an atmo-lithocline, or a litho-thalassocline, and this is explained as follows (Gibbs 1970):

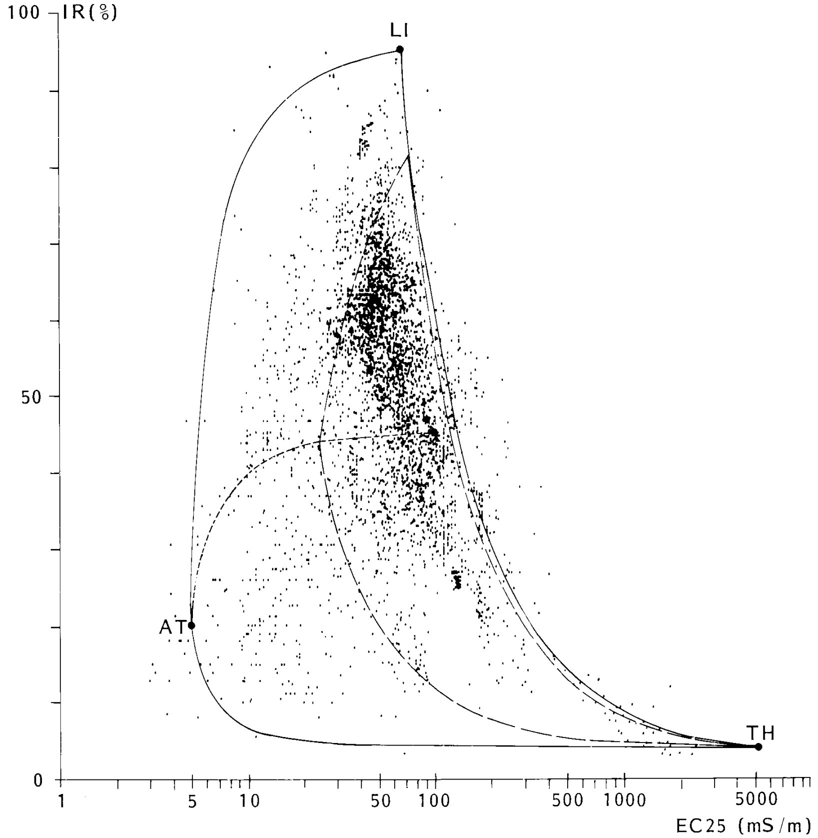


Fig.D.10 EC-IR diagram, showing the plotting position of more than 5000 analyses of (mainly surface) waters in The Netherlands (RIN archives)

'The compositions of the world's surface waters plot as two diagonal lines. This ordered arrangement can serve as a basis for discussion of the several mechanisms that control world water chemistry.

The first of these mechanisms is atmospheric precipitation. The chemical composition of low-salinity waters are controlled by the amount of dissolved salts furnished by precipitation.

...

The precipitation control zone is one end-member of a series. The opposite end-member of this series is comprised of waters having as their dominant source of dissolved salts the rocks and soils of their basins. This grouping defines the second mechanism controlling world water chemistry as rock dominance. The waters of this rock-dominated end-member are more or less in partial equilibrium with the materials in their basins. ...

The third major mechanism that controls the chemical composition of the earth's surface waters is the evaporation-fractional crystallization process. ..., this mechanism produces a series extending from the Ca-rich, medium salinity (freshwater), "rock source" end-member grouping to the opposite, Na-rich, high-salinity end-member. The rivers and lakes in this group are usually located in hot, arid regions. A number of these rivers ... show evolutionary paths ... starting near the Ca or "rock source" end-member with changes in composition toward the Na-rich, high-salinity end-member as the rivers flow toward the ocean. This change in composition and concentration along the length of these rivers is due to evaporation, which increases salinity, and to precipitation of $CaCO_3$ from solution, which increases the relative proportion of Na to Ca. ...

The Na-rich, high-salinity, end-member components are the various seawaters of the earth whose compositions cluster near the Na-rich axis.'

Gibbs even concludes that, in his diagrams, the axes showing data for total dissolved salts, could be replaced with precipitation or runoff data without materially altering the interpretation. According to him, second-order factors, such as relief, vegetation, and composition of material in the basin dictate only minor deviations within the zones dominated by the three prime factors (atmospheric precipitation, rock dominance, and the evaporation-crystallization process).

It is apparent that, in North-West Overijssel, the litho-thalassocline is not caused by the evaporation-crystallization process, but rather represents a litho-molunocline caused by water pollution. This can be proved with older analytical data, *e.g.* those by Gunning in Vereniging (1870). The composition of Rhine water about 1860 was characterized by an IR of 88% and an EC_{25} (calculated) of about 30 mS/m, compared to 45% and 100 mS/m, respectively, in 1975.

MAION similarity: An extension of the EC-IR characterization

Since the variety of EC and IR values found in natural waters can be conveniently delimited by the LAT framework, the latter may also be capable of spanning the associated variety of other parameters of water quality. The MAION similarity coefficient (Section D.2) was used in the mixing model with the LAT analyses in order to investigate this point. Before the results of this investigation are being presented, some attention will be paid to the way the MAION similarity formula handles a water analysis.

Visualization of the MAION feature vector

The nine parameters used in the MAION similarity computation were defined in Section D.2. These parameters may be looked upon as a vector, the feature vector, in a multi-dimensional space.

The MAION similarity coefficient was defined with the product-moment formula known from correlation analysis. This formula incorporates a centering of the numerical data around 0, and a standardization of the variances to the value 1, *i.e.*,

$$x_i' = (x_i - x_{av})/s(x)$$

$$\text{with } x_{av} = \Sigma_i x_i/n \text{ and } s(x) = \{\Sigma_i (x_i - x_{av})^2/n\}^{1/2}$$

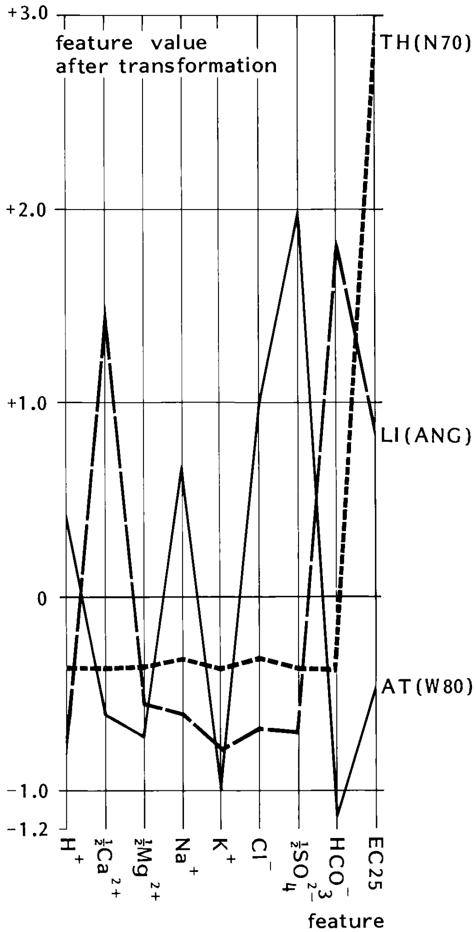


Fig.D.11 Diagram of feature vectors of LAT analyses as used in MAION similarity computations

The name of each feature indicates the analytical parameter it is associated with

These transformations of the feature vector have also been accounted for in Fig.D.11, which thus shows the centred and standardized feature vectors. It is clear that there is hardly any similarity between the three benchmark samples.

Visualization of similarities in the LAT framework

If the above-mentioned centering and standardizing transformations were carried out in advance of application of the MAION similarity formula,

$$r(X,Y)= (n\Sigma_i x_i y_i - \Sigma_i x_i \Sigma_i y_i) / \{(n\Sigma_i x_i^2 - (\Sigma_i x_i)^2)\ (n\Sigma_i y_i^2 - (\Sigma_i y_i)^2)\}^{½}$$

the latter would reduce to

$$r(X,Y)= \Sigma_i x_i y_i/n$$

$$\text{with } \Sigma_i x_i/n = \Sigma_i y_i/n = 0 \text{ and } \Sigma_i x_i^2/n = \Sigma_i y_i^2/n = 1$$

For analysis X, r(X,Y) thus is a weighted mean of the elements of its standardized and centred feature vector. The weighting coefficients are the elements of the standardized and centred feature vector of analysis Y, for instance one of the LAT analyses. In this respect, the method can be considered a method of comparative filtering, with L, A, and T as numerical filters.

It was shown already in Section D.1 that the MAION similarities to two of the LAT analyses can be used as a basis for a graphical representation. Such a representation can be imagined as a projection onto a plane in the multi-dimensional feature space. This plane is chosen in such a way, that the feature vectors of two of the LAT analyses lie in it. It follows from the similarities of the LAT analyses to one another, that the rTH-rAT and rTH-rLI diagrams will comprise less redundant information than the rAT-rLI diagram, since r(AT,LI) deviates more from zero than do the other similarities. The rTH-rLI diagram is given in Fig.D.12 which shows the same simulated analyses as Fig.D.9.

Since the similarities of AT-W80 to TH-N70 and LI-ANG, respectively, are -17% and -56% (Table D.1), the sample AT-W80 is plotted at the location (-17, -56) in the diagram. Likewise, TH-N70 and LI-ANG, respectively, are plotted at (100, 30) and (30, 100). Note that, while TH and LI lie in the plane of the diagram, AT lies in another plane in the multidimensional space considered, and it is projected onto the plane of the diagram, as are other water samples.

As the similarity to both TH and LI decreases, the projected plotting position for a particular sample is closer to the one of AT. Yet, rAT for such a sample may be low. It is advisable to check rAT for samples which have both rLI and rTH <50%. The interpretation of such samples as being more similar to AT, should be backed by rAT>50%. Meanwhile, one must be aware that samples, which have approximately the same EC and IR values, and which will thus be plotted close to one another in the EC-IR diagram (Fig.D.9) may, likewise, differ with respect to other parameters.

Inferences from the TH-LI diagram (Fig.D.12)

The hatched fAT>90% area ABC in Fig.D.12 will now be considered as a first example of how to read the TH-LI diagram, and so as to mention some conclusions with regard to the application of MIX, the mixing model. It appears that an admixture of only 10% LI water in AT water will shift the plotting position to C, where rLI=90%. Further addition of LI water will move the position from C to L, thus mainly increasing rTH. This is due to the fact that LI has a positive similarity of 30% to TH. When TH water is added to AT water, 10% of volume of TH water will render the mixture very similar to TH (point B). The large shifts to C and B upon admixture of only 10% of LI or TH can be explained by the much higher concentrations of LI, and especially of TH, as compared to AT. The hatched area is an illustration of the plotting areas of a litho-atmocline (ACKA) and a thalasso-atmocline (ABKA).

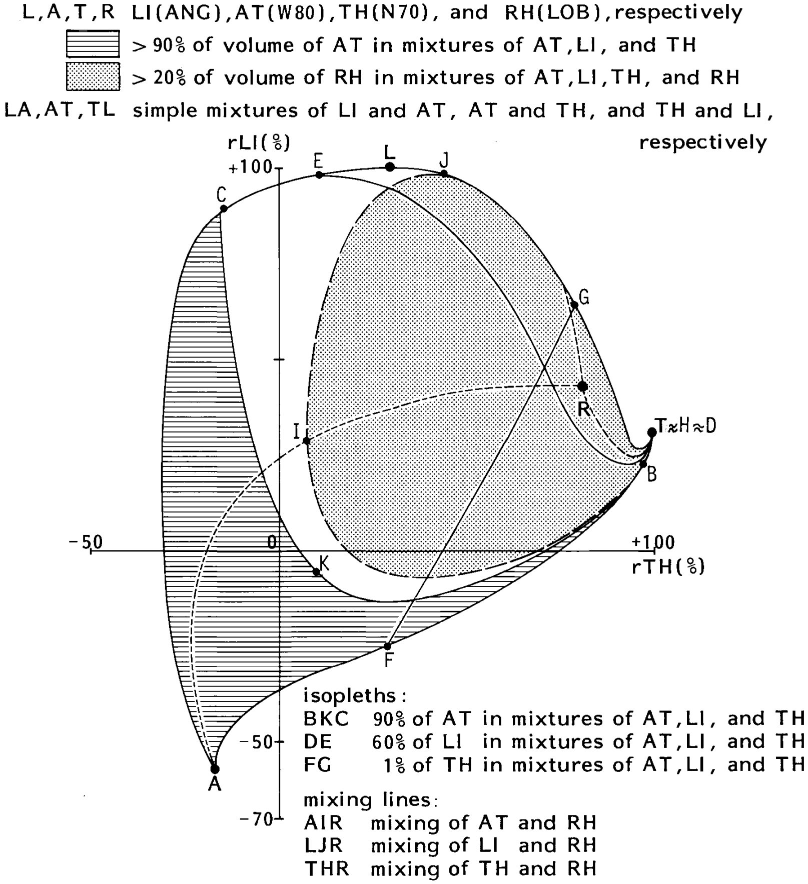


Fig.D.12 rTH-rLI diagram, showing the results of application of the MIX model
Explanation in the text

The diagram also shows that the addition of 1% of TH to AT (point F), or to LI (point G), will have a considerable effect on the position of the mixtures in the diagram. Mixing 40% of AT in LI, on the other hand, will only slightly shift the plotting position of the mixture away from LI to E. Further points in Fig.D.12 are marked to indicate the same mixtures as plotted in Fig.D.9.

