Proceedings of the symposium on peat lands below sea level

Dairy farm in the peat district in the western Netherlands
Photo C. B. H. Schneider

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Peat lands lying below sea level in the western part of the Netherlands, their geology, reclamation, soils, management and land use

Edited by
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FOREWORD

The International Symposium on Peat Lands below Sea Level was held in Wageningen, The Netherlands, from August 24th to 28th 1981.
The initiative for the Symposium was taken in Norway during the 1978 Symposium of Commission III of the International Peat Society and the IPS Council accepted the Symposium during its meeting in Duluth (USA) on the occasion of the 6th International Peat Congress in 1980.
Its subject was 'Peat lands lying below sea level in the western part of The Netherlands, their geology, reclamation, soils, management and land use'. It was sponsored by Commission III of the IPS, and because there is no National Committee of the IPS in The Netherlands, also by the Netherlands Soil Science Society.
The idea was worked out by an organizing committee of the following members:
Chairman: H. de Bakker, Soil Survey Institute, Wageningen.
Scientific Secretary: M.W. van den Berg, State Geological Survey, Lochem.
Administrative Secretary and Treasurer: J. Drijver, International Agricultural Centre, Wageningen.
Members:
W.H. van der Molen, Agricultural University, Wageningen
J.C. Pape, Netherlands Soil Science Society, Wageningen
L.J. Pons, Agricultural University, Wageningen
G.P. Wind, Institute for Land and Water Management Research, Wageningen.
The Organizing Committee obtained the valuable support from various Dutch organizations: the Soil Survey Institute, the Institute for Land

and Water Management Research, the Agricultural University, the State Geological Survey, the International Agricultural Centre (executive agency), the International Institute for Land Reclamation and Improvement (publisher of the proceedings), Vereniging van Nederlandse Verveners en Turfstrooiselfabrikanten, Grontmij N.V., N.V. Heidemaatschappij Beheer, 'Oranjewoud' B.V. Consulting Engineers, Eykelkamp Equipment for Soil Research B.V. (financial support from these five last-mentioned institutions). Last but not least we thank the Dutch colleagues who presented these papers and the colleagues from abroad, who reviewed the papers during the meeting.

The Programme of the Symposium included a visit to the International Soil Museum in Wageningen and two days excursion in the western part of The Netherlands. A trial farm with different drainage levels was visited, in newly built suburban quarters difficulties with constructions in peat areas was demonstrated, soils and geological conditions, different water levels and management of polder water were shown, and a Research Station for Horticulture were visited.

Like other Symposia of Commission III in the past in Finland (1974), GDR (1974), Israel (1975) and Norway (1978) this kind of meetings gives a good opportunity for exchange of experiences and ideas for new work. The proceedings of these earlier meetings are available by IPS Secretariat Unioninkatu 40 B, SF 00170 Helsinki 17, Finland.

On behalve of IPS, especially Commission III, I hope that these new proceedings of this Symposium in The Netherlands 1981 may contribute to the development of peat areas in other places of the world and that researchers elsewhere may benefit from the age-long experience of the Dutch in 'making their landscape'.

H. Kuntze

Chairman, Commission III/IPS

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SESSION II ENGINEERING

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PREFACE

The proceedings of this symposium contain 24 papers: 1-18, invited papers; 19 and 20, added papers; and 21-24, selected items from the excursions. Nine from the invited papers were given by Dutchmen and deal with the topic 'Peat lands lying below sea level in the western part of the Netherlands'. This region is roughly indicated by the encircled area on Figure 1 in Chapter 3. These nine papers discuss the geology (1), the reclamation (3), the soils (5), the water management (7), the effect of the drainage (9), the urban land use (11), the grassland (13), the management of dairy farms (15), and the horticulture (17) of peat soils in that area. Nine colleagues from abroad had a preview of these papers, and reviewed them during the symposium against the background of their own research. The Dutch papers and their reviews were presented in three sessions: Geography (1-6), Engineering (7-12), and Land Use (13-18). Unhappily three of the invited reviewers were not able to attend the symposium, two reviews were read and one was received after the symposium, all three are included in the proceedings.
There were two additional papers given by other participants concerning horticulture and drainage (19 and 20).
The excursion guide contained valuable and original information, the editors thought it worthwhile to include some of these items in the proceedings (21-24).
Some reviews have notes from the editors or from the authors of the reviewed papers; some of the other Chapters have notes from their authors.
Finally we thank authors as well reviewers for their willingness to present their papers, and for their tolerancy to our editorial remarks both about text and figures.

H. de Bakker

M.W. van den Berg

GEOLOGY OF THE HOLOCENE IN THE WESTERN PART OF THE NETHERLANDS

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1.1 Abstract

After the last glaciation, rapid melting of the ice sheets resulted in a fast rise in sea-level during the Holocene. The sea invaded a gently sloping plain dipping to the west. As a result of the rapidly rising sea-level a thick sequence of clastic sediments and some peat was formed behind small coastal barriers. This peat was mainly formed in the landward part of the area enclosed by the coastal barriers. After 5000 BP, the rate of the relative rise in sea-level was much less. The coastal barriers became better developed, and behind them peat formed over the marine deposists. The formation of peat was locally interrupted by incursions of sea-water through the coastal barriers, and dunes developed on top of these barriers. After 2000 BP, part of the coastal-barrier system was broken up by the sea. Some of the peat was eroded and marine deposits were formed in this area. Large dunes were formed on the remains of the coastal barriers.

1.2 Introduction

Holocene marine and perimarine deposits occupy about 40 per cent of the present inhabitable area of the Netherlands (see Figure 1). More than half the population, which totals 14 million, live in this area. These figures indicate the importance of the study of the Holocene deposits for the Netherlands. They have been intensively studied and mapped for geological, geotechnical, pedological and other purposes.