It can be concluded that additions of very small amounts of thalassotrophic water will render any type of water very much like TH in this diagram. Quite substantial amounts of LI are needed to have the same effect in waters originally resembling atmotrophic water. Only very large amounts of atmotrophic water can contribute appreciably to rendering samples atmotrophic.

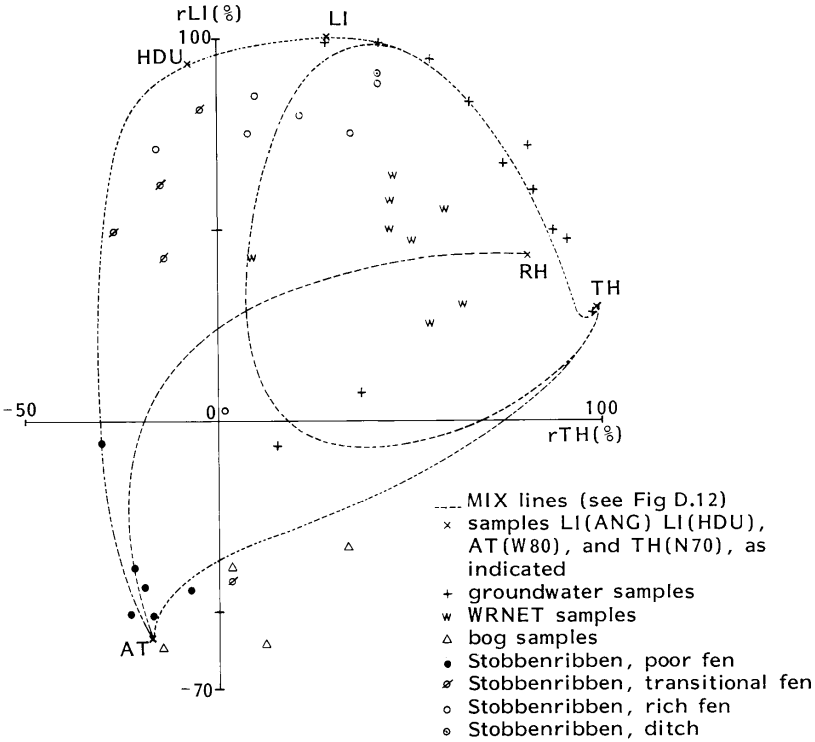


Fig.D.13 rTH-rLI diagram for the samples in Table D.3

Note that the WRNET samples (w) were selected to fill in some of the otherwise open space in the diagram, rather than to represent the composition of the *boezem* water in "De Weerribben"

The dotted area HIJH in the diagram represents the plotting position of mixtures of TH, LI, and AT, containing more than 20% by volume of RH-LOB, *i.e.,* Rhine water. Clearly this addition will make the water more similar to thalassotrophic water, although especially lithotrophic water will still remain quite lithotrophic after an addition of up to 20% of RH. Most of the dotted area represents mixtures with much AT, as can be traced by means of the dotted line AIR indicating mixtures of AT and RH only. A cluster of samples occupying the dotted area might be regarded as a molunocline. As stated before, this is due to human activity: Rhine water analysed until the beginning of this century plots very close to LI in the diagram.

Fig.D.13 shows the analyses from Table D.3 in a TH-LI diagram. This diagram illustrates the general trend that only few analyses of natural waters plot in the central area. A comparison of the TH-LI diagrams with the EC-IR diagrams suggests that their use will not lead to very different conclusions. This is confirmed by Fig.D.14, showing the plotting positions of more than 5000 water analyses in RIN archives (compare Fig.D.10).

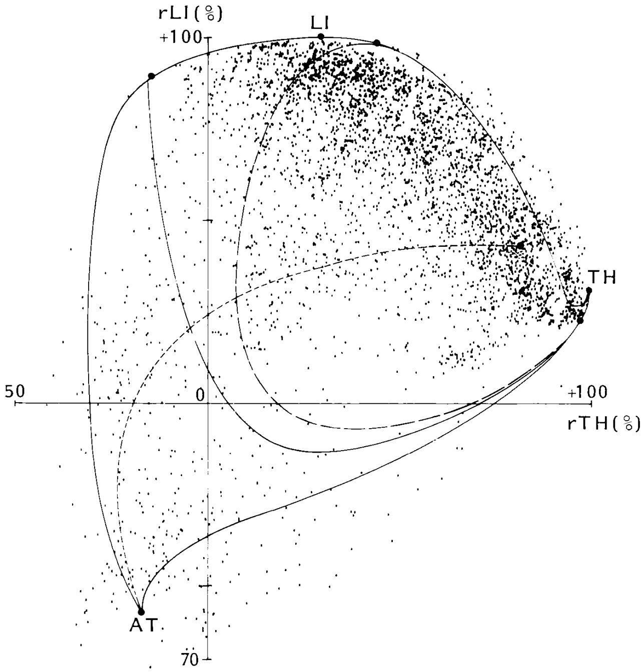


Fig.D.14 rTH-rLI diagram, showing the plotting position of more than 5000 analyses of (mainly surface) waters in The Netherlands (RIN archives)

A comparison with conventional statistical methods

Grootjans (1985) and Hoogendoorn (1983) and others have used conventional statistical methods to arrange or classify water analyses. The relation between such methods and the MAION similarity method is shortly described here.

"Cluster analysis" is mostly applied in a standard form which has not been adapted to the treatment of the numerical data resulting from water analysis. With the MAION similarity coefficient, it has the comparison of feature vectors in common, and the computation of coefficients of similarity is a central item in clustering techniques. The main difference lies in the (dis)similarity formula chosen, in the definition of the feature vector to be used, and in the application of particular transformations to such vectors. Some aspects can be illustrated on the basis of the MAION similarity coefficient.

When, in MAION, EC_{25} would have been omitted, or just not squared, the result of the similarity calculations would be independent of the overall concentration of water samples, as should be clear from the discussion in Section D.2. In that case, the similarity coefficient would reflect differences in ionic composition of the water only, as does the Piper diagram (Fig.D.1, Section D.1).

Use of the covariance instead of the correlation as a measure of similarity would correspond to a centering, rather than a centering and standardizing of the feature vector and the subsequent application of the simple formula presented before:

$$r(X,Y)= \Sigma_i(x_i y_i /n) \text{ with } \Sigma_i(x_i /n) = \Sigma_i(y_i /n) =0$$

The usually undesired effect is that the method becomes especially sensitive to the overall concentration. The values thus found, moreover, have no upper and lower limit.

This type of problem may have been of influence in the cluster analysis reported by Grootjans (1985, p.111-115). The clusters found, all show a wide variety of IR values, while they are strongly correlated with EC_{25} (written communication to the author by A.P. Grootjans, R. van Diggelen, M. Wassen & W. Wiersinga, April 1983). This may be attributable to the clusters being implicitly defined mainly on the basis of overall concentrations.

Hoogendoorn (1983, part 1, p.47-48,146) recommends Q-mode factor analysis for the study of the multivariate relations between water samples. Mathematically, factor analysis is not very different from principal component analysis (Pielou 1977, p.332-340). The MAION similarity method, as well as the study of relations between water samples in graphical representations (Section D.1) may be considered a simpler alternative. Where the statistical methods depend on the frequency distributions of the numerical data *within* the data set considered, the LAT analyses provide an independent framework. Like EC and IR do for the parameter variability, the similarity to the LAT samples, for being "extreme" with respect to these very parameters will "explain" most of the variability of the analyses.

In conclusion, conceivably advanced statistical techniques might be modified in such a way that they yield better solutions to the problem of comparing and evaluating water samples than do the MAION techniques presented here. Yet, these statistical methods require a well-balanced data set and an appropriate definition of the feature vector to be used for water samples. For the time being, the MAION processing has proved to be able to treat the numerical data of water analyses in a satisfactory manner, especially when no *a priori*-knowledge is available with respect of the representation of specific types of water in the area studied.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX E

Evapo-transpiration from lysimeters with fen vegetation

In order to relate evapo-transpiration from fen vegetation to the evaporation from an open water surface, and thus to standard data provided by meteorological stations (Penman 1963), five lysimeters were installed in De Weerribben and followed in the 1975-1976 period (Bot 1975, Brandsma 1975, Straathof 1976, Vegt 1978). Oil- drums (210 l, diameter 58 cm, height 80 cm) were filled with a *kragge* cylinder and inserted in the holes so formed (Fig.E.1). The lysimeters were allowed to float up and down with the *kragge* and the water level was adjusted to a fixed level once every second day. For a precise adjustment water was added or removed, with a calibrated vessel, until the meniscus just drew level with the tip of a nail in the middle of the water surface. As demanded by the relative movement of the surrounding water level, the fixed water level in the lysimeters was reset, to which purpose the contact nail could be vertically adjusted with a micrometer slide.

The five lysimeters contained vegetation dominated by *Phragmites australis*, by *Sphagnum flexuosum* and *Juncus subnodulosus*, by *Scorpidium scorpioides* and *Carex lasiocarpa*, *C.diandra* and *C.elata*, by *Cladium mariscus*, and by *Polytrichum commune*, respectively, and they were inserted in exactly the same place where the *kragge* cylinders had been cut out. It must be mentioned that these places differed in their exposure to wind and sun. Large lysimeters were used in order to reduce border effects and to avoid damage to the plants. The installation proved difficult, however, due to the large volume and heavy weight of the lysimeters. The vegetation fragment in the *Cladium* and *Polytrichum* lysimeters shortly exhibited reduced growth, and the *Polytrichumkragge* even drowned in the lysimeter, the moss not recovering afterwards.

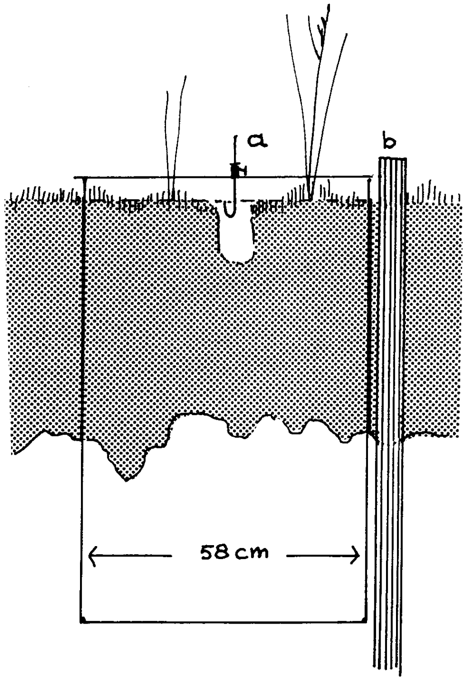


Fig.E.1 Lysimeter installed in a quagfen *kragge*
a adjustable pin for water level control; b one of three posts forming a float-shaft, and used as support of walking planks

The *Phragmites* lysimeter stood in a dense stand of reed. The vegetation in the lysimeter did not grow as high as the surrounding reed, but it was similar to other natural stands in the middle of *kraggen* where the supply of nutrients is reduced (Table E.1).

The results of the lysimeter study have been summarized in Table E.2, presenting regression constants for the equations

(1) $Ea = f(E_0)$
(2) $Ea = a(E_0) + b$

where
Ea: actual evapotranspiration (mm/d)
E_0: evaporation from an open water surface according to Penman (1963)
f: multiplication factor (‘vegetation factor’)
a,b: constants in linear regression equation

It should be noticed that the water supply to the vegetation fragments in the lysimeters has always been unlimited, as it is in the natural situation. For this reason the measured actual evapo-transpiration (Ea) may be taken as representative of the potential value (Ep).

Table E.1 Average characteristics of the lysimeters

Lysimeter:	**Sphagnum**	**Polytrichum**	**Cladium**	**Scorpidium**	**Phragmites**
Height of vegetation as compared to the surrounding stand:					
	up to 5 cm higher (mosses)	15 cm lower (mosses, died due to drowned kragge)	40 cm lower (Cladium)	equal	50 to 80 cm lower at end of season (Phragmites)
Growth of the vegetation as compared to the surrounding stand:					
	vital	strongly reduced	equal	equal	reduced at end of season
Cover of various types in lysimeter as seen from above:					
Open water:	5%	25%	50%	10%	10%
Dead plants:	0%	50%	30%	0%	0%
Mosses:	90%	25%	<5%	85%	5%
Helophytes:	5%	1%	15-20%	5%	85%
Kragge thickn.:	55 cm	>65cm	45 cm	45 cm	65 cm
Remarks:					
		lower part of kragge torn off and lost	sheltered due to high standing dead Cladium around		sheltered due to vital, 1.3-2 m high reed around

The correlations are rather poor, as is shown by the low values for r^2, especially in 1976. There may be various reasons why the evapotranspiration from lysimeters did not show a strict correlation with Penman's E_0:

- Any active role of the vegetation cover is empirically treated by the introduction of the vegetation factor;
- The vegetation fragment in the lysimeters is isolated from the subsurface water flow system in the mire, and may have suffered physiological damage by the installation;
- The whole procedure of frequent level adjustments and associated calculations is somewhat inaccurate, and further errors are introduced by technical deficiencies in the installed lysimeters;
- Lysimeters may not be expected to receive the same amount of rain as do well-installed rain-gauges;
- The lysimeters are subject to locally different micrometeorological environments;
- Penman's E_0 values, as calculated for data obtained at the weather stations in Leeuwarden and Lelystad, are only estimates, and these localities are at a considerable distance from the lysimeter site.