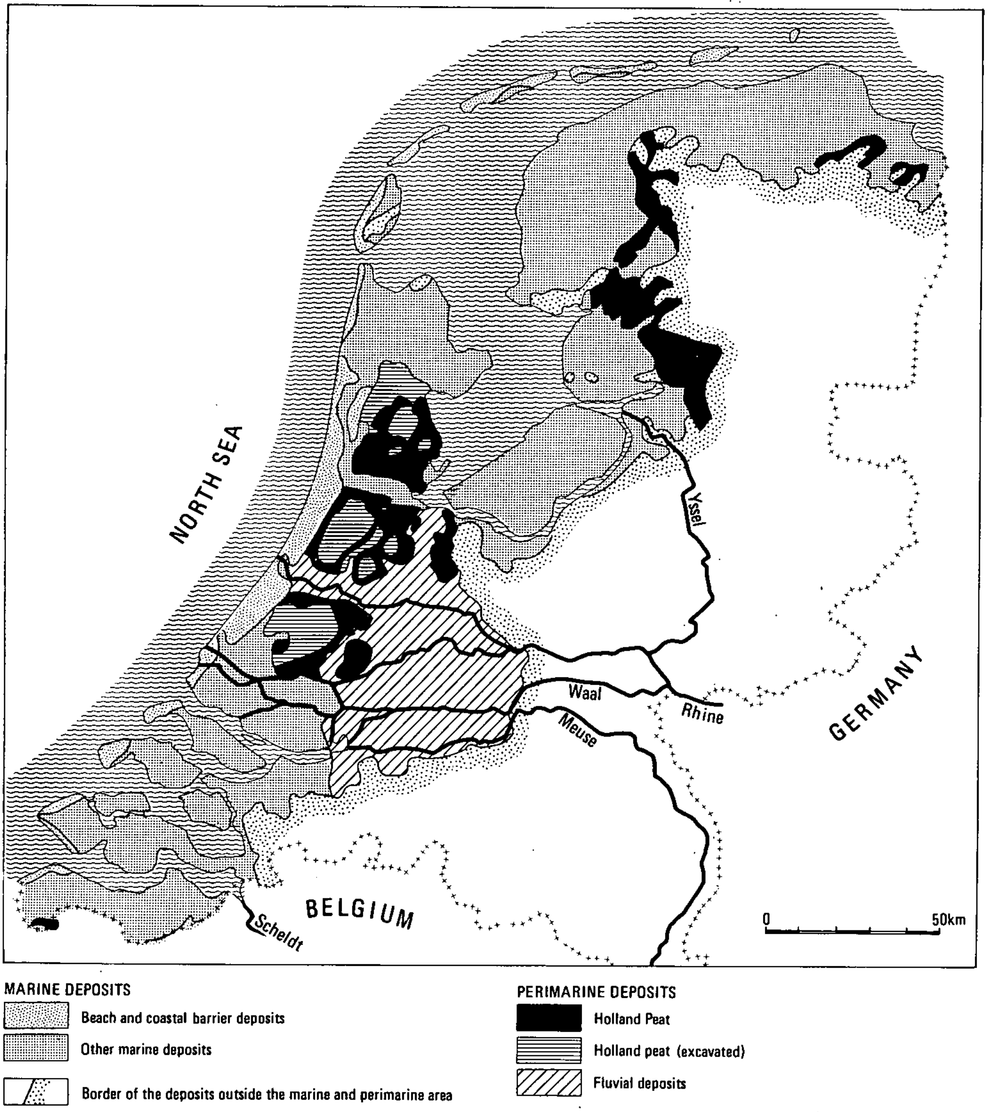


Figure 1 Generalized geological map of the Netherlands (after: Geologische overzichtskaart van Nederland 1 : 600 000; Rijks Geologische Dienst, Haarlem, 1975).

1.2.1 The Pleistocene subsoil

At the end of the Pleistocene, in the Weichselian glacial, the western part of the Netherlands was a gently westward sloping plain. A great deal of this plain was made up of aeolian sands with little relief, the so-called cover sands. These fine to very fine sands were deposited during the last part of the Weichselian. Two shallow valleys occurred in the plain (Figure 2), the northern one marking a former course of the Rhine, the southern one marking the course of the Meuse and the Rhine.

Figure 2 Top of the Pleistocene subsoil in metres below Dutch Ordnance Level (after: Overzichtskaart toegepaste geologie 1 : 600 000; Rijks Geologische Dienst, Haarlem, 1975)

during the Late Weichselian. Coarse sand with gravel, often covered by a thin clay layer, occurs in these valleys. In and along the southern valley, high river dunes - known as *donken* - were formed during the Late

Weichselian. They consist of medium sand (Verbraeck, 1974). They were often blown to such a height that they were not covered by Holocene sediments.

In the middle and northern part of the Netherlands, older landforms occur. They are remnants of an earlier glacial period when inland ice reached the Netherlands. These landforms consist of sand, gravel and glacial till, pushed up by this inland ice.

1.2.2 The sea-level during the Holocene

Before the Holocene, in the Weichselian glacial, a great deal of water was taken from the oceans to form large continental ice sheets. It is estimated (Jelgersma, 1979) that in about 18 000 BP (BP means years before present = 1950 AD) the sea-level was 130 metres lower than it is at present. At the end of the Weichselian, the ice sheets began to melt causing a worldwide rise in sea-level. At the beginning of the Holocene, 10 000 BP, the sea had risen to about 70 metres below the present level. At that time much of the North Sea was still dry land.

In the Early Holocene, the sea-level was still rising very rapidly, about two metres every hundred years, resulting in a fast transgression of the coastline. In about 8000 BP, the coastline reached Dutch territory. In about 6000 BP, most of the ice sheets had melted and the rise in sea-level began to slow down.

Figure 3 shows the curve of the relative rise of the sea-level in the Netherlands after Jelgersma (1979). The relative sea-level changes in the Netherlands are the combined effects of the worldwide rise and tectonic movements. The tectonic movements, caused by the subsiding of the North Sea Basin, of which the Dutch coastal area is a part, are in the order of one or two centimetres per hundred years in the western part of the Netherlands. The worldwide rise in sea-level, together with the tectonic movements, work in one direction: the drowning of the Dutch coastal area.

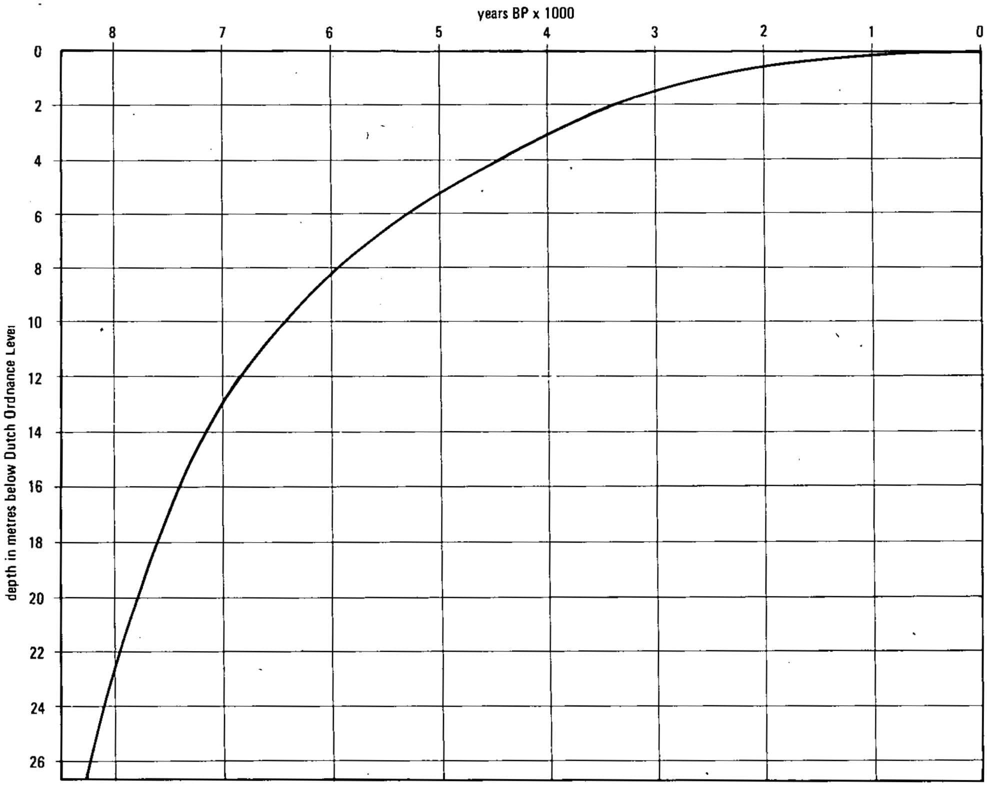


Figure 3 Curve showing the relative rise in sea-level during the Holocene (after Jelgersma, 1979 and Van de Plassche, 1980)

1.3 The stratigraphy of the Holocene

1.3.1 Chronostratigraphy

The Holocene is the warm period after the last glacial period of the Pleistocene, the Weichselian. The Holocene started with a definite improvement of the climate in about 10 000 BP. The chronostratigraphic subdivision of the Holocene is based on differences in the vegetation. The subdivision is partly determined by the climate, especially the influence of the climate on the vegetation. During the Early Holocene however a natural vegetation succession, not the climate, is the main cause of the differences in the vegetation. The boundaries are defined on the evidence of pollen analysis, and dated with the radiocarbon method (see Table 1).

Table 1 Chronostratigraphic subdivision of the Holocene

Subatlantic	
-------------	2900 BP
Subboreal	
-------------	5000 BP
Atlantic	
-------------	8000 BP
Boreal	
-------------	9000 BP
Praeboreal	
-----------	10 000 BP

1.3.2 Lithostratigraphy

Although the curve of the relative rise in sea-level shows a continuous upward trend during the Holocene (Figure 3), the influence of the sea was not always the same in the coastal area. There is a more or less cyclic development in the sedimentary record, showing that the sea had a strong influence during certain periods and less influence during others. In the periods strongly influenced by the sea, mainly clastic sedimentswere formed and the periods in which they were formed are called transgression phases. In those periods less influenced by the sea, the deposition of clastic material decreased and the formation of peat became important. The periods when mainly peat was formed are called regression phases.

The cause of the cyclic development is not known. Either the rise in sea-level was not as continuous as the curve shown in Figure 3 suggests, or local developments such as the formation of coastal barriers had a strong influence. A combination of these factors seems the most likely explanation.

A sedimentary coast, such as the Dutch one, acts as a buffer to changes in sea-level. This means that a continuous rise in sea-level, does not cause a continuous shift of the coastline. The coastline only shifts if the capacity of the buffer is exceeded. These shifts may then be more sudden and catastrophic than the sea-level curve would lead one to expect.

In the coastal area, four main lithostratigraphic units are distinguished: a lower peat layer (Basal Peat), a lower clastic unit (Calais Deposits), an intermediate peat layer (Holland Peat) and an upper clastic unit (Dunkerque Deposits). In the Calais and Dunkerque Deposits eight main transgressive sedimentary cycles are distinghuished by the Geological Survey; see Table 2 and Figure 4. These cycles are separated by peat layers, vegetation or inhabitation horizons or by zones of decalcification.

Table 2. Lithostratigraphic subdivision of the Calais and Dunkerque Deposits

Lithostratigraphic unit	Dating of the transgressive phase
Calais I Deposits	between 8000 and 6250 BP
Calais II Deposits	between 6250 and 5250 BP
Calais III Deposits	between 5250 and 4650 BP
Calais IV Deposits	between 4650 and 3750 BP
Dunkerque 0	between 3450 and 2950 BP
Dunkerque I Deposits	between 2450 and 2150 BP
Dunkerque II Deposits	between 1700 and 1350 BP
Dunkerque III Deposits	after 1150 BP

The scheme is further subdivided for regional mapping purposes. The complete subdivision indicates a cycle length of about 500 years (Roeleveld, 1974; Jelgersma et al., 1979).

In mapping practice, the deposits are more easily recognized by their dating than by their lithological properties. The names of the deposits are therefore also used for the phases in which they were formed. Thus, the Calais I Deposits have been formed in the Calais I transgressive phase. The regressive phases do not have names.

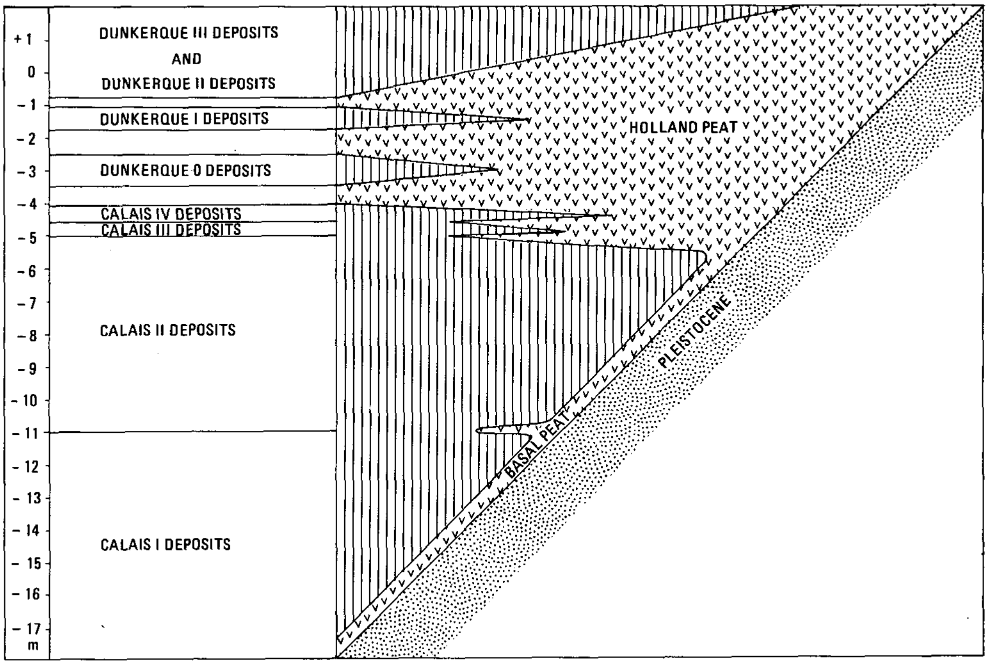


Figure 4 Scheme of the lithologic succession in the marine and perimarine area (after Pons et al., 1963)

1.4 The coastal environment

The coastal environment is subdivided into a marine area and a perimarine area. In the marine area, the deposits are formed by the sea. The area where the sedimentation is influenced by the sea (either by the sea-level movements or by the tides) but where the sea-water could not penetrate, is called the perimarine area (Hageman, 1969).

1.4.1 The marine area

The marine area can be subdivided into environments according to their position in relation to the tidal influence. The subtidal environment lies below the Mean Low Water (MLW) level. The intertidal environment is situated between MLW and Mean High Water (MHW) level, the supratidal environment is situated above MHW and is only flooded during spring and storm tides. A further subdivision can be made, based on the available energy. The amount of energy depends on the exposure of the area to the waves and on the tidal-gully pattern. High-energy environments are found where the coast is open; low-energy environments in the more sheltered places behind coastal barriers or in embayments. Table 3 gives the complete subdivision.

Table 3 The subdivision of the marine area

Environment	Energy	
	high	low
Supratidal	coastal barrier	salt marsh
Intertidal	beach	tidal flats
Subtidal	gullies	lagoon

1.4.1.1 The high-energy environment

The high-energy coastal environment is characterized by frequent erosion and redeposition of sediments by tidal currents and wave action. The fine grains of the sediments are winnowed out and the deposits, therefore, consist of sand. The grain size of the sand is dependent on the material available, which is usually only fine sand. Deposits formed in the high-energy environment are gully and beach deposits. If the amount of sand brought to the beach by current and wave action is large, the landward part of the beach can be built up to above MHW by storm waves, and a coastal barrier is formed. Dunes often develop on the coastal barrier which add to its height.
Coastal barriers are very important in the development of the Dutch coastal area. They restrict the high-energy environments to the seaward parts of the coastal barriers and to the inlets through the barriers. It depends on the development of the coastal barriers whether a low- or a very low-energy environment will form behind them.