It is obvious, from Fig.E.2, that the evapotranspiration from the various lysimeters in both 1975 and 1976 shows a similar pattern (correlations with the *Sphagnum* lysimeter vary between 0.78 and 0.96), although the correlation with Penman's E_0 is poorer, especially in 1976. Both

Table E.2 Regression results for evapotranspiration from lysimeters, as a linear function of Penman's E_0

Lysimeter	750520-751031 n=16				760320-760915 n=18				both periods n=34			
	f	a	b	r^2	f	a	b	r^2	f	a	b	r^2
Sphagnum	0.59	0.60	-0.02	0.79	0.73	0.59	0.49	0.41	0.67	0.63	0.14	0.56
Polytrichum	0.40	0.54	-0.44	0.69	0.49	0.25	0.91	0.18*	0.45	0.42	0.10	0.44
Cladium	0.49	0.62	-0.44	0.77	0.59	0.48	0.42	0.39	0.55	0.58	-0.12	0.58
Scorpidium	0.61	0.77	-0.50	0.68	0.52	0.22	1.11	0.19*	0.56	0.49	0.23	0.44
Phragmites	0.47	0.63	-0.48	0.73	0.47	0.16	1.11	0.09*	0.47	0.41	0.21	0.40

Entry data: mm/d for periods of ten days; f: ratio Ea/E0; b: offset (mm/d) in linear regression equation;
r^2: coefficient of determination; * not significant at the 0.01 level (t-test, two-sided)

years were extremely dry, 1976 even more so than 1975. This may have influenced the processes involved in the evapotranspiration. One should note, among other things, that the evapotranspiration from the *Polytrichum*, *Scorpidium* and *Phragmites* lysimeters in June and July 1976 was low. The upper surface of the moss plants in the *Polytrichum* and *Scorpidium* lysimeters dried out during this summer period and may have had a reduced evapotranspiration. The *Phragmites* lysimeter became sheltered, during the growing season, by the up to 0.8 m higher surrounding reed, which kept the atmosphere moister.

If extremes are removed, a better correlation with E_0 can be obtained, but I cannot visualize any method to obtain results that can 'safely' be applied to other periods and places.

In 1986, Koerselman & Beltman (1988) also used lysimeters to assess the evapotranspiration of quagfen vegetation. Their results suggest a multiplication factor of 0.75 for the types of vegetation involved, and they found high correlations with E_0 at a small quagfen site near Utrecht, using meteorological data for De Bilt, at a distance of about 8 km from the lysimeter site. A general perusal of their results shows that the pattern for E_0 was quite similar to that found in the present study. In view of the strong correlations between lysimeters in both studies, I do not think that possible differences in the accuracy of measurements and calculations can fully explain the different value found for the vegetation factor. The following factors may explain the differences recorded:

The lysimeters used in the present study had a 1.66 times larger surface area and a 2.3 times larger depth, possibly resulting in a more representative experimental system in the *Phragmites*, *Sphagnum*, and *Scorpidium* lysimeters. This concerns especially the height of the water table, relative to the *kragge* level, and the growth of the vegetation fragment. A rise or fall of only 1 or 2 cm of the relative height of the water table may strongly interfere with the evapotranspiration through a changing relative area of surface water in the lysimeters. From the study by Koerselman & Beltman, who included open water pans, it appeared that pan evaporation is only 0.4-0.5 times E_0, which suggests sheltered conditions. The evapotranspiration from the lysimeters in the present study is apparently closer to open water pan evaporation than to evapotranspiration measured in quagfen lysimeters with a relative water level 3 cm below the *kragge* surface by Koerselman & Beltman. Indeed, surface water covered a substantial part of the lysimeters in the present study (see Table E.1).

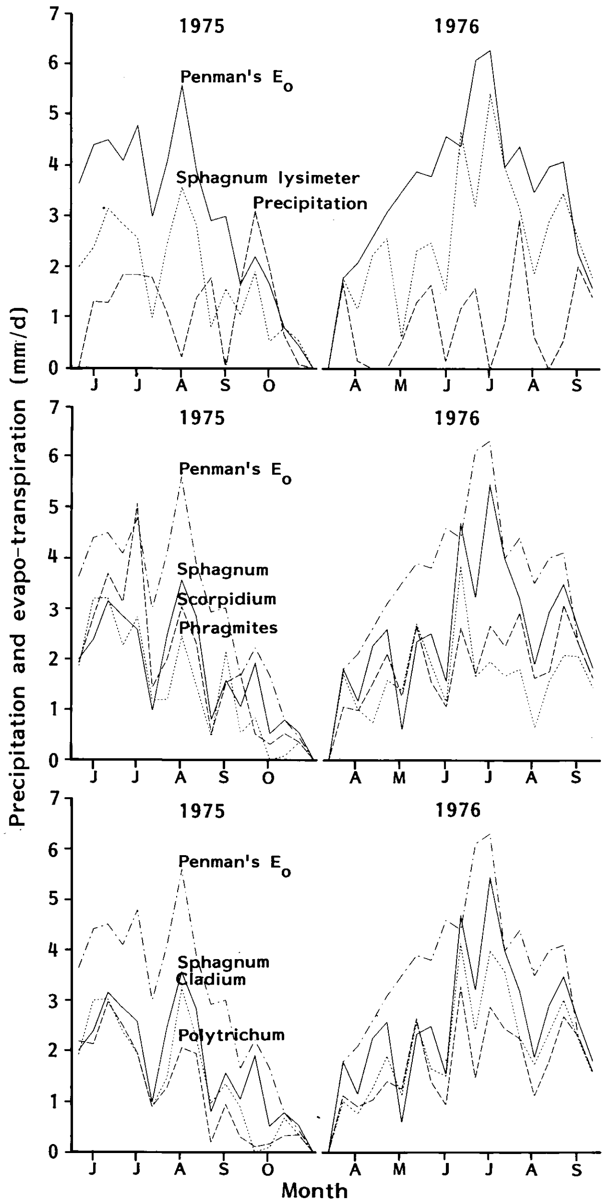


Fig.E.2 Precipitation, Penman's E_0, and evapo-transpiration from lysimeters in De Weerriben

Average values per decade have been used; the start of each month is marked on the axis

In the present study, the aerial extension of the plants rooting in the lysimeter was essentially confined to the cilindrical body of air just above the lysimeter, and above-ground herb biomass was probably lower than in Koerselman's lysimeters.

Koerselman & Beltman conducted their study in small quagfen parcels in an open grassland area. This may have increased the importance of advection of dry air and so increased the evapotranspiration as compared to the large mire area, with much open water, in North-West Overijssel.

In conclusion, during the growing season the evapotranspiration from quagfen in De Stobbenribben is probably ca 0.6 times Penman's E_0 as calculated on the basis of weather data from Leeuwarden and Lelystad, but a variation of ca 30% may exist. Insufficient data are available for any precise explanation and calculation of this variation.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

APPENDIX F

Data reports

This appendix lists data reports and manuscripts resulting from the present project, and is primarily intended to acknowledge the contributions of many students not explicitly referred to in other parts of this book, rather then to provide a complete list.

Anonymus 1973. Waarnemingen verricht tijdens de veldcursus oecologie door studenten van het 3e studiejaar, richting B3 en B4. Mscr. Hugo de Vries-Laboratorium, UvA, Amsterdam.

Bergmans, W. 1975. Synoekologisch onderzoek in enige suksessiereeksen in het C.R.M.-reservaat De Weerribben (N.W.-Overijssel). Int. Rapp. 16. Hugo de Vries-Lab., UvA, Amsterdam, 67p., bijl.

Blanksma, W.J. 1974. Hydrologisch Onderzoek in een kraggecomplex in het C.R.M.-Reservaat "De Weerribben". Int. Rapp. 11. Hugo de Vries-Lab., UvA, Amsterdam, 17p., bijl.

Boeye, D. 1983. Verslag van een ecohydrologische stage in "De Weerribben" (N.W.-Overijssel, NL). Vrije Universiteit Brussel, Dienst Hydrologie, Brussel, 22p., bijl.

Bon, J. 1975. Hydrologisch overzicht van het natuurreservaat De Wheerribben en omgeving. Nota 865. Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen, 13p.

Bos, C. & E. Moolhuizen. 1975. Enige zanddiepte-metingen in De Weerribben. Mscr. SBB, Zwolle.

Bot, A.K. 1975. Hydrologisch onderzoek in drie proefterreinen in het C.R.M.-Reservaat "De Weerribben". Int. Rapp. Inst. v. Cultuurtechniek en Waterhuishouding, Wageningen, 31p., bijl.

Brand, L.J. & J.A. Leemburg 1978. Een onderzoek naar de relatie tussen reflektie-eigenschappen en hoeveelheid groene biomassa bij enige halfnatuurlijke vegetaties. Mscr. Lab. v. Plantenoecologie RUG/Rijksinst. v. Natuurbeheer, Haren/Leersum, 61p.

Brandsma, J. 1975. Voortgezet hydrologisch onderzoek in "De Weerribben". Int. Rapp. Inst. v. Cultuurtechniek en Waterhuishouding/Staatsbosbeheer, Oldemarkt, 37p., bijl.
Brijker, H. & J. Hartevelt 1976. De vegetatie van het Woldlakebos, een verdroogd moerasgebied in Noord-West Overijssel. Int. Rapp. 28. Hugo de Vries-Lab., UvA, Amsterdam, 28p., bijl.
Calis, J.N.M. & J.C.J. van Wetten 1983. Onderzoek van successie en hydrologie, in het trilveen-complex "De Wobberibben" (De Weerribben N.W.-Overijssel). Int. Rapp. 153. Hugo de Vries-Lab., UvA, Amsterdam, 91p.
Claassen, T.H.L. 1976. De beoordeling van oppervlaktewater in Noordwest-Overijssel op basis van biologische, chemische en fysische gegevens. Int. Rapp. 26. Hugo de Vries-Lab., UvA, Amsterdam, 29p., bijl.
De Boer, J., R, J. Holtland & I. Lucassen 1977. Kan hoogveen ontstaan in de Polletjesgaten?. Int. Rapp. Rijksinstituut voor Natuurbeheer, Leersum, 53p., bijl.
De Waard, J. 1979. Een onderzoek naar het voorkomen van boomopslag op enkele percelen in het CRM-reservaat "De Weerribben". Int. Rapp. 72. Hugo de Vrieslab., UvA, Amsterdam, 58p.
Heringa, R.B. & P.G.M. van der Sloot 1973. Manuscript vegetatiekaart. Mscr.
Holtland, J. & I. Lucassen 1976. De bereikbaarheid van de kraggen voor boezemwater in een gedeelte van "De Weerribben". Mscr. Staatsbosbeheer, Zwolle, 18p.
Jalink, M. 1990. Een evaluatie van digitaal beeldmateriaal en vegetatiekundige gegevens van de Stobbenribben, NW-Overijssel. Int. Rapp. 90/3. Rijksinstituut v. Natuurbeheer, Arnhem, 140p.
Klijn, J.A. 1973. Interpretatie false color luchtfoto's De Weerribben. Mscr. ITC/Hugo de Vries-Lab., UvA, Enschede/Amsterdam.
Kooijman, A.M. 1985. Een onderzoek naar de nutriëntenhuishouding van een trilveen in "De Weerribben". Rapp. Vakgr. Bot. Oec., Sectie Landschapsoecologie, RUU, 77p.
Lumkes, M. 1976. Kartering van Watervegetaties in verband met milieu-eisen van krabbescheer. Mscr., 16p.
Muis, A. 1974. Windmoleninventarisatie in "De Weerribben". Rapp. BCS, Velp, 34p, map.
Mulder, M.A.A. 1985. Geohydrologische modelstudie Weerribben. Rapp. T. H. -Delft, Afd. Civiele Techniek, Vakgr. Waterbeheersing, 76p.
Noot, J. 1974. Ecologisch onderzoek van het Duiningermeer. Concept-verslag. Hugo de Vries-Lab., UvA.
Oosterbroek, P. & B.J. Post 1977. Een vegetatiekartering m. b. v. false-colour luchtfoto's in het C.R.M.-reservaat "De Weerribben" (N.W.-Overijssel). Int. Rapp. 40. Hugo de Vries-Lab., UvA, Amsterdam, 45p., bijl.
Raeymaekers, G. 1975. Eem vegetatiekundig onderzoek in verband met de waterhuishouding van enige kraggegebieden in het Natuurmonument "De Wieden" (N.W.-Overijssel). Int. Rapp. 14. Hugo de Vries-Lab., UvA, Amsterdam, 21p., bijl.
Raeymaekers, G. 1977. Het verband tussen waterhuishouding en vegetaties in waterrijke gebieden. Dumortiera 7-8, 38-47.
Rengersen, J. 1980. Een verspreidingsmodel voor conservatieve stoffen in het oppervlaktewater van NW-Overijssel. Report. T. H. -Twente, Afd. Chemische Technologie, Onderzoeksgr. Techn. Milieubeh., 122p.
Ruitenburg, G.J.M. 1974. Vegetatiekartering van De Wobberibben. Concept-verslag. Hugo de Vries-Lab. UvA.
Schoof, A. J. G. 1973. Een gedetailleerde vegetatiekartering op een groeiplaats van enige Ericaceae in het C.R.M.-Reservaat "De Weerribben" (N.W.-Overijssel). Int. Rapp. 5. Hugo de Vries-Lab., UvA, Amsterdam, 39p., bijl.

Straathof, N. 1976. Praktijkverslag over hydrologisch onderzoek in de Weerribben. Int. Rapp. Staatsbosbeheer/Rijksinstituut voor Natuurbeheer, Zwolle, 11p., bijl.

Touber, L. 1973. Hydrologisch Onderzoek in enige verlande petgaten in het C.R.M.-Reservaat "De Weerribben", N.W.-Overijssel. Int. Rapp. 3. Hugo de Vries-Lab., UvA, Amsterdam, 34p., bijl.

Van Leeuwen, C.H. 1978-'83. Temperatuur en electrische geleiding in De Stobbenribben. Rijksinstituut voor Natuurbeheer, Leersum (ongepubliceerd).

Van Opbroek, G. 1976. Verslag van de vegetatie-opnamen en kaartering van de hoogveenontwikkeling op het terrein bij Tietema's Vaart. Mscr.

Van der Perk, J.C. & M.J. Smit 1975. Een hydrologisch onderzoek ten behoeve van het natuurbeheer in de "Wieden". Int. Rapp. 17. Hugo de Vries-Lab., UvA, Amsterdam, 56p., bijl.

Vegt, J.J. 1978. Herkenning van natuurlijke vegetaties met behulp van multi-spectrale Remote Sensing. Int. Rapp. Rijksinstituut voor Natuurbeheer, Leersum, 48p., bijl.

Vegt, J.J. 1978. Verdamping, berging en indringing van boezemwater in het moerasgebied "De Weerribben". Int. Rep., RIN, Leersum, 51p., bijl.

Verhoeven, J.T.A., A.M. Kooijman & G. van Wirdum 1988. Mineralization of N and P along a trophic gradient in a freshwater mire. Biogeochemistry 6, 31-43.

Verschoor, A. 1978. Vegetatiekartering met behulp van luchtfoto's in het CRM-reservaat "De Weerribben" (N.W.-Overijssel). Int. Rapp. 56. Hugo de Vries-lab., UvA, 31p.

Verschuren, B. 1976. Een krabbescheerinventarisatie in Noordwest-Overijssel en Zuid-Friesland. Int. Rapp., Hogere Tuinbouwschool ('s Hertogenbosch).

Vromen, H, L. Klamer & J. de Vries 1974. Voortgezet Hydrologisch onderzoek in enige verlande petgaten in het C.R.M.-reservaat "De Weerribben". Int. Rapp., HBCS/SBB (Zwolle).

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

REFERENCES

Amann, J. 1928. Bryogéographie de la Suisse. Matériaux pour la flore cryptogamique suisse VI(2). Fretz, Zürich, 453p.

Anonymus 1982. Makrophytische Indikatoren für die ökochemische Beschaffenheit der Gewässer. Ausgewählte Methoden der Wasseruntersuchung, Band II, Biologische, mikrobiologische und toxikologische Methoden, 1.1.2. Gustav Fischer, Jena, 67-88.

Balátová-Tuláčková, E. 1972. Flachmoorwiesen im mittleren und unteren Opava-Tal. Vegetace ČSSR A(4). Praha, 201p.

Balátová-Tuláčková, E. 1976. Rieder- und Sumpfwiesen der Ordnung *Magnocaricetalia* in der Záhorie-Tiefebene und dem nördlich angrenzenden Gebiete. Vegetácia ČSSR B(3). Veda, Bratislava, 257p.

Bear, J. 1972. Dynamics of fluids in porous media. Elsevier, New York etc., 764p.

Bergmans, W. 1975. Synoekologisch onderzoek in enige suksessiereeksen in het C.R.M. reservaat De Weerribben (N.W.-Overijssel). Int.Rapp.16. Hugo de Vries-Lab., UvA, Amsterdam, 67p., bijl.

Bick, W., A. Robertson, R. Schneider, S. Schneider & P. Ilnicki 1976. Słownik torfoznawczy Niemiecko-Polsko-Angielsko-Rosyjski (Glossary for bog and peat, German-Polish-English-Russian). Biblioteczka Wiadomości IMUZ nr 51. Instytut Melioracji i Użytków Zielonych, Państwowe wydawnictwo rolnicze i leśne, Warszawa, 178p.

Bloemendaal, F.H.J.L. & J.G.M. Roelofs 1988. Waterverharding. In: F.H.J.L. Bloemendaal & J.G.M. Roelofs (red.), Waterplanten en Waterkwaliteit. Nat.Hist.Bibl. KNNV 45. Kon. Ned. Nat.-Hist. Ver., Utrecht, 147-158p.

Boeye, D. 1983. Verslag van een ecohydrologische stage in "De Weerribben" (N.W.-Overijssel, NL). Vrije Universiteit Brussel, Dienst Hydrologie, Brussel, 22p., bijl.

Bon, J. 1975. Hydrologisch overzicht van het natuurreservaat De Wheerribben en omgeving. Nota 865. Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen, 13p.

Bonetto, A.A. 1975. Hydrologic regime of the Paraná River and its influence on ecosystems. In: A.D. Hasler (ed.), Coupling Land and Water Systems. Springer, Berlin etc., 175-197.

Boros, A. 1968. Bryogeographie und Bryoflora Ungarns. Akadémiai Kiadó, Budapest, 466p.

Bot, A.K. 1975. Hydrologisch onderzoek in drie proefterreinen in het C.R.M.-Reservaat "De Weerribben". Int.Rapp. Inst. v. Cultuurtechniek en Waterhuishouding, Wageningen, 31p., bijl.

Brand, L.J. & J.A. Leemburg 1978. Een onderzoek naar de relatie tussen reflektie-eigenschappen en hoeveelheid groene biomassa bij enige halfnatuurlijke vegetaties. Mscr. Lab. v. Plantenoecologie RUU/Rijksinst.v.Natuurbeheer, Haren/Leersum, 61p.

Brandsma, J. 1975. Voortgezet hydrologisch onderzoek in "De Weerribben". Int.Rapp. Inst.v.Cultuurtechniek en Waterhuishouding/Staatsbosbeheer, Oldemarkt, 37p., bijl.
Braun, W. 1968. Die Kalkflachmoore und ihre wichtigsten Kontaktgesellschaften im Bayerischen Alpenvorland. Dissertationes Botanicae 1. Cramer, Lehre, 134p., bijl.
Bredenbeek, P., P. Gerrits & V. van Loon 1979. Vegetatiekartering van de Stobbenribben in het natuurreservaat "De Weerribben" te Ossenzijl (N.W.-Overijssel). Sticht. Opleiding Leraren, Utrecht, 46p.
Brockhaus 1961. Die Entwicklungsgeschichte der Erde. Brockhaus, Leipzig, 772p.
Calis, J.N.M. & J.C.J. van Wetten 1983. Onderzoek van successie en hydrologie, in het trilveen-complex "De Wobberibben" (De Weerribben N.W.-Overijssel). Int.Rapp.153. Hugo de Vries-Lab., UvA, Amsterdam, 91p.
CHO-TNO 1986. Water in The Netherlands. Proc. and Inf. 37. TNO Committee on Hydrological Research (CHO), The Hague, 70p.
Clymo, R.S. 1983. Peat. In: A.J.P Gore (ed.), Mires: swamp, bog, fen and moor, General studies. Ecosystems of the world 4a. Elsevier, Amsterdam etc., 159-224.
Coesel-Wouda, M.J. 1967. Onderzoek naar de oecologie van de Europese Utricularia-soorten. Rapp. Hugo de Vries-Laboratorium/RIVON, Amsterdam/Leersum, 48p.
Connell, J.H. & R.O. Slatyer 1977. Mechanisms of succession in natural communities and their role in community stability and organization. The American Naturalist, vol. 111(982),1119-1144.
Corporaal, A. 1984. *Calamagrostis x gracilescens* (Blytt) nieuw voor Nederland (Engl. Summ.: *Calamagrostis x gracilescens* (Blytt) new for the Netherlands). Gorteria 12(5),109-111.
De Boer, J., R,J. Holtland & I. Lucassen 1977. Kan hoogveen ontstaan in de Polletjesgaten?. Int.Rapp. Rijksinstituut voor Natuurbeheer, Leersum, 53p., bijl.
De Crook, Th. 1979. Het berekenen van de verticale grondwatersnelheid uit grondtemperatuurprofielmetingen. Scientific Rep. WR 79-11. Koninklijk Nederlands Meteorologisch Instituut, De Bilt, 35p.
De Graaf, F. 1955. De micro-organismen van plankton, lasion en bodem van het plassengebied Het Hol. In: W. Meijer & R.J. De Wit (red.), Kortenhoef, Een veldbiologische studie van een Hollands verlandingsgebied. Commissie voor de Vecht en het Oostelijk en Westelijk Plassengebied, Amsterdam, 67-91.
De Lange, L. 1972. An ecological study of ditch vegetation in The Netherlands. Thesis. University of Amsterdam, 112p.
De Vries, D.A. 1963. Thermal properties of soils. In: W.R. van Wijk (ed.), Physics of plant environment. North-Holland, Amsterdam, 210-235.
De Wit, R. 1951. De draadzegge-gemeenschap in Noordwest-Overijssel. Kruipnieuws 13(1/2):3-6, also in: J.C. Smittenberg (red.), Plantengroei in enkele Nederlandse landschappen (1973). Bondsuitgeverij van de Jeugdbonden voor Natuurstudie (N.J.N, C.J.N. en K.J.N.), Amsterdam, 345-357.
Den Boer, P.J. 1986. The Present Status of the Competitive Exclusion Principle. Tree 1(1). Elsevier, Amsterdam, 25-28.
Den Held, J.J. & A.J. den Held 1973. Beknopte handleiding voor vegetatiekundig onderzoek. Wetenschappelijke Mededelingen van de KNNV 97. Koninklijke Ned. Natuurhistorische Ver., Hoogwoud, 39p.
Dickinson, C.H. 1983. Micro-organisms in peatlands. In: A.J.P. Gore (ed.), Mires: swamp, bog, fen and moor, General studies. Ecosystems of the world 4a. Elsevier, Amsterdam, 225-245.
Dierssen, K. 1982. Die wichtigsten Pflanzengesellschaften der Moore NW-Europas. Conservatoire et Jardin botaniques, Genève, 382p.
Dirkse, G.M., H.M.H. van Melick & A. Touw 1989. Checklist of Dutch bryophytes. Lindbergia 14(3), 167-175.
Dykyjová, D. & J. Květ (eds.) 1978. Pond Littoral Ecosystems. Springer, Berlin etc., 464p.
Ellenberg, H. 1974. Zeigerwerte der Gefässpflanzen Mitteleuropas. Scripta Geobotanica 9, Göttingen, 97p.
Ellenberg, H. 1978. Vegetation Mitteleuropas mit den Alpen in ökologischer Sicht. Ulmer, Stuttgart, 981p.
Etherington, J.R. 1975. Environment and Plant Ecology. Wiley, London etc., 347p.
Eurola, S., S. Hicks & E. Kaakinen 1984. Key to Finnish Mire Types. In: P.D. Moore (ed.), European Mires. Academic Press, London etc., 11-119.
Faber, F.J. 1960. Aanvullende hoofdstukken over de geologie van Nederland, IV. Noorduijn, Gorinchem, 607p.
Gallandat, J.D. 1982. Prairies marécageuses du Haut-Jura. Matériaux pour le levé géobotanique de La Suisse. Flück-Wirth, Teufen, 327p.
Geologische Dienst 1979. Geologisch onderzoek natuurgebied "De Weerribben". Rapp. 10312. Rijks Geologische Dienst, Haarlem, 3p., bijl.
Gibbs, R.J. 1970. Mechanisms controlling world water chemistry. Science 170, 1088-1090.
Giller, K.E. 1982. Aspects of the plant ecology of a flood-plain mire in Broadland, Norfolk. Thesis. University of Sheffield, Sheffield, 239p.
Giller K.E., & B.D. Wheeler 1986. Peat and peat water chemistry of a flood-plain fen in Broadland, Norfolk, U.K. Freshwater Biology 16, 99-114.
Godwin, H. 1978. Fenland, its ancient past and uncertain future. Cambridge University Press, Cambridge etc., 196p.
Golterman, H.L., R.S. Clymo & M.A.M. Ohnstad 1978. Methods for physical and chemical analysis of fresh waters. IBP Handbook 8. Blackwell, Oxford etc., 213p.
Gonggrijp, G., V. Langenhoff & W. Schroevers 1981. Ontdek N.W.-Overijssel. Nederlandse Landschappen. IVN, Amsterdam, 288p.

Gore, A.J.P. (ed.) 1983. Mires: Swamp, Bog, Fen and Moor, A: General Studies, B: Regional Studies. Ecosystems of the world 4. Elsevier, Amsterdam etc., 440, 479.

Gorham, E. S.J. Eisenreich, J. Ford & M.V. Santelmann 1985. The chemistry of bog waters. In: W. Stumm (ed.), Chemical processes in lakes. Wiley, New York etc., 339-363.

Grime, J.P. 1979. Plant strategies and vegetation processes. Wiley, Chichester etc., 222p.

Grootjans, A.P. 1985. Changes of groundwater regime in wet meadows. Thesis. University of Groningen, Groningen, 146p.