1.4.1.2 The low-energy environment

Depending on the amount of sediment available in the area behind the coastal barriers, either a tidal lagoon or a tidal-flat area will develop.
If the sedimentation behind the coastal barriers cannot keep pace with the rising sea-level, a coastal lagoon is formed that is always filled with water. A high-energy environment, caused by tidal activity through the inlet, exists near the tidal inlets. It is here that sand is deposited. Away from the inlets, a low or very low-energy environment exists. Here, clay with a high amount of organic matter is usually deposited.
If a large amount of sediment is brought in by the sea through the tidal inlets or by rivers, sedimentation can keep pace with the rising sea-level. The coastal barriers then enclose an area which is filled at high tide and partly emptied at low tide. Part of this area may be situated between MLW and MHW and is then called a tidal flat. The high-energy environment penetrates into the tidal-flat area through large tidal gullies that branch into channels away from the inlets. The channel pattern changes frequently, causing strong reworking of the sediments. Thus, the sediments in the tidal-flat area usually consist of sand.
In the tidal-flat area, fine sediments (silt and clay) are deposited at each turn of the tide during the short period when there is no water movement. Usually, this material is swept away by the next tide except from places where the water velocity is generally low: near the margins of the tidal flat or on the watersheds between the gullies. Here, the level of the tidal flat gradually rises. As soon as the surface approaches MHW, plants can colonize the area and a salt-marsh is formed. In the vegetation, more fine-grained sediment is trapped and the salt-marsh grows upwards. The lower part of the salt-marsh is covered by water at almost every high tide and sedimentation here is rapid. The highest marshes are covered only during high spring and storm tides, and sedimentation is slow.
Water movement in the salt-marshes occurs through numerous creeks, which are well-defined and bordered by natural levees. These levees consist of somewhat coarser sediment than the pans they enclose. The creeks are often meandering and form a dendritic pattern.

1.4.2 The perimarine area

The area where sedimentation or peat formation takes place under the influence of either the rising sea-level or tidal movements of the sea, but which is not covered by salt water, is called the perimarine area. It can be subdivided into an area where sedimentation is mainly caused by rivers, and the peat formation is strongly influenced by the rivers, and an area where the influence of the rivers is small or absent and only peat is formed.

1.4.2.1 The fluvial area

If the coastal barriers along the coast are only small, or non-existent, the perimarine area is restricted to the lower courses of the rivers, where the influence of the tidal movement is perceptible. If, however, a rather closed belt of coastal barriers is combined with a rapidly rising sea-level, the perimarine area can be very large. The outward flow of the rivers is impeded and the lower courses of the rivers are strongly compressed. As a result, there is rapid sedimentation of the rivers in their lower courses. Large areas are regulary flooded by water from the rivers. Thus, an area occurs with river gullies bordered by clay strips and with extensive peat formation in the backswamps between the gullies. With a rising sea-level, this whole landscape increases in height very rapidly.

The low velocities of the rivers in the perimarine area cause regular silting up of the gullies, especially during periods of strong sea influence when the outward flow is more impeded. Thus, the rivers often change their courses, and a very complex vertical sequence of sandy gully-fills is formed, with sandy clay and clay strips alongside a peat matrix. Sedimentation and peat accumulation have been concordant with the rise in sea-level and the gully systems, therefore, often lie at different heights. The courses of the channels changed during intervals related to transgressions of the sea.

With a low rate of sea-level rise, conditions in the fluvial part of the perimarine area are somewhat stabilized. A normal sedimentation pattern with rather stable gullies, natural levees and backswamps is formed. The

areas outside the gullies are flooded less frequently. While, at first only Phragmites peat was formed in the backswamps, trees could now grow and wood peat developed.
If the rivers debouch into a lagoon, part of it is filled with brackish or fresh water. This part then belongs to the perimarine area. Fluvial clay is deposited in the lagoon and if the lagoon is not too deep Phragmites peat can be formed.

1.4.2.2 The peat area

The first peat in the present coastal area was formed in isolated shallow depressions in the Pleistocene landscape. It is related to the high groundwater table in the gently sloping area.
The rise in sea-level caused a rise in the groundwater table in a belt along the coast. Here, conditions became favourable for peat formation. As with the rising sea-level, the coastline moved inland and the peat belt also moved inland. On the seaward side of the belt, the peat was covered by lagoonal and marine deposits. On the landward side, it formed on more highly situated areas. This process resulted in the formation of the so-called Basal Peat that occurs nearly everywhere between the Pleistocene subsoil and the marine deposits. The Basal Peat is obviously a lithostratigraphic unit with a strong diachronous character. The start of Basal Peat formation is dependent on the height of the Pleistocene subsoil. (It is this relation that makes the construction of a relative sea-level curve possible, see Figure 2). As the Basal Peat formation was influenced by the groundwater, it is eutrophic peat with remains of Phragmites, Carex and trees.
In the area not subsequently covered by marine deposits, peat formation started in the same way. Here, however, it could continue for a much longer time and thick peat deposits could be formed. This thick development of the peat was only possible after the rate in the relative sea-level rise had diminished so far that peat formation could keep pace with it.
During periods when the sea was less active (regression phases), the perimarine peat-area could extend over the tidal marshes and even over the tidal flats. During transgression phases this peat was either eroded

or drowned by salt-water.
Various types of peat occur in the peat area. As a rule, the peat growth started under eutrophic conditions and Pragmites-Carex or wood peat was formed. The nutrient supply came from the groundwater or from the rivers. Close to the rivers these conditions never changed and a thick wood peat formed. In places where the inundation water from the rivers could not penetrate, the peat, because it grew upwards, depended solely on precipitation for its nutrient supply. Here, Sphagnum peat formed over the eutrophic peat. The Spagnum peat bogs grew upwards more rapidly than the wood peat alongside the rivers and formed raised bogs. Because of their height, these bogs could not be inundated by the rivers and conditions remained oligotrophic. Even if during transgression phases the sea penetrated through the river channels into the peat area, only the borders of the raised bogs would be affected and the centres would remain oligotrophic.
Close to the sea, in the lagoons, on the tidal marshes and on the tidal flats Phragmites peat nearly always formed. Only behind an almost closed system of coastal barriers could peat grow up so high for oligotrophic conditions to be reached. In the Dutch coastal area, this occurred after about 5000 BP when the so-called main peat layer of the Holland Peat was formed. This main peat layer lies between the Calais Deposits and the Dunkerque Deposits.

1.5 The palaeogeography of the coastal area

In about 8000 BP, the coastline reached Dutch territory. The rise in sea-level was still very fast (more than 60 cm per hundred years), so that the coastline moved rapidly inland.
The palaeogeography of the Netherlands in about 7000 BP, is depicted in Figure 5. The sea-level was about 13 metres lower than the present one - and Figure 5 shows the situation during the Calais I transgression phase. In the river valleys the sea reached relatively far inland. The perimarine peat-area was well developed. The presence of coastal barriers is assumed from the character of the Calais I Deposits, which include lagoonal deposits.
The sedimentation pattern did not change essentially during the next two thousand years, but the rising sea-level made the whole system shift

further inland.

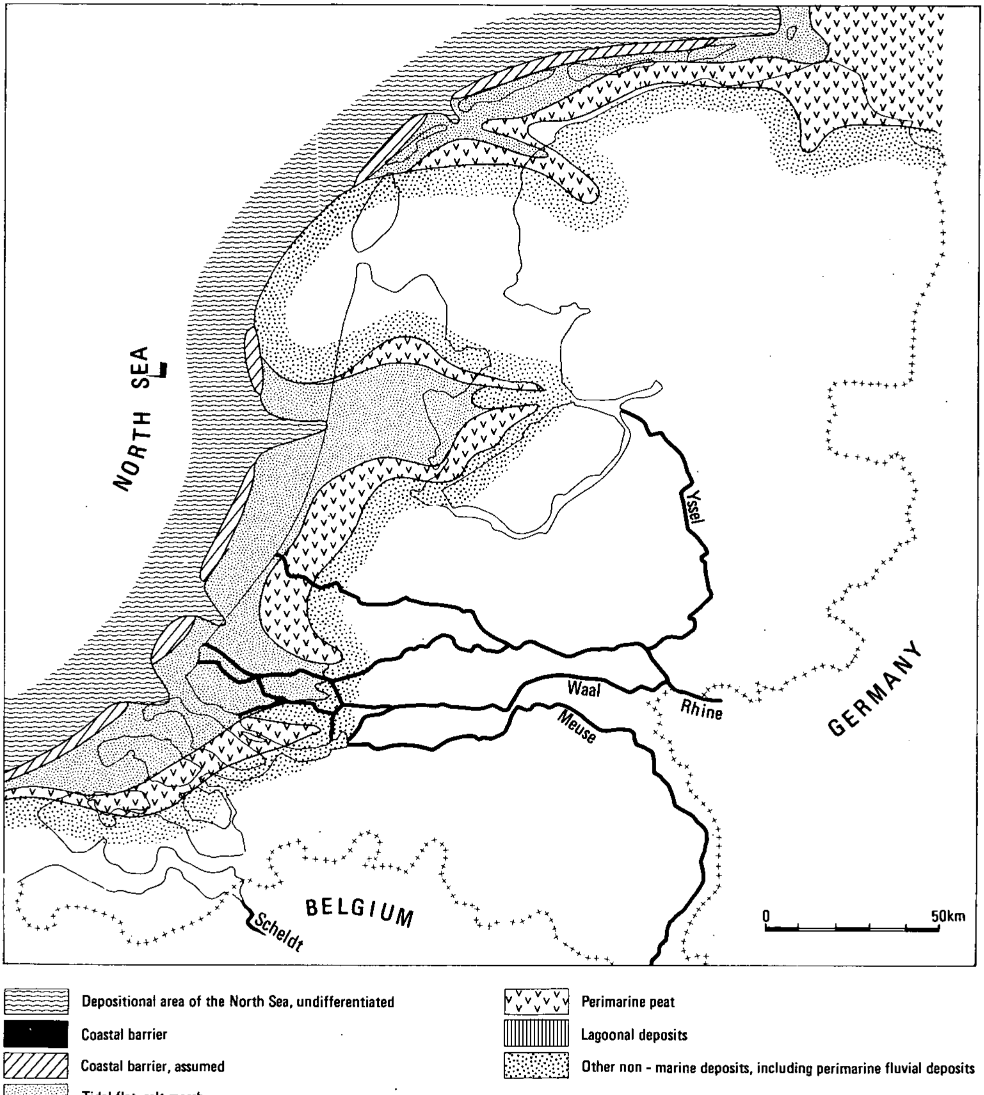
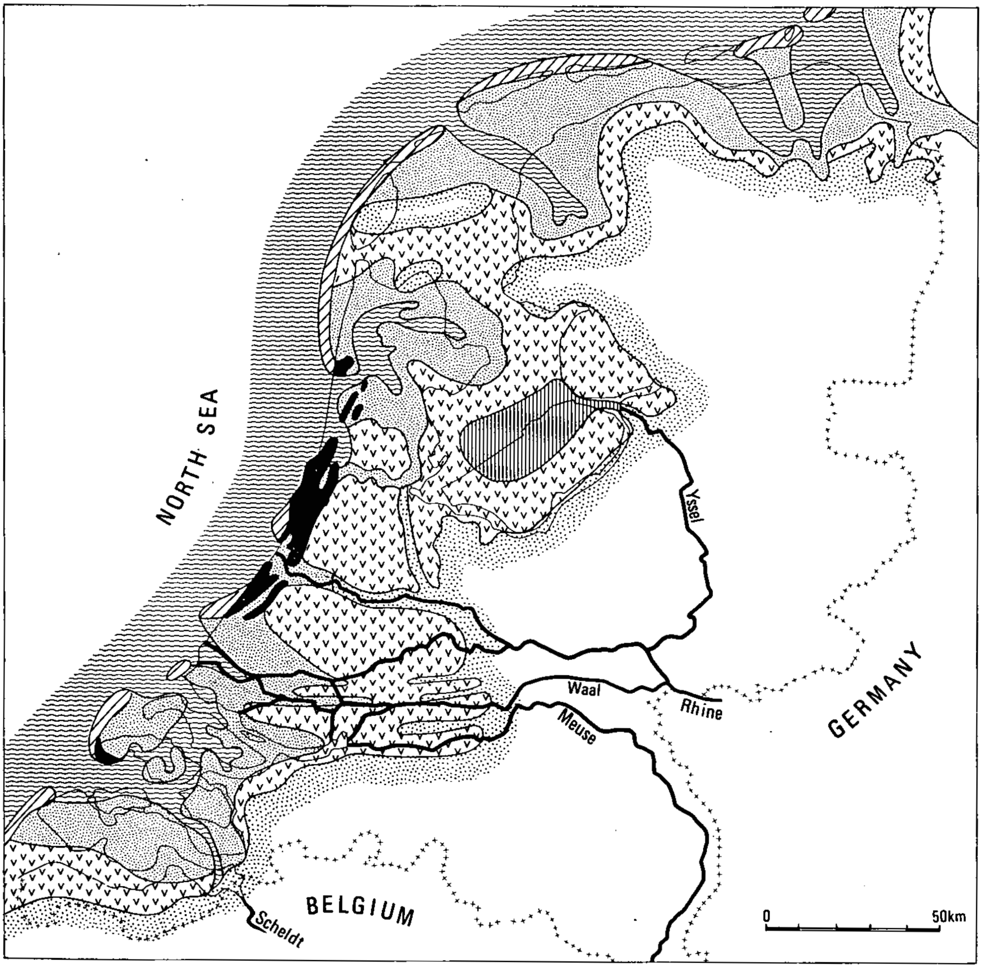


Figure 5 Palaeogeographical map of the Netherlands in about 7000 BP
(slightly modified after Zwagwijn, 1974).

In about 5000 BP, during the Calais III transgression phase, conditions in the coastal area became more stabilized. The coastline was further inland than the present one. Sedimentation kept pace with the rise in sea-level that had decreased to an average of 27 cm per hundred years.

The coastal barriers formed during the Calais III transgression phase were not immediately drowned and eroded. They even extended seawards, thus shifting the coastline towards the sea.
In the following 1000 years, the coastal barrier system extended further to the west. Due to breaks in the coastal barriers, the influence of the sea increased substantially (Calais III and Calais IV transgression phases). In the central part of the coastal area no breaks occurred and the Calais IV Deposits are either thin or absent. The so-called Older Dunes were formed on the coastal barriers.