Grubb. P.J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. Biol.Rev. 52, 107-145.

Gunning 1870. See Vereniging 1870, p.125.

Haans, J.C.F.M. 1951. De rietgroei in de Schut- en Grafkampen onder de gemeente Oldemarkt. Rapp. 265. Stichting voor Bodemkartering, Wageningen, 14p.

Haans, J.C.F.M. & C. Hamming 1954. De bodemgesteldheid van het ruilverkavelingsgebied Vollenhove. Int. Rapp. 392. Stichting voor Bodemkartering, Wageningen.

Haans, J.C.F.M. & C. Hamming 1962. Over de bodemgesteldheid in het veengebied in het Land van Vollenhove. Int. Rapp. 563. Stichting voor Bodemkartering, Wageningen, 58p.

Hack, J. 1973. Kartering en oecologie van een aantal water- en oeverplanten in De Weerribben te Oldemarkt. Int. Rapp. Hugo de Vries-Lab., UvA/Rijksinst.v.Natuurbeheer, Amsterdam/Leersum, 48p., bijl.

Havinga, A.J. 1957. Bijdrage tot de kennis van het rietland in Noordwest-Overijssel. Boor en Spade 8, 131-140.

Hedenäs, L. 1989. The genera *Scorpidium* and *Hamatocaulis*, *gen. nov.*, in northern Europe. Lindbergia 15(1), 8-36.

Heij, G.J. & T. Schneider (eds.) in press. Acidification research in The Netherlands. Elsevier, Amsterdam.

Hem, J.D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. Water-Supply Paper 1473. Geological Survey. U.S. Government Printing Office, Washington, 363p.

Heringa, R.B. & P.G.M. van der Sloot 1973. Manuscript vegetatiekaart. Mscr.

Het Oversticht 1939. Bezwaren tegen de verdere inpoldering in het Land van Vollenhove. Rapp. Ingenieursbureau voor bouw- en waterkunde Het Oversticht, Deventer, 35p.

Hoffer, R.M. & C.J. Johannsen 1969. Ecological potentials in spectral signature analysis. In: P.L. Johnson, Remote Sensing in Ecology. University of Georgia Press, Athens, 1-16.

Hoogendoorn, J.H. 1983. Hydrochemie Oost-Nederland. Rapport OS 83-38, 4 dln. Dienst Grondwaterverkenning TNO, Delft-Oosterwolde, 157p.

Hooghart, J.C. (red.) 1986. Verklarende hydrologische woordenlijst. Rapp. en Nota's 16. CHO-TNO,'s-Gravenhage, 130p.

Huijsmans, T.M.F., & F.W. Zwietering 1980. De waterhuishouding van "De Weerribben". Rapp. Anonymus, 102p.

Huston, M. 1979. A general hypothesis of species diversity. The American Naturalist 113(1), 81-101.

Hutchinson. G.E. 1975. A Treatise on Limnology, III, Limnological Botany. Wiley, New York etc., 660p.

International Peat Society 1984. Russian-English-German-Finnish-Swedish Peat Dictionary. IPS, Helsinki, 595p.

Jalink, M. 1990. Een evaluatie van digitaal beeldmateriaal en vegetatiekundige gegevens van de Stobbenribben, NW-Overijssel. Int. Rapp. 90/3. Rijksinstituut v. Natuurbeheer, Arnhem, 140p.

Jelgersma, S. & J.B. Breeuwer 1975. Toelichting bij de geologische overzichtsprofielen door Nederland. In: W.H. Zagwijn & C.J. van Staalduinen (red.), Toelichting bij de geologische overzichtskaarten van Nederland. Rijks Geologische Dienst, Haarlem, 91-93.

Jol, C. & J. Laseur (ed.) 1982. Waterkwaliteitsaspecten in het proefgebied Nationaal Landschap Noordwest-Overijssel. Rapp. Zuiveringschap West-Overijssel, Zwolle, 43p.

Kelts, K. & K.J. Hsü 1978. Freshwater Carbonate Sedimentation. In: A. Lerman (ed.), Lakes: chemistry, geology, physics. Springer, New York etc., 295-321.

Kielland 1937. See Hem 1970.

Kinzel, H. 1982. Einführung. In: H. Kinzel (ed.), Pflanzenökologie und Mineralstoffwechsel. Ulmer, Stuttgart, 13-31.

Kleijn, H.F. 1986. Agressiviteit en de oplosbaarheidsconstante van calciumcarbonaat. H_2O 19(13), 309-310.

Klötzli, F. 1981. Végétation. In: C. Roth et al. (ed.), Étangs naturels - comment les projeter, les aménager, les recréer. Office fédéral des forêts, Division de la protection de la nature et du paysage, Berne, 27-37.

Knipling, E.B. 1969. Leaf reflectance and image formation on color infrared film. In: P.L. Johnson, Remote Sensing in Ecology. University of Georgia Press, Athens, 17-29.

KNMI 1972. Klimaatatlas van Nederland. Koninklijk Nederlands Meteorologisch Instituut. Staatsuitgeverij,'s-Gravenhage, 18p., maps.

Koch, W. 1926. Die Vegetationseinheiten der Linthebene unter Berücksichtigung der Verhältnisse in der Nordostschweiz. Jahrbuch St.-Gallischen Naturwissensch. Gesellsch. 61(2).

Koerselman, W. 1989. Groundwater and surface water hydrology of a small groundwater-fed fen. Wetlands Ecology and Management 1, 31-43.

Koerselman, W., S.A. Bakker & M. Blom in press. Nitrogen, phosphorus and potassium mass balances for two small fens surrounded by heavily fertilized pastures. J.Ecol.

Koerselman, W. & B. Beltman 1988. Evapotranspiration from fens in relation to Penman's potential free water evaporation (Eo) and pan evaporation. Aquatic Botany 31, 307-320.

Koerselman, W., H. de Caluwe & W.M. Kieskamp in press. Denitrification and dinitrogen fixation in two quaking fens in the Vechtplassen area, The Netherlands. Biogeochemistry.

Koerselman, W., D. Claessen, P. ten Den & E. van Winden in press. Dynamic hydrochemical gradients in fens in relation to the vegetation. J.Ecol.

Kooijman, A.M. 1985. Een onderzoek naar de nutriëntenhuishouding van een trilveen in "De Weerribben". Rapp. Vakgr. Bot. Oec., Sectie Landschapsoecologie, RUU, 77p.

Kroes, J. & T. Hol 1979. Het Land van Vollenhove; een historisch-geografische studie van het Noordwest-Overijsselse cultuurlandschap. Report. Anonymus, Zwolle, 296p.

Kruijne, A.A., D.M. de Vries & H. Mooi 1967. Bijdrage tot de oecologie van de Nederlandse graslandplanten (Engl. summ.: Contribution to the ecology of the Dutch grassland plants). Versl. Landbouwk. Ond. 696, Med. 338 IBS. Pudoc, Wageningen, 65p.

Kuiper, P. & Kuiper, C. 1958. Verlandingsvegetaties in Noordwest-Overijssel. Kruipnieuws 20(1): 1-19, also in J.C. Smittenberg (red.), Plantengroei in enkele Nederlandse landschappen. Bondsuitgeverij Jeugdbonden voor Natuurstudie, Amsterdam, 357-401.

Kuiper, P. & C. Lapré 1956. Verslag excursies 1956, I, II. Mscr. Staatsbosbeheer, Utrecht, 34p., krtn.

Lambert, J.M., J.N. Jennings, C.T. Smith, C. Green & J.N. Hutchinson 1960. The making of the Broads. A reconsideration of their origin in the light of new evidence. Research Series 3. The Royal Geographical Society, London, 153.

Landwehr, J. (m.m.v. J.J. Barkman) 1966. Atlas van de Nederlandse bladmossen. Bibliotheek KNNV 15. Koninklijke Nederlandse Natuurhistorische Vereniging, Amsterdam, 504p.

Landwehr, J. (m.m.v. S.R. Gradstein & H. van Melick) 1980. Atlas van de Nederlandse levermossen. Bibliotheek KNNV 27. Koninklijke Nederlandse Natuurhistorische Vereniging, 287p.

Leentvaar, P. 1960. Hydrobiologische waarnemingen in het plassengebied van N.W.-Overijssel. Rapp. Rijksinstituut voor Veldbiologisch Onderzoek t.b.v. het Natuurbehoud, Zeist, 19p., bijl.

Levine, I.N. 1978. Physical Chemistry. McGraw-Hill, New York etc., 847p.

Lindenbergh, A.G. 1956. De watervoorziening van de lichte gronden in de oostelijke helft van de Noordoostpolder (Engl. Summ.: The irrigation of the light soils in the eastern half of the North-Eastern polder). Van Zee tot Land 17. Tjeenk Willink, Zwolle, 51p.

Londo, G. 1975. Nederlandse lijst van hydro-, freato- en afreatofyten; See G. Londo 1988. Rapp. Rijksinstituut voor Natuurbeheer, Leersum.

Londo, G. 1988. Nederlandse freatofyten (Engl. Summ.: Dutch freatophytes). Pudoc, Wageningen, 108p.

Lumkes, M. 1976. Kartering van Watervegetaties in verband met milieu-eisen van krabbescheer. Mscr., 16p.

Lyklema, L. & G. van Straten 1977. De waterbeweging in het plassengebied van N.W.-Overijssel. H_2O 10(16), 360-363.

Malmer, N. 1962. Studies on mire vegetation in the Archaean area of South-Western Götaland (South-Sweden), II, Distribution and seasonal variation in elementary constituents on some mire sites. Opera Botanica 7(2), 1-67.

Malmer, N. 1963. Studies on mire vegetation in the Archaean area of Southwestern Götaland (South Sweden), III, On the relation between specific conductivity and concentrations of ions in the mire water. Botaniska Notiser 116(2), Lund, 149-256.

Margadant, W.D. & H. During 1982. Beknopte flora van de Nederlandse Blad- en Levermossen. Bibliotheek KNNV 28. Thieme, Zutphen, 517p.

Masing, V. 1984. Estonian bogs: Plant cover, succession and classification. In: P.D. Moore (ed.), European mires. Academic Press, London etc., 119-148.

Maucha, R. 1932. Hydrochemische Methoden in der Limnologie. Die Binnengewässer 12. Schweizerbart, Stuttgart, 173p.

McIntosch, R.P. 1973. Matrix and plexus techniques. In: R.H. Whittaker (ed.), Ordination and Classification of Communities, Handbook of Vegetation Science 5. Junk, The Hague, 157-191.

Meijer, W. & R.J. de Wit (eds.) 1955. Kortenhoef, Een veldbiologische studie van een Hollands verlandingsgebied. Cie. voor de Vecht en het O. en W. plassengebied, Amsterdam, 128p.

Meijer, W. & R.J. de Wit 1955. De verlanding in het kwelgebied van het Hol. In: W. Meijer & R.J. de Wit (red.), Kortenhoef, Een veldbiologische studie van een Hollands verlandingsgebied. Cie. voor de Vecht en het O. en W. plassengebied, Amsterdam, 45-49.

Molenaar, W.J., R. van Diggelen & A.M. Kooijman 1990. Vegetation Succession and Hydrology in De Bollemaat, De Wieden. Acta Botanica Neerlandica 39(3), 318-319.

Mönkemeyer, W. 1927. Die Laubmoose Europas, Ergänzungsband, Andreaeales-Bryales. Dr. L. Rabenhorsts Kryptogamen-Flora von Deutschland, Österreich und der Schweiz IV. Akad. Verlagsgesellsch., Leipzig, 960.

Moore, P.D. (ed.) 1984. European Mires. Academic Press, London etc., 367p.

Moore, P.D. & D.J. Bellamy 1973. Peatlands. Elek Science, London, 221p.

Moss, B. 1978. The ecological history of a mediaeval man-made lake, Hickling Broad, Norfolk, United Kingdom. Hydrobiologia 60(1), 23-32.

Mueller-Dombois, D. & H. Ellenberg 1974. Aims and methods of vegetation ecology. Wiley, New York etc., 547p.

Muis, A. 1974. Windmoleninventarisatie in "De Weerribben". Rapp. BCS, Velp, 34p., map.

Müller, K. 1954-'57. Die Lebermoose Europas, eine Gesamtdarstellung der europäischen Arten. Dr. L. Rabenhorst's Kryptogamen-Flora von Deutschland, Österreich und der Schweiz VI(1,2). Akad. Verlagsgesellsch., Geest & Portig, Leipzig, 1365p.
Oberdorfer, E. 1979. Pflanzensoziologische Exkursionsflora. Ulmer, Stuttgart, 997p.
Oosterbroek, P. & B.J. Post 1977. Een vegetatiekartering m.b.v. false-colour luchtfoto's in het C.R.M.-reservaat "De Weerribben" (N.W.-Overijssel). Int.Rapp. 40. Hugo de Vries-Lab., UvA, Amsterdam, 45p., bijl.
Pałczyński, A. 1984. Natural differentiation of plant communities in relation to hydrological conditions of the Biebrza valley. Polish Ecological Studies 10(3-4), 347-385.
Pallis, M. 1916. The structure and history of plav: the floating fen of the Danube. J.Linn.Soc.(Bot.) 43, 233-290.
Penman, H.L. 1963. Vegetation and Hydrology. Techn. Comm. 53. Commonwealth Bureau of Soils, Harpenden; Commonwealth Agricultural Bureaux,Farnham Royal, Bucks, 124p.
Pielou, E.C. 1977. Mathematical Ecology. Wiley, New York etc., 385p.
Pietsch, W. 1982. See Anonymus 1982.
Raeymaekers, G. 1975. Een vegetatiekundig onderzoek in verband met de waterhuishouding van enige kraggegebieden in het Natuurmonument "De Wieden" (N.W.-Overijssel). Int.Rapp.14. Hugo de Vries-Lab., UvA, Amsterdam, 21p., bijl.
Raeymaekers, G. 1977. Het verband tussen waterhuishouding en vegetaties in waterrijke gebieden. Dumortiera 7-8, 38-47.
Rengersen, J. 1980. Een verspreidingsmodel voor conservatieve stoffen in het oppervlaktewater van NW-Overijssel. Report. T.H.-Twente, Afd. Chemische Technologie, Onderzoeksgr. Techn. Milieubeh., 122.
Rijksbureau voor Drinkwatervoorziening 1938. Rapport inzake een geo-hydrologisch onderzoek ten behoeve van den Noordoostpolder. Rapp. Rijksbureau voor Drinkwatervoorziening.
Rijksinstituut voor Natuurbeheer 1979. Levensgemeenschappen. Natuurbeheer in Nederland. Pudoc, Wageningen, 392p.
Robinson, R.A. & R.H. Stokes 1955-'70. Electrolyte Solutions (revised edition). Butterworth, London, 560.
Roelofs, J.G.M. & M.J.R. Cals 1989. Effecten van de inlaat van gebiedsvreemd water op de waterkwaliteit en vegetatie-ontwikkeling in laag- en hoogveenplassen. In: J.G.M. Roelofs (red.), Aanvoer van gebiedsvreemd water: omvang en effecten op oecosystemen. Faculteit Natuurwetenschappen, KUN, 72-85.
Rose, C.W. 1969. Agricultural physics. Pergamom, Oxford etc., 320p.
Ruuhijärvi 1983. The Finnish mire types and their regional distribution. In: A.J.P Gore (ed.), Mires: swamp, bog, fen and moor, Regional studies. Ecosystems of the world 4b. Elsevier, Amsterdam etc., 47-67.
Rybníček, K. 1964. Die Braunmoorgesellschaften der Böhmisch-Mährischen Höhe (Tsjechoslowakei) und die Problematik ihrer Klassifikation. Preslia 36, 403-415.
Rybníček, K. 1974. Die Vegetation der Moore im südlichen Teil der Böhmisch-Mährischen Höhe. Vegetace ČSSR A6. Academia, Praha, 243p., apps.
Rybníček, K. 1984. The vegetation and development of Central European mires. In: P.D. Moore (ed.), European Mires. Academic Press, London etc., 177-201.
Schmidt, G. 1969. Vegetationsgeographie auf ökologisch-soziologischer Grundlage. Teubner, Leipzig, 396p.
Schoeller, H. 1962. Les eaux souterraines. Masson, Paris, 642p.
Schurer, K. & J.C. Rigg 1980. Grootheden en eenheden in de landbouw en de biologie. Pudoc, Wageningen, 121p.
Sculthorpe, C.D. 1967. The Biology of Aquatic Vascular Plants. Arnold, London, 610p.
Seddon, B. 1967. The lacustrine environment in relation to macrophytic vegetation. E.J. Cushing & H.E. Wright, Jr. (eds.), Quarternary Palaeoecology. Proceedings of the VII Congress of the Int. Ass. for Quarternary Res., 7. Yale University Press, New Haven and London, 205-215.
Segal, S. 1965. Een vegetatieonderzoek van de hogere waterplanten in Nederland. WM 57. Kon. Ned. Nat.-hist. Ver., Hoogwoud, 80p.
Segal, S. 1966. Ecological studies of peat-bog vegetation in the North-Western part of the province of Overijssel (The Netherlands). Wentia 15, 109-141.
Segal, S. 1966. Oecologie van hogere waterplanten. Vakblad voor Biologen 46, 138-149.
Segal, S. 1968. Schwierigkeiten bei der Systematik von Moorgesellschaften. In: R. Tüxen (ed.), Pflanzensoziologische Systematik. Int. Symp. Stolzenau/Weser 1964. Junk, Den Haag, 220-229.
Segal, S. & M.C. Groenhart 1967. Het Zuideindigerwiede, een uniek verlandingsgebied. Gorteria 3, 165-181.
Senden, W. 1980. Geo-elektrisch onderzoek Stavoren/Steenwijk. Rapport GF-124. DGV-TNO, 27p., bijl.
Sheffield, C. 1985. Selecting band combinations from multispectral data. Photogr.Engineering and Remote Sensing 51(6), 681-687.
Shimwell, D.W. 1971. Description and Classification of Vegetation. Sidgwick & Jackson, London, 322p.
Sikora, L.J. & D.R. Keeney 1983. Further aspects of soil chemistry under anaerobic conditions. In: A.J.P. Gore (ed.), Mires: swamp, bog, fen and moor, General studies. Ecosystems of the world 4a. Elsevier, Amsterdam etc., 247-256.
Sjörs, H. 1983. Mires of Sweden. In: A.J.P. Gore (ed.), Mires: swamp, bog, fen and moor, Regional studies. Ecosystems of the world 4b. Elsevier, Amsterdam etc., 69-94.
Slicher van Bath, B.H. 1957. Een samenleving onder spanning. Van Gorcum, Assen, 768p.

Spiegel, M.R. 1972. Theory and problems of statistics in SI units. Schaum's Outline Series. McGraw-Hill, New York etc., 359p.
Staatsbosbeheer 1974-'75. Vegetatiekaart van De Weerribben (see Heringa & van der Sloot 1973). Unpublished, Zwolle.
Staatsbosbeheer 1988. Beheersplan voor de periode 1988-1998 (De Weerribben). Rapp. Staatsbosbeheer, Utrecht/Zwolle, 273p., bijl.
Stallman, R.W. 1965. Steady one-dimensional fluid flow in a semi-infinite porous medium with sinusoidal surface temperature. Journal of Geophysical Research 70(12), 2821-2827.
Stanek, W. & I.A. Worley 1983. A terminology of virgin peat and peatlands. C.H. Fuchsman & S.A. Spigarelli (eds.), Proc. Int.Symp. on Peat Utilization. Bemidji State University, Bemidji, 75-102.
Stegeman, J.H.J. 1968. Onderzoek van de Bryophyten in verlandingsreeksen in Noord-West Overijssel in afhankelijkheid van milieu en vegetatie. Rapp. Hugo de Vries-Laboratorium/RIVON, Amsterdam, 31p., bijl.
Straathof, N. 1976. Praktijkverslag over hydrologisch onderzoek in de Weerribben. Int.Rapp. Staatsbosbeheer/Rijks-instituut voor Natuurbeheer, Zwolle, 11p., bijl.
Stumm, W. & J.J. Morgan 1970. Aquatic Chemistry. Wiley, New York etc., 583p.
Stuyfzand, P.J. 1983. De berekening van het elektrisch geleidingsvermogen van natuurlijke wateren: een zeer nauwkeurige methode met voorbeelden van toepassing. KIWA rapport SWE-83.001, Nieuwegein, 40p.
Stuyfzand, P.J. 1983. Een zeer nauwkeurige berekening van het elektrisch geleidingsvermogen ter controle en aanvulling van wateranalyses. H_2O 16(16), 358-361, 363.
Succow, M. 1988. Landschaftsökologische Moorkunde. Gustav Fisher, Jena, 340p.
Suzuki, S. 1960. Percolation measurements based on heat flow through soil with special reference to paddy fields. Journal of Geophysical Research 65(9), 2883-2885.
Ter Wee, M.W. 1962. The Saalian glaciation in The Netherlands. Meded. Geol. St., N.S. 15, 57-77.
Ter Wee, M.W. 1966. Toelichting bij de geologische kaart van Nederland, blad Steenwijk Oost. Geologische Stichting, Afd. Geol. Dienst, Haarlem, 106p., maps.
Thomson, A. & H.A.P. Ingram 1981. Notes. In: K.E. Ivanov, Water movement in mirelands (transl. by A. Thomson & H.A.P. Ingram). Academic Press, London etc, 252-257.
Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton.
Tomaszewska, K. 1988. Plant cover of peatland in the Biebrza river valley and its changes determined on the basis of aerial photographs. Proc. VIII Int. Peat Congress (1). International Peat Society, Helsinki, 199-207.
Touber, L. 1973. Hydrologisch Onderzoek in enige verlande petgaten in het C.R.M. Reservaat "De Weerribben", N.W.-Overijssel. Int.Rapp.3. Hugo de Vries-Lab., UvA, Amsterdam, 34p., bijl.
Touw, A. & W.V. Rubers 1989. De Nederlandse Bladmossen. Bibliotheek KNNV 50. KNNV, Utrecht, 532p.
Uil, H. & E. de Heer (1985). Grondwaterkaart van Nederland, Stavoren/Steenwijk. Rep. GWK 34. DGV-TNO, 91p., maps.
Van der Linden, M.J.H.A. 1980. Nitrogen economy of reed vegetation in the Zuidelijk Flevoland Polder. Acta Oecologica/Oecol. Plantarum 1(15), 219-230.
Van der Linden, M.J.H.A. 1986. Phosphorus economy of reed vegetation in the Zuidelijk Flevoland Polder (The Netherlands): seasonal distribution of phosphorus among shoots and rhizomes and availability of soil phosphorus. Acta Oecologica/Oecologia Plantarum 7(21),4, 397-405.
Van der Meijden, R., E.J. Weeda, F.A.C.B. Adema & G.J. de Joncheere 1983. Heukels/Van der Meijden Flora van Nederland. Wolters-Noordhoff, Groningen, 583p.
Van der Perk, J.C. & M.J. Smit 1975. Een hydrologisch onderzoek ten behoeve van het natuurbeheer in de "Wieden". Int.Rapp.17. Hugo de Vries-Lab., UvA, Amsterdam, 56p., bijl.
Van der Toorn, J. 1972. Variability of *Phragmites australis* (Cav.)Trin. ex Steudel in relation to the environment. Van Zee tot Land 48. Staatsuitgeverij, 's-Gravenhage, 122p.
Van Leeuwen, C.G. 1966. A relation theoretical approach to pattern and process in vegetation. Wentia 15, 25-46.
Van Wirdum, G. 1972. Beknopt verslag over de eerste fase van een onderzoek naar de waterhuishouding in het kraggelandschap van De Weerribben en de betekenis daarvan voor de vegetatie. Int.Rapp. Hugo de Vries-Laboratorium, UvA,Amsterdam, 30p.
Van Wirdum, G. 1973. Het verband tussen de successie en enige veranderingen in de eigenschappen van het water in de Weerribben. Samenvatting van een voordracht gehouden op de 81e dag voor het vegetatie-onderzoek van de Koninklijke Nederlandse Botanische Vereniging op 19-12-1972 te Wageningen ("laagveendag"). Jaarboek KNBV 1972, 49-52.
Van Wirdum, G. 1977. Natuurgebieden Noord-West Overijssel. In: N.J.N. Bunnik et al., Onderzoek naar de toepassingsmogelijkheden van multispectrale scanning. Publ.44, Nederlandse Interdepartementale Werkgroep voor het Applicatieonderzoek van Remote Sensing Technieken (NIWARS), Delft, 314-331.
Van Wirdum, G. 1978. Een landschapsecologische basis voor de normering van de waterkwaliteit. Int.Not. Rijksinstituut voor Natuurbeheer, Leersum, 8p.
Van Wirdum, G. 1979. Dynamic aspects of trophic gradients in a mire complex. Proc. and Inf. 25. CHO-TNO, The Hague, 66-82.