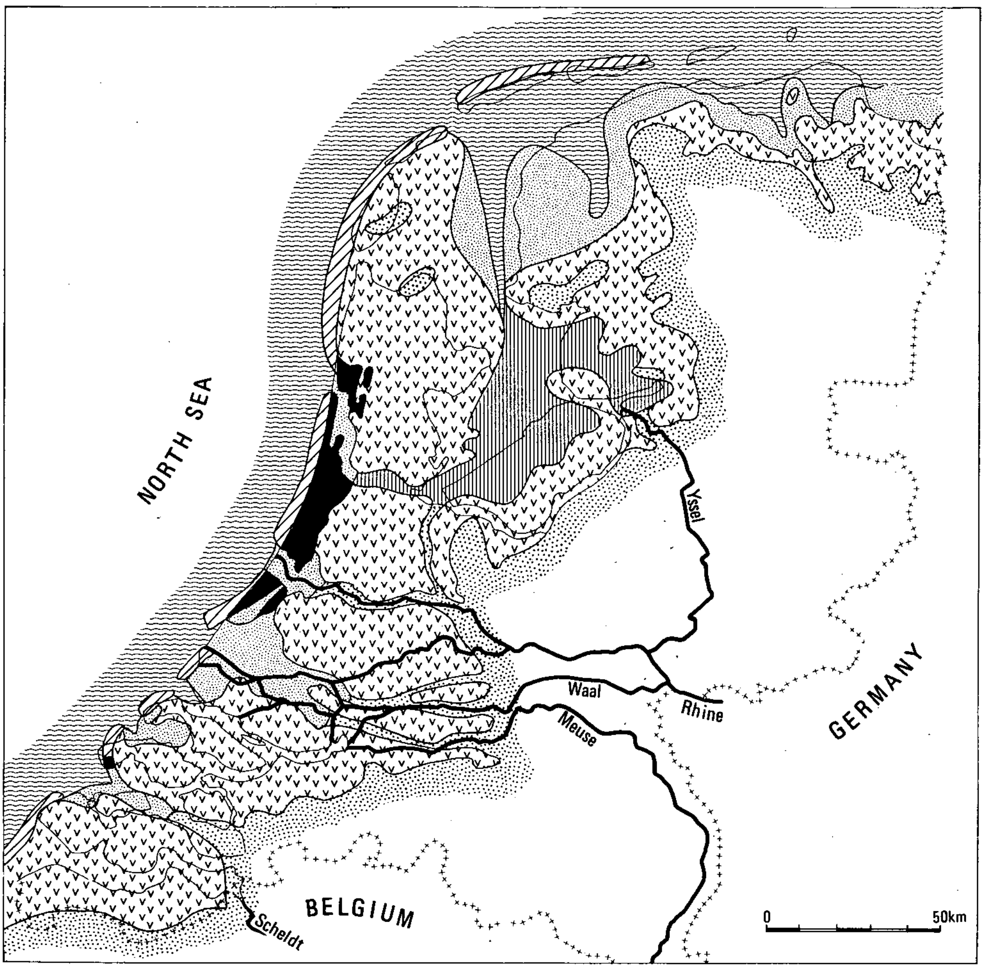


See for the legend Figure 5

Figure 6 Palaeogeographical map of the Netherlands in about 4300 BP (slightly modified after Zagwijn, 1974 and Jelgersma et al., 1979)

Figure 6 depicts the palaeogeography during an early substage of the Calais IV transgression phase in about 4300 BP. The sea-level was about 4 metres lower than the present one. The perimarine area has extended. At that time, peat also formed on the marine deposits in the central part of the coastal area. South and north of this area the sea reached far inland through breaks in the coastal barriers.

In about 3700 BP, the coastal barrier system almost closed. Marine sedimentation in the western part of the Netherlands discontinued. The for-



See for the legend Figure 5

Figure 7 Palaeogeographical map of the Netherlands in about 2300 BP (slightly modified after Jelgersma et al., 1979) mer tidal area was covered by peat. The general occurrence of this peat layer makes the distinction in Calais and Dunkerque Deposits possible. In about 3400 BP, formation of coastal barriers had ceased but formation of the Older Dunes still continued. Most of the coastal area was still covered by peat. In the perimarine area the rivers formed a more stable pattern of channels. Inundations were limited to the areas alongside the river channels. In combination with the already existing thick peat cover this made the development of oligotrophic Sphagnum bogs possible. The Dunkerque 0 transgression phase marks the beginning of a period of increased activity of the sea that has lasted until the present time. Figure 7 depicts the palaeogeography of about 2300 BP, during the Dunkerque I transgression phase. The sea-level was about 1 metre lower than the present one and the rise in sea-level was about 13 cm per hundred years. In the central part of the coastal area peat forming continued, mainly as large raised bogs. The first degradation of the coastal barriers in the southern part of the coastal area is indicated by the number of inlets. In the north an increased influence of the sea can also be seen.

Although the rise in sea-level further decreased to only a few centimetres per hundred years, the destruction of the coastal barrier system and the peat area behind it continued. Both in the northern and southern parts of the coastal area, large parts of the peat area were again covered by the sea. The peat was either eroded or covered by marine deposits. The influence of man in the coastal area became steadily more important. The coastal area had become a battlefield where the struggle between the sea and the Dutch people was fought. The frontlines were the embankments. A great deal of land was lost to the sea particularly during the Dunkerque III transgression phase (after 1150 BP). Over the last few centuries, increased technological possibilities have helped in regaining much of this lost land. The defence of the coast was also made easier by the formation of the Younger Dunes. Much of the material eroded from the coastal barriers by the sea was blown inland from the beaches to form the Younger Dunes. Their formation started in about 700 BP.

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2 REVIEW OF CHAPTER 1: THE OCCURRENCE AND SIGNIFICANCE OF PEAT IN THE HOLOCENE DEPOSITS OF THE GERMAN NORTH SEA COAST

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2.1 Introduction

The present configuration of the coastal area and the dynamic processes at work there today are part of a changing and in no way completed geological process. In comparison with previous phases which sometimes involved exceedingly rapid and far reaching changes, the present situation, seen geologically is a relatively stable stage of development. The Holocene transgression follows the transgressions during the Holsteinian and the Eemian interglacials and is the third marine invasion in the North Sea basin in the course of the Quaternary.

2.2 Geomorphological situation

The German Bight has a roughly triangular outline; the base of the triangle runs west-east between the rivers Ems and Elbe, and the line between the Elbe and the island of Sylt forms the eastern side.
In the centre of the triangle is the island of Helgoland, an isolated outcrop of Mesozoic rocks which were forced up by the halokinetic rise of a salt dome. The island consists of Bunter (red sandstone), and layers of Upper Bunter to Upper Cretaceous are cropping out in a wave cut platform on the northern and eastern sides of the island.
The Holocene deposits are relatively thin under the North Sea. They reach their greatest thickness, about 30 m, in the seaward part of the tidal flats and wedge out against the Pleistocene hinterland which is

2.3.2 Peat layers

Peat may occur at the base of the Holocene sedimentary sequence, intercalated in the sediments and also on top of them. The significance of a peat layer as to the height and the direction of changes in the water level (and the contemporary sea level) has to be reconstructed from the trend of the depositional environments and the development of the vegetation. The details of these environmental changes were described by Menke (1968). Based on palynological studies, he distinguished so-called 'allogenic series' which indicate increasing wetness, eutrophication, and occasionally brackish influences, from the 'autogenic series' which are characterized by decreasing wetness and oligotrophication or dystrophication. Streif (1979 a) and Behre & Streif (1980) stated that the whole system of changing water quality and water depth in the coastal zone is governed by the ecologically relevant hydrological factors, which are not necessarily directly related to sea-level fluctuations.