Van Wirdum, G. 1980. Eenvoudige beschrijving van de waterkwaliteitsverandering gedurende de hydrologische kringloop. J.C. Hooghart (ed.) Waterkwaliteit in grondwaterstromingsstelsels. CHO-TNO, rapporten en nota's 5, Den Haag, 118-143.
Van Wirdum, G. 1981. De waterkwaliteit in de natuurgebieden in het waterschap Vollenhove. Mscr. Rijksinstituut v. Natuurbeheer, Leersum, 72p.
Van Wirdum, G. 1981. Linking-up the natec subsystem in models for the watermanagement. Water resources management on a regional scale, Proc. and Inf. 27. CHO-TNO, The Hague, 108-128.
Van Wirdum, G. 1982. Design for a land-ecological survey of nature protection. S.P. Tjallingii & A.A. de Veer (eds.) Perspectives in Landscape Ecology, contributions to research, planning and management of our environment. Pudoc, Wageningen, 245-251.
Van Wirdum, G. 1982. The ecohydrological approach to nature protection. Annual Report 1981. Research Institute for Nature Management, Arnhem etc., 60-74.
Van Wirdum, G. 1983. De mosseninventarisatie van De Weerribben. Buxbaumiella 14. Bryologische en Lichenologische Werkgroep van de KNNV, 10-47.
Van Wirdum, G. 1984. Development of techniques for ecohydrological research. Annual Report 1983. Research Institute for Nature Management, Arnhem, Leersum and Texel, 21-25.
Van Wirdum, G. 1985. Verschil moet er blijven (Eng. Summ.: There must be difference). De Levende Natuur 86(3,5), 97-101, 193.
Van Wirdum, G. 1986. Water-related impacts on nature protection sites. Proc. and Inf. 34. CHO-TNO, The Hague, 27-57.
Van Wirdum, G. 1987. The rôle of spatial variety in the application of ecology to nature protection and ecology. Annual Report 1986. Research Institute for Nature Management, Arnhem, Leersum and Texel, 31-33.
Van Wirdum, G. 1989. Ecohydrologische aspecten van waterinlaat in laagvenen. Salient features of terrestrializing fens in The Netherlands. In: J.G.M. Roelofs (red.), Aanvoer van gebiedsvreemd water: omvang en effecten op ecosystemen. Faculteit Natuurwetenschappen, KUN, Nijmegen, 52-71.
Van Wirdum, G., A.J. den Held & M. Schmitz in press. Salient features of terrestrializing fens in The Netherlands In: J.T.A. Verhoeven (ed.) Fens and bogs in The Netherlands. Kluwer.
Van Wirdum, G. & R.H. Kemmers 1990. Hydrologie, bodem en natuurontwikkeling. In: F. Berendse (red.), Natuurontwikkeling en landbouw. Agrobiologische Thema's 1. Cabo, Wageningen, 45-65.
Van Wirdum, G. & D. van Dam 1984. Standplaats en plant; bewerking ecologische indicatiewaardenlijsten. SWNBL-rapport 1. Studiecommissie Waterbeheer Natuur, Bos en Landschap, Utrecht, 116p.
Van Zon-van Wagtendonk, A.M. 1965. Vegetatiekartering van een gedeelte van het natuurreservaat "de Weerribben" te Oldemarkt (NW-Overijssel). Rapport. Hugo de Vries-Laboratorium/RIN, Amsterdam, 40p., bijl.
Van Zon-van Wagtendonk, A.M. 1969. Vegetatiekartering van het natuurreservaat "De Weerribben" in NW-Overijssel. Rapp. Hugo de Vries-Laboratorium/RIN, Amsterdam, 39p., bijl.
Veenenbos, J.S. 1950. De bodemgesteldheid van het gebied tussen Lemmer en Blokzijl in het randgebied van de Noordoostpolder (Engl.Summ.: Soil conditions of the area between Lemmer and Blokzijl in the border area of the Noordoost-Polder). Verslagen van landbouwkundige onderzoekingen 55.12, De bodemkartering van Nederland, V. Staatsuitgeverij, 's-Gravenhage, 162p.
Vegt, J.J. 1978. Verdamping, berging en indringing van boezemwater in het moerasgebied "De Weerribben". Int.Rep., RIN/LH, Leersum, 51p., bijl.
Vereniging voor de Statistiek in Nederland 1870. Algemeene Statistiek van Nederland. Sijthoff, Leiden.
Verhoeven, J.T.A., & H.H.M. Arts 1987. Nutrient dynamics in small mesotrophic fens surrounded by cultivated lands, II, N and P accumulation in plant biomass in relation to the release of inorganic N and P in the peat soil. Oecologia (Berlin) 72, 557-561.
Verhoeven, J.T.A., A.M. Kooijman & G. van Wirdum 1988. Mineralization of N and P along a trophic gradient in a freshwater mire. Biogeochemistry 6, 31-43.
Verschoor, A. 1978. Vegetatiekartering met behulp van luchtfoto's in het CRM-reservaat "De Weerribben" (N.W.-Overijssel). Int. Rapp. 56. Hugo de Vries-lab., UvA, 31p.
Volker, A. 1948. Geo-hydrologische gesteldheid van het oude land langs de Noordoostpolder tussen Lemmer en Blokzijl. Rapport. Anonymus, 22p., bijl.
Vromen, H, L. Klamer & J. de Vries 1974. Voortgezet Hydrologisch onderzoek in enige verlande petgaten in het C.R.M.-reservaat "De Weerribben". Int.Rap., Staatsbosbeheer Zwolle, 20p., bijl.
Waldhauer, F.D. 1982. Feedback. Wiley, New York etc., 651p.
Wassen, M.J., A. Barendregt, M.C. Bootsma & P.P. Schot 1989. Groundwater chemistry and vegetation of gradients from rich fen to poor fen in the Naardermeer (The Netherlands). Vegetatio 79, 117-132.
Weeda et al. 1988. See Weeda et al. 1985-'88, 3.
Weeda, E.J., R. van der Meijden & P.A. Bakker 1990. Rode lijst van de in Nederland verdwenen en bedreigde planten (*Pteridophyta* en *Spermatophyta*) over de periode 1.I.1980-1.I.1990 (Engl. summ.: Red Data List of the extinct, endangered and vulnerable plants in the Netherlands in the period 1960-1990. Gorteria 16(1), 2-26.
Weeda, E.J., R. Westra, Ch. Westra & T. Westra 1985-'88. Nederlandse oecologische flora, 1,2,3. IVN, 910p.

Westhoff, V., P.A. Bakker, C.G. van Leeuwen, & E.E van der Voo 1971. Wilde planten. Flora en vegetatie in onze natuurgebieden 2, Het lage land. Natuurmonumenten, Amsterdam, 304.

Westhoff, V. & A.J. den Held 1969. Plantengemeenschappen in Nederland. Bibliotheek KNNV 16, RIVON Verhandeling 5. Thieme, Zutphen, 324p.

Wheeler, B.D. 1978. The wetland plant communities of the River Ant Valley, Norfolk. Transactions of the Norfolk & Norwich Naturalists' Society 24(4), 153-187.

Wheeler, B.D. 1980. Plant communities of rich-fen systems in England and Wales. I. Introduction. Tall sedge and reed communities. J.Ecol.68, 365-395.

Wheeler, B.D. 1980. Plant communities of rich-fen systems in England and Wales. II. Communities of calcareous mires. J.Ecol.68, 405-420.

Wheeler, B.D. 1984. British Fens: A Review. In: P.D. Moore (ed.), European Mires. Academic Press, London etc., 237-281.

Wheeler, B.D. & K.E. Giller 1982. Species richness of herbaceous fen vegetation in Broadland, Norfolk in relation to the quantity of above-ground plant material. Journal of Ecology 70, 179-200.

Zijlstra, G. 1981. Some remarks on the *Cirsio-Molinietum* and the *Caricion davallianae*. Proc. Kon.Ned.Akad.v.-Wetensch. C84(1), 89-106.

Zuiveringschap West-Overijssel, Technologische Dienst 1981-'88. Kwaliteit oppervlaktewater in het gebied van het zuiveringschap West-Overijssel. (Half)jaarrapporten. Zuiveringschap West-Overijssel, Zwolle.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

SAMENVATTING

Vegetatie en waterhuishouding van trilvenen

In de verlanding van petgaten in het laagveengebied van Nederland neemt het kraggestadium een belangrijke plaats in. In sommige gevallen vindt een snelle ontwikkeling plaats van rietlanden naar door veenmossen of houtige gewassen gedomineerde vegetaties, terwijl in andere gevallen zeer langdurig slaapmossen, waaronder Schorpioenmos, en kleine zeggen het aspect bepalen. Dit laatste vegetatietype en verschillende daarvoor karakteristieke plantesoorten worden veelal als kwelindicatoren beschouwd. Die veronderstelling vormt in dit proefschrift de leidraad voor een nader onderzoek naar de waterhuishoudkundige factoren die bepalend zijn voor de ontwikkeling van deze trilvenen *par excellence*. Het onderzoek voerde van een analyse van het door de vegetatie geïndiceerde milieu, via een hydrologische beschrijving van de omgeving, naar een poging tot kwantitatief begrip hoe het kennelijke milieu van de vegetatie onder invloed van de waterhuishouding wordt bepaald.

Een gedetailleerde analyse van de bronliteratuur (hoofdstuk 2) bracht aan het licht dat het optreden van kwel op de "typelokaties" en het veronderstelde verband met botanische "kwelindicaties" niet overtuigend zijn bewezen. In het thans uitgevoerde onderzoek kon op verschillende "klassieke" lokaties geen kwel, maar juist wegzijging worden aangetoond. Voor één gebied, "De Stobbenribben", is dit in de hoofdstukken 7-10 in detail beschreven.

Uit de internationale ecologische literatuur blijkt dat de "kwelindicatoren" niet eenduidig op kwel wijzen, maar wel op een goede basenverzorging van het veen, in het bijzonder op

kalkrijkdom (hoofdstuk 3). In dit proefschrift wordt een en ander nader besproken op grond van onderzoek in Noordwest-Overijssel, een sleutelgebied voor de "kweltheorie".
In hoofdstuk 4 wordt een korte geografische en historische beschrijving van dit gebied gegeven.

De waterhuishouding van het noordelijk deelgebied "De Weerribben" wordt in detail behandeld in hoofdstuk 5. Hier komt thans geen noemenswaardige uitstroming van grondwater voor. Vóór de drooglegging van de Noordoostpolder in 1941 zou er plaatselijk enige kwel kunnen zijn geweest, maar de uitstroming van grondwater in die periode moet toch ondergeschikt zijn geweest aan de toestroming van oppervlaktewater en ook aanzienlijk geringer dan de huidige wegzijging. Belangrijke nadere aanwijzingen komen voort uit een analyse van de samenstelling van het grondwater sinds 1935. In het centrum van het gebied bevonden zich toen nog restanten zwak brak water in het bovenste gedeelte van het zandpakket onder De Weerribben. Ook thans zijn er nog belangrijke brakwatervoorkomens, maar kalkrijk zoet grondwater is door de inzijging tot grote diepte teruggedrongen. De aanwezigheid van zulk water in het trilveenmilieu moet in de laatste eeuw voornamelijk bepaald zijn geweest door de aanvoer van oppervlaktewater.

Gegevens over de oppervlaktewaterkwaliteit zijn pas vanaf ca. 1960 beschikbaar. In de periode 1960-1987 varieerde de samenstelling van het oppervlaktewater ten gevolge van de kunstmatige beheersing van het boezempeil door inlaat en uitmalen. Vooral in de zeventiger jaren is de invloed van verontreinigd inlaatwater, uiteindelijk grotendeels afkomstig uit de Rijn, sterk toegenomen. De detail-uitvoering van de waterbeheersing was in die periode oorzaak van de aanvoer van zeer grote hoeveelheden inlaatwater, in het bijzonder gedurende de "droge jaren" 1975-'76. Door opeenvolgende inlaat-episodes raakte het water tussen 1973 en 1976 in vrijwel de gehele boezem sterk vermengd met dit inlaatwater. Dit werd pas zeer geleidelijk teruggedrongen door bij het peilbeheer naar minimalisering van inlaat te streven en door het uitblijven van extreme droogte. Bij het onderzoek naar de samenstelling van het water werd gebruik gemaakt van een tijdens dit onderzoek ontwikkelde "fenomenologische" methode die berust op een kwantificering van de gelijkenis van het water met de extreme typen uit de waterkringloop, regenwater, kalkrijk grondwater, en zeewater (appendix D).

In hoofdstuk 6 is het optreden van de zogenaamde kwelindicatoren in de vegetatie van De Weerribben besproken. Ook wanneer de ecologische indicatie van deze kwelindicatoren zelf buiten beschouwing wordt gelaten wijst het optreden van vegetatie met dergelijke soorten op een betere basenverzorging. Één van de meest eenduidige "kwelindicatoren", Schorpioenmos, blijkt zich sinds 1960 in De Weerribben nadrukkelijk te hebben uitgebreid over een deel van het gebied waar zeker geen kwelinvloeden zijn. Er zijn echter duidelijke aanwijzingen dat in dit deelgebied in dezelfde periode de invloed van zwak brak water is teruggedrongen, terwijl voldoende jonge verlandingsstadia aanwezig waren voor de vestiging van Schorpioenmos en enkele andere "kwelindicatoren". Vermoed wordt dat de vroegere aanwezigheid van brak water nog steeds in de basenverzorging van het veen doorwerkt, terwijl het chloride-gehalte is gezakt tot een niveau dat voor zoetwater-planten geschikt is.

De hoofdstukken 7-10 gaan over een *case-study* in De Stobbenribben, een trilveen-complex dat in de bronliteratuur over de "kweltheorie" wordt genoemd als een goed voorbeeld van het optreden van kwel en kwelindicatoren. Door de ligging en opbouw was dit complex bovendien bijzonder geschikt om de invloed van de waterhuishouding na te gaan. Sinds de aanleg van een polder op zeer korte afstand, omstreeks 1955, is er in dit gebied sprake van een sterke wegzijging. Vanuit een sloot aan één zijde stroomt als gevolg hiervan oppervlaktewater toe. Er bevindt zich een zonering van een productieve rietvegetatie bij de aanvoersloot, via een trilveenvegetatie met veel "kwelindicatoren", naar een door veenmossen gedomineerde en door randeffecten beïnvloede vegetatie. De ecologische indicatie van het middengedeelte met "kwelindicatoren" wijkt van de rest af door een nadrukkelijk voedselarm-basenrijke component (hoofdstuk 7).

In hoofdstuk 8 is een methode beschreven om met behulp van het warmtetransport in het veen de eventuele verticale waterbeweging te kwantificeren. Hoewel aan deze methode duidelijke bezwaren kleven door de vermoedelijk sterke laterale waterbeweging, kon toch een consistent beeld worden verkregen door de metingen van de veentemperatuur regelmatig te herhalen en het verloop tot een diepte van 1,8 m per decimeter te beschouwen. Over korte afstand varieert de gevonden waarde voor de wegzijging van 2-10 mm/d met een gemiddelde van ongeveer 5 mm/d.