The basal peat

The term 'basal peat' only describes the position of a peat layer which occurs at the base of the sedimentary sequence of the coastal Holocene. It would be misleading to assume that these bogs were generally formed under the influence of rising sea level. Such a genetic assumption was commonly included under the term basal peat in the older German literature.
Lange & Menke (1967) and Menke (1968) dealt with this subject in detail. They demonstrated that a great many of basal peats are formed in typical inland mires and develop under various conditions. Some such peats were formed on terraces of the rivers Eider, Sorge and Arlau (Wiermann 1962, Lange & Menke 1967) and on the Weichselian low terrace of the river Weser (Preuss 1979). Other fen peats were formed in pre-existing depressions together with the sediments of fresh-water lakes (Menke 1976). Haarnagel (1950) described mires on plains where the bog growth was caused by high groundwater level due to the poor drainage. In the present tidal-flat region to the south of the island of Juist, Grohne (1957) studied raised bogs which were formed independent of the local

groundwater-level.
Besides these inland mires, a great number of the basal mires certainly originated as a result of rising groundwater, caused by rising sea--level. Lange & Menke (1967) therefore proposed restricting the term *Basistorf* (basis peat) only to mires where a causal relationship can be proved between peat formation and sea-level rise. This can be demonstrated by palynological evidence of increasing wetness, eutrophication and brackish influences. It is the typical vegetation development of the allogenic series of Menke (1968).

The intercalated peat layers

Intercalated peat layers are often used for a cyclic lithological subdivision of the coastal Holocene. They have also been looked upon as indicators of temporary lowerings of sea-level. However, such a conclusion is commonly invalid (Streif 1979 a, Behre & Streif 1980).
Bog growth is always connected with sedentary accumulation of organic material. It can therefore occur in the coastal zone under the influence of rising sea-level as long as the rate of bog growth keeps pace with or is higher than the rate of the contemporary sea-level rise.
Even if peat is found on top of tidal-flat sediments, indicating a change from marine to fresh-water conditions, this does not necessarily point to a stable sea-level or a sinking one. This can even take place under slowly rising sea-level by changes in the drainage pattern, e.g. under the influence of the formation of natural barriers.
The intercalated peat layers are mostly Phragmites peat and sedge peat, but wood peat and raised bog peat also occur. According to Scheer (1953) the formation of Phragmites peat in the brackish water and tidal zone is restricted to a narrow zone between 26 cm below and 72 cm above the mean high tide level. In places where the groundwater-level oscillates in relation with tidal movements, the upper limit of the groundwater is clearly lower than the mean high tide level.
A transitional sequence from a fen peat to a raised bog peat is a very important criterion with regard to water-level oscillations. Such a change requires a stationary or sinking watertable because ombrotrophic bogs only grow above the ($\pm$ eutrophic) groundwater. The occurrence of

raised bog peat on the top of Phragmites peat or sedge peat indicates that the natural plant succession of the filling-up process has been interrupted by the sinking of the groundwater-level. In most cases, however, the raised bog peat occurs on the top of wood peat. Such profiles indicate that the natural filling up sequence of a lowmoor bog had come to an end before a raised bog started to form. In this case it is clear that, at least during the initial growing phase of the raised bog, the groundwater did not rise, but remained stationary or even fell. When the raised bog peat has reached a certain height, bog growth can keep ahead of the rising groundwater table as long as the bog is not flooded.
Raised bogs may provide protection for their hinterland by floating on the water during floods. A recent example of such a floating bog is the *Sehestedter Außendeichsmoor* on the eastern side of the Jade bay (Künnemann 1941, Wiermann 1965, Behre et al. 1979). Fossil counterparts of floating bogs have been found in many places (Dechend 1956, Grohne 1957, Streif 1971). They can be demonstrated by the so-called *Klappklei*. This is a clay layer a few millimetres thick which comes from the suspended material in the water which was intruded between the floating and the stable parts of the bog during the flood. Repeated floating can lead to a sequence of numerous layers which occur on top of each other and which show graded bedding. The most diagnostic criteria of a *Klappklei* are the $CaCO_3$ content of the clay layer and the fact that it is not penetrated by younger roots.

Horizons of decomposed peat

Horizons of decomposed peat are often observed within sequences of relatively fresh fen peat. They can be regarded as a type of soil formation and indicate at least a temporary lowering of the groundwater table. In this case organic production at the surface of the bog was reduced and oxidation of peaty matter was dominant.
Eggelsmann (1960) studied these processes under the present climatic conditions. Menke (1969) dealt with the decomposition of peat in the coastal region of western Schleswig-Holstein. Preuss (1979) described a horizon of decomposed peat from the lower Weser and explained its relationship to a fossil soil on clastic sediments. Until recently,

these horizons have been rarely used as evidence of a lowering of water-level. More emphasis should be given to decomposed peat, its significance, spatial occurrence and age, especially during studies of sea-level fluctuations.

2.4 Temporal occurrence of peat in the coastal zone

The rise in sea-level from about -45 m to about → ½m between 9,000 and 6,500 B.P. caused an unidirectional, landward and upward shift of the coastline (Menke 1976, Behre et al. 1979, Ludwig et al. 1977, 1981). During this early phase, uninterrupted clastic sedimentary sequences of marine and brackish facies were deposited on top of pre-Holocene sediments and basal peat. The formation of the intercalated peat layers started at about 6,500 B.P., when the rate of sea-level rise slowed down. Between 2,600 and 1,600 B.P., intercalated peats were formed on a very limited scale and only in low-lying moist areas; while on drier ground soils were formed (Streif & Köster 1978). The coastal development between 6,500 and 2,600 B.P., or locally up to 1,600 B.P., is characterized by repeated alternation of transgressive and regressive overlap. Within this time interval, phases of enhanced peat formation can be demonstrated to have occurred over the whole region at about 6,000 B.P., between 4,800 and 4,200 B.P., and between 3,300 and 2,300 B.P. Within the general trend of rising sea-level, a temporary fall can be demonstrated at about 2,000 B.P. and another is widely believed to have occurred at about 2,800 B.P. (Preuss 1979, Ludwig et al. 1981). Each local environmental system reacts in its own individual way to the supraregional tendencies. Thus supraregional' changes in sea-level may be modified by local influences in such a manner that in places evidence for them is totally masked. A local succession is therefore a record, often an incomplete one, of the interplay between the 'supraregional' changes and the local environment.
For this reason, there are great problems in establishing an interregional lithostratigraphic system for the subdivision of the coastal Holocene. The local facies, incomplete sedimentary sequence due to erosion, and the varying influence of compaction make it difficult to correlate peat layers or sedimentary layers over long distances. Pu-

rely lithostratigraphic correlations can only be made within restricted areas showing uniform paleogeographic development. Reliable interregional correlations, however, have to be based on biostratigraphic or radiocarbon dates. It is for this reason that a lithological classification system has been developed (Barckhausen et al. 1977, Barckhausen & Streif 1978, Streif 1979 b) for geological mapping purposes. This system is based on the vertical succession and lateral interfingering of clastic sediments and peat. This classification can be linked with a chronostratigraphical system based on radiocarbon ages, but both systems must be regarded as two independent methods of subdividing the coastal Holocene. A reconstruction of coastal development in terms of time and space, i.e. in a paleogeographic sense, can only be achieved using a combination of both systems.