Door herhaald meten van de soortelijke electrische geleiding in het veen kon worden vastgesteld dat de laterale waterbeweging vanuit de aanvoersloot geconcentreerd is in een preferent kanaal juist onder de kragge (hoofdstuk 9). De "kwelindicatoren" komen voor in een zone waar gedurende de winter het aangevoerde slootwater weer enigszins wordt teruggedrongen.

In hoofdstuk 10 wordt een poging gedaan de wateraanvoer en het effect daarvan op de chemische samenstelling van het veenwater te kwantificeren. Hiervoor is een eenvoudig model opgesteld dat met de waarnemingen in overeenstemming is. Volgens dit model worden de kalkrijk-voedselarme omstandigheden in het middengedeelte van het trilveen in stand gehouden door de aanvoer van basen met het instromende water. De voedselrijkdom van het slootwater wordt in de productieve rietvegetatie tot een "achtergrondsniveau" teruggedrongen. Aan het andere einde van de gradient is de invloed van regenwater overheersend. De doorlatendheid van het preferente stroomkanaal, de structuur van de kragge, de intensiteit van de inzijging, en de aanvoercapaciteit van de sloot zijn aldus bepalend voor de zonering in de vegetatie. Waarschijnlijk vindt in De Stobbenribben thans een toename plaats van de invloed van regenwater. Dit wordt veroorzaakt door het dichtraken van de aanvoersloot en door de voortschrijdende verlanding, waardoor de uitwisseling tussen de kragge en het preferente stroomkanaal daaronder vermindert. Elders in het onderzoeksgebied heeft zich een dergelijke "atmotrofiëring" reeds volledig voltrokken, vooral onder invloed van het dichtraken van sloten.

In hoofdstuk 11 wordt een uitgebreide samenvatting en bredere discussie van de bereikte resultaten gegeven. De basenverzorging van het veen is vermoedelijk bepalend voor de verschillen tussen de belangrijkste typen laagveenvegetatie. De waterhuishouding speelt hierbij een sturende rol. In Noordwest-Overijssel is het kalkrijk-voedselarme type laagveenvegetatie, met de zogenaamde kwelindicatoren, niet gebonden aan het uittreden van grondwater, maar veelal juist aan de combinatie van wegzijging en laterale instroming van oppervlaktewater. Wellicht schept de vroegere aanwezigheid van brak water een bijzonder gunstig uitgangsmilieu. Naarmate de wegzijging geringer is kan een snellere verzuring optreden. De Stobbenribben is als voorbeeldgebied representatief omdat de "kwelvegetatie" hier, ondanks de geconstateerde wegzijging, nog steeds vrijwel optimaal voorkomt. Elders in Noordwest-Overijssel en in het Vechtplassengebied is onder andere de karakteristieke moslaag met Schorpioenmos nog slechts fragmentair ontwikkeld, en treden verschillende plantesoorten van meer voedselrijk milieu op de voorgrond.

Hoewel het onderzoek geheel betrekking heeft op trilvenen, spelen de beschreven mechanismen ongetwijfeld ook elders een belangrijke rol. De "kwelindicatoren", waarvan hier is aangetoond dat zij niet noodzakelijkerwijs op kwel in strikte zin wijzen, en die dat in Noordwest-Overijssel meestal ook niet doen, zijn gebonden aan een combinatie van vrij voedselarme (blijkend uit een geringe biomassaontwikkeling van de vegetatie) en toch basenrijke omstandigheden. Deze komen voor waar in de bovenste 0-30 cm van het veen regenwater-invloeden tenminste periodiek belangrijk zijn, terwijl een definitieve uitspoeling van basen verhinderd wordt door de aanvoer van basenrijk grond- of oppervlaktewater. Dit treedt in ons klimaat van nature op in een zone tussen grote voedsel- en basenarme landschapselementen (hoogvenen, heiden) en rivieren of beken, eventueel zee-invloeden. Wanneer geen afvoer van biomassa plaats vindt (door maaien of begrazen) ontwikkelt de vegetatie in deze zone zich bij ons echter tot broekbos, waarin slechts een beperkt deel van de aangetroffen soorten meer dan uiterst lokaal kan voorkomen.

Reprinted from: Geert van Wirdum, 1990. Vegetation and hydrology of floating rich-fens. Datawyse, Maastricht, 310 p. (ISBN 90-5291-045-6). Known errors corrected.

SUMMARY

Vegetation and hydrology of floating rich-fens

Floating fens, or quagfens, are common in former turbaries in The Netherlands. Some are subject to a fast development from reed-beds into sphagnaceous vegetation or carr; others, with a strongly yielding *kragge* go through a long-continued stage dominated by amblystegiaceous mosses, such as *Scorpidium scorpioides*, and slender sedge species (*Carex lasiocarpa*, *C. diandra*). The occurrence of this type of vegetation and the species involved are usually considered *seepage* indicators in The Netherlands. That hypothesis was taken as the starting point for the present research into the hydrologic factors involved. The main line leads from the environment indicated by plant species, via an empirical analysis of the ambient hydrologic conditions, into some quantitative understanding of the relationship between the two.

A detailed analysis of the source literature (Chapter 2) revealed that the occurrence of *seepage*, and especially of discharging groundwater, had never been convincingly proved, even not for the ‘type locations’, and that the concept of *seepage indicators* must be considered hypothetical. In the present survey an infiltration of mire water towards the underlying body of groundwater was found at several ‘classic’ locations, as is reported in detail with regard to ‘De Stobbenribben’ (see below, Chapters 7-10).

The European literature indicates that the presumed *seepage indicators* are especially indicative of a high base state and calcidity of the local peat. A deeper inquiry was made in

North-West Overijssel, a key area for the *seepage* hypothesis. A geographical and historical description of this area is presented in Chapter 4.

Hydrological details about the northern part, the nature reserve 'De Weerribben' (inclusive of De Stobbenribben), are given in Chapter 5. No groundwater discharge of any importance is presently found in this area. Although this may have been different before the reclamation of the Noordoost-Polder in 1941, any local discharge of groundwater even in that period must have been less important than the inflow of surface water, and also considerably less important than the present infiltration towards the underlying body of groundwater. Important clues come from an analysis of the groundwater composition in the area since 1935. Slightly brackish water remaining from former sea influences was present in the underlying sand bottom in the central part of the area in 1935. Even today slightly brackish water is found at several places and any calcareous fresh groundwater is only present at a depth of 50 m or more. The high base state indicated by the quagfen flora must therefore be due to an inflow of surface water.

Not much is known about the chemical composition of the surface water before 1960. Since then a fluctuation has occurred as a result of artificial discharge and supply for the *boezem* water management. The influence of the polluted inlet water, largely originating from the Rhine system, increased dramatically during the 1970s. The actual supply strategy followed in those years led to an unnecessarily large influx of polluted water, especially during the droughts of 1975-'76. Between 1973 and 1976 virtually the whole body of *boezem* water became admixed with this water. Through a more prudent water management, and favoured by the absence of extreme droughts, a gradual improvement was realized in the following years. The water composition was investigated with a variety of methods, inclusive of a quantification of the similarity of water composition to the extreme types in the hydrologic cycle: rain water, calcareous groundwater, and sea water (Appendix D). It appears that the surface water before ca 1960 at least temporarily was slightly brackish. Large reclamations of polders and other influences on the water management brought a type of freshwater into the area which was very similar to calcareous groundwater in the 1960s and early 70s. The 1970s were dominated by the effects of the increased inlet of then polluted Rhine water.

The distribution of *seepage indicators* in the vegetation of De Weerribben is concerned in Chapter 6. Even when the *seepage* indicators themselves are not counted, stands of vegetation comprising such species floristically indicate a higher base state than other stands. *Scorpidium scorpioides*, an undebated *seepage indicator*, appears to have recently invaded a part of the area where certainly no groundwater discharges. This part of the area has long been slightly brackish and so provided with a high base state, whereas the desalting apparently has now progressed far enough to render the area suitable for true freshwater species. This apparently coincided with a young stage of terrestrialization, favourable for the settlement of quagfen species in the 1960s.

In Chapters 7-10 a case study of De Stobbenribben is concerned. De Stobbenribben is one of the classic *seepage* sites, and its topography is especially suitable for eco-hydrologic investigations. Substantial quantities of mire water appear to leak away from De Stobbenribben into the underlying strata, especially since a nearby polder was reclaimed ca 1955. As a result of this leakage an inflow of surface water is generated from a ditch bordering the quagfen parcels of De Stobbenribben at one narrow end, the 'open end'. This has led to a zonation from eutrophic reed swamp vegetation near the ditch, via a brownmoss-sedge zone characterized by an abundance of *seepage indicators*, to sphagnaceous vegetation with dwarfshrubs, and a zone with edge effects at the ‘dead end’ of the parcels where the inflow of ditch water is small or absent. The species composition of the middle zone with *seepage indicators* points towards a notably meso-oligotrophic environment with a high base state.

Chapter 8 deals with a method to trace the vertical water flow in the quagfen body by means of observations relating to heat transportation. Although the strong lateral inflow hampers an exact quantification, consistent results were achieved by frequent measurements of peat temperature profiles and by calculations pertaining to layers of 10 cm thickness. The apparent downward seepage so determined roughly varies between 2 and 10 mm/d with an average value of ca 5 mm/d.

Similarly detailed measurements of the electrical conductivity in the quagfen body showed that the lateral inflow is concentrated in a preferential flow channel just below the floating *kragge* (Chapter 9). The *seepage indicators* are especially abundant in the middle zone of the quagfen parcels were the ditch water flowing in in summer is ‘pushed back’ somewhat by rain water in winter.

Chapter 10 presents an attempt to quantify the inflow of ditch water and its consequencies in regard of the chemical composition of the mire water. This is done with a relatively simple computational model, according to which the inflow of ditch water is essential to maintain a high base state in the middle part of the quagfen parcels. The nutrient load of the ditch water is strongly decreased in the reed swamp zone at the open end near the ditch. The dead ends of the parcels are subject to a dominant influence of rain water. The hydraulic transmissivity of the preferential flow channel, the structure of the *kragge*, the intensity of the downward seepage, and the supply capacity of the ditch thus determine the zonation of the vegetation. It is indicated that the influence of rain water in De Stobbenribben is presently increasing as a result of clogging of the ditch and ongoing peat accrual and terrestrialization in the quagfen, decreasing the water exchange between the *kragge* and the underlying flow channel. A positive feedback comes from the increased growth of *Sphagnum* species. Elsewhere in the investigated area such an ‘atmotrophication’ has already lead to entirely atmotrophic vegetational stages, especially through the terrestrialization of ditches.

Chapter 11 contains a comprehensive summary and broader discussion of the results obtained. The base state of the peat, as governed by hydrological processes is held responsible for the main differences found in the vegetation of Dutch quagmires. In North-West Overijssel the occurrence of meso-oligotrophic, alkaliphilic fen vegetation with many *seepage indicators* is mostly not due to discharging groundwater, but often to a combination of downward seepage with a lateral inflow of surface water. The former presence of slightly brackish water in the area may have favoured a high base state already in early successional stages. As the seepage decreases, acidification is accellerated. De Stobbenribben is a representative case since the *seepage* vegetation is still almost optimally represented here in spite of the downward seepage which has been occurring here for more than 35 years already. It is one of the ‘best’ sites for *Scorpidium scorpioides* in The Netherlands at present, since the species has disappeared from most other quagfen areas, such as ‘De Vechtplassen’ in the province of Utrecht and several locations in North-West Overijssel.

Although this report pertains to quagfens, the mechanisms shown must be important in other types of fen mire as well. The *seepage indicators* apparently don't necessarily indicate a groundwater discharge, as they indeed mostly don't in North-West Overijssel, but rather a combination of relatively nutrient-poor (indicated by a small standing crop), yet base-rich conditions. Such conditions prevail where rain-water influences are at least periodically important in the upper 30 cm of the peat, while an ongoing leaching of bases to a greater depth is prevented by a supply of base-rich ground- or surface water. In our climate this specific environment may be stable in-between large oligotrophic land units (bogs, heathlands), and (small) rivers, or even land units with sea-influences. When no biomass is harvested (mowing, grazing) the vegetation in this intermediate zone mostly develops into carr, where the majority of the populations of presently abundant red-list species can only locally persist.

QUAGGERY

Oh quaggy swampy fen,
What variety of plants I saw
Dwelling upon your mossy scraw!:
The radar of my imagination,
Relating hydrology to vegetation.

Oh quaggy swampy fen,
With inner warmth you puzzled my brain,
Taught more than physics could explain.
Sure the patches on your scraw
Sprout from the juice below.

Oh quaggy swampy fen,
Fousolving and Quagsolving I lost ground
In a miry maze of numbers with Maucha's bats around,
Till Maion's similarity
Revealed some regularity.

Oh quaggy swampy fen,
I tasted the Mix in your interior,
And thought the cooks were not bad,
Though the materials they get
At times were inferior.

Oh quaggy swampy fen,
From the signs on your skin comes my advice:
Honestly, dear, you need a protective device
To prevent you to end
As a boggy fat vamp.

DATAWYSE, MAASTRICHT
ISBN 90 5291 045 6

Vegetation and hydrology of floating rich-fens   Geert van Wirdum