2.5 The reaction of man to variations in sea-level

The reaction of man to variations in sea-level along the German North Sea coast has been summarized by Behre et al. (1979). According to this study the oldest settlements were established on former flat marsh surfaces *(Flachsiedlungen)*. The oldest settlement of this type so far explored lies in the marsh bordering the river Weser near Rodenkirchen and is, certainly not older than Bronze Age.

Between the rivers Ems and Elbe, different phases of settlement on the flat marsh surface can be distinguished. They date from the Early Iron Age (700-300 B.C.) and the Roman period, and are commonly separated from each other by clastic sediments which were deposited between approximately 300 and 100 B.C. In the marshes to the north of the Elbe, settlements came into being in about the 1st century A.D.

An early type of protection against flooding was the artificial raising of the dwelling places. Successive habitation layers were covered with layers of clay by early man, forming the so-called dwelling mounds *(Terpen, Wurten)*. The first phase of mound construction began in the 1st century A.D. and came to an end in the 4th to 5th century. The general abandonment of settlements in the German North Sea marshes during the migration period (4th to 5th century) was probably not influenced by sea-level changes. It is known that settlements on the higher Pleistocene hinterland were also abandoned at the same time.

Renewed habitation of the clayey marshes began in the early Middle Ages, from about the 8th century onwards. Most of the preexisting dwelling mounds were re-inhabited, and new mounds were also built (Reinhardt 1969). In addition, villages were founded on the natural levees which were already sufficiently high.

The rather passive resistance of man to flooding by the sea, expressed by his construction of dwelling mounds, was superceded at the end of the 10th century by systematic building of dikes. The earliest of these dikes were ring-shaped constructions and in about the 13th century a continuous protective dike was built along the sea coast (Reinhardt 1979).

The dikes caused a considerable increase in flood level, and in addition drainage measures were required in the diked areas. This led to compaction, particularly in peat areas, often leaving the surface below mean high-tide level. Furthermore, in some parts of North Friesland, extensive peat digging was carried out for fuel and salt production from salt bearing peat. Altogether, these factors resulted in great losses of land and disastrous effects when dikes were breached. In Lower Saxony, such losses of land took place between the 12th and 16th century in the Dollart, Leybucht, Harlebucht and Jadebusen areas with most land being lost in the 15th century. Schleswig-Holstein also suffered great losses of land during the late Middle Ages and in early modern times, in fact North Friesland between Eiderstedt and Sylt was, except for a few places, almost completely lost.

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3 HISTORY OF THE RECLAMATION OF THE WESTERN FENLANDS AND OF THE ORGANIZATIONS TO KEEP THEM DRAINED

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3.1 The earliest occupation of the fenlands and its progress in the north of Holland

Around the 8th century the midwest of the Netherlands consisted of far larger areas of peat fenland than it does now. In the centre of this area the small, freshwater lake Almere was situated. The Almere was fed by the rivers Gelderse IJssel and Utrechtse Vecht. It had only a narrow passage between Friesland and Northern Holland to the North Sea.
In those early times the whole area between the Frisian Islands to the north and the Zeeland islands to the south, consisted or large cushions of peat, extending inland from the dunes and geest on the coastal areas. The peat areas, or fenlands as they are commonly known, were interspersed between many rivers. The land along the river banks consisted of clay and layers of clay on peat, and the land furthest from the influence of the rivers was pure peat.
There is evidence that the sandy geestland (fossil coastal barriers behind the dunes, cf. Figure 7 in Bijlsma's paper) along the whole of the coastline was already settled in the eight century AD), together with some places scattered along the larger rivers. Although there is evidence of some sparse habitation in the northern part of the fenlands in the mid-west at this time, these vast wastes remained largely in their wild, uninhabited state. That there was some habitation in the northern part of this area is obvious when one looks at data about place names of the area.
The suffix *more* (an old Dutch word for peat) was in evidence:

Tijslemore, Langenmore, etc., are to be found in the ecclesiastical records of properties of those days.

There are no sources of information of mans' progress in the fenlands during the ninth century or the first half of the tenth century. We can only guess that the lack of finds relating to this period is due to the Dane raids in the area, or to a higher number of storm surges, which would have discouraged new colonization, the people preferring to remain in the safer regions of the dunes.

We do know that in the second half of the tenth century the first vigorous efforts were made to occupy the wild fenlands in the area now known as the province of North Holland . The chronicles of properties and reports of place names indicate the gradual colonization of the fens to the east. Most of the area must have been occupied by the year 1100 AD. Data of a later date concerning the payment of *bodding* by most of the settlements in the area, corroborates this. Because we know that *bodding* (a kind of tax paid by settlements to the count) was no longer required of those settlements which had been established after the beginning of the 11th century, it is clear that those settlements which paid *bodding* must have been founded before this time.

We can also make deductions about the system of reclamation used there in those times. The map still shows the lines of the ditches used for the drainage of settlements. The unequal length of these ditches as well as the irregular courses of waterways and canals, indicate that the work was carried out under conditions of "free enterprise", by which I mean that there was no control from a higher authority. It is possible that the reclamation was organized by the old settlements and probably, in part, by the Abbey of Egmond, which in that period was the only Abbey in this region.

Further testimony about the system of reclamation at that time can be found in an Icelandic legend dating back to the tenth century. This gives reports of a Norman raid on the Frisian coast, in which the invaders were faced by flat lands, cut by numerous ditches. So both the map and the legend reveal that, in those early times, the system of reclamation (which was later called the Dutch-Frisian system), was applied on a large scale in this area. The method used was the digging of shared parallel ditches, or feather-patterned ditches, straight out from small streams or, in the later stages when it was necessary to open up more of the wilderness, by the digging of canals into the hinterland.

3.2 The Holland-Utrecht lowland plain: the beginnings of its systematic reclamation

3.2.1 Pre-1955 viewpoint

Until quite recently the vast Holland-Utrecht plain (Figure 1), which lies to the south of the area discussed above, was thought to have always consisted of flat swamplands. This assumption was based on the work of the famous Dutch geographic historian, A.A. Beekman (1854-1947). Common opinion held that, because the plain consisted of swamplands, no regular reclamation could have taken place before about 1200 AD, which is the supposed time of the construction of continuous dykes along the lower reaches of the river Maas in the south, and the IJ in the north. It was thought that the area was under constant threat both to the south and the north from tidal rivers and sea branches. Only after dyking, (with sluices to rid the land of excess water at low tide), could the fens have been reclaimed and colonized.
In the 1930's, however, the historian Heeringa began to question earlier theories about the reclamation of the Holland-Utrecht plain. In an essay on reclamation in the province of Utrecht he called attention to a few historical data from the eleventh and twelfth centuries which showed evidence that man must have inhabited several places in the centre of the fen area. Heeringa was the first to suggest that there must already have been agrarian settlements in what was previously thought to have been only swampy fenland. He was of the opinion that this land must have been drained by localized dykes surrounding it, and surplus water pumped off either by hand or with horse driven mills. However, he left open the question of dyking outside the actual cultivated areas which, in the 1930's, was generally held to have been necessary.

3.2.2 Post-1955 viewpoint

My initial approach in the 1950's was that of a law historian, but my work soon led to the wider question of the earliest history of the reg-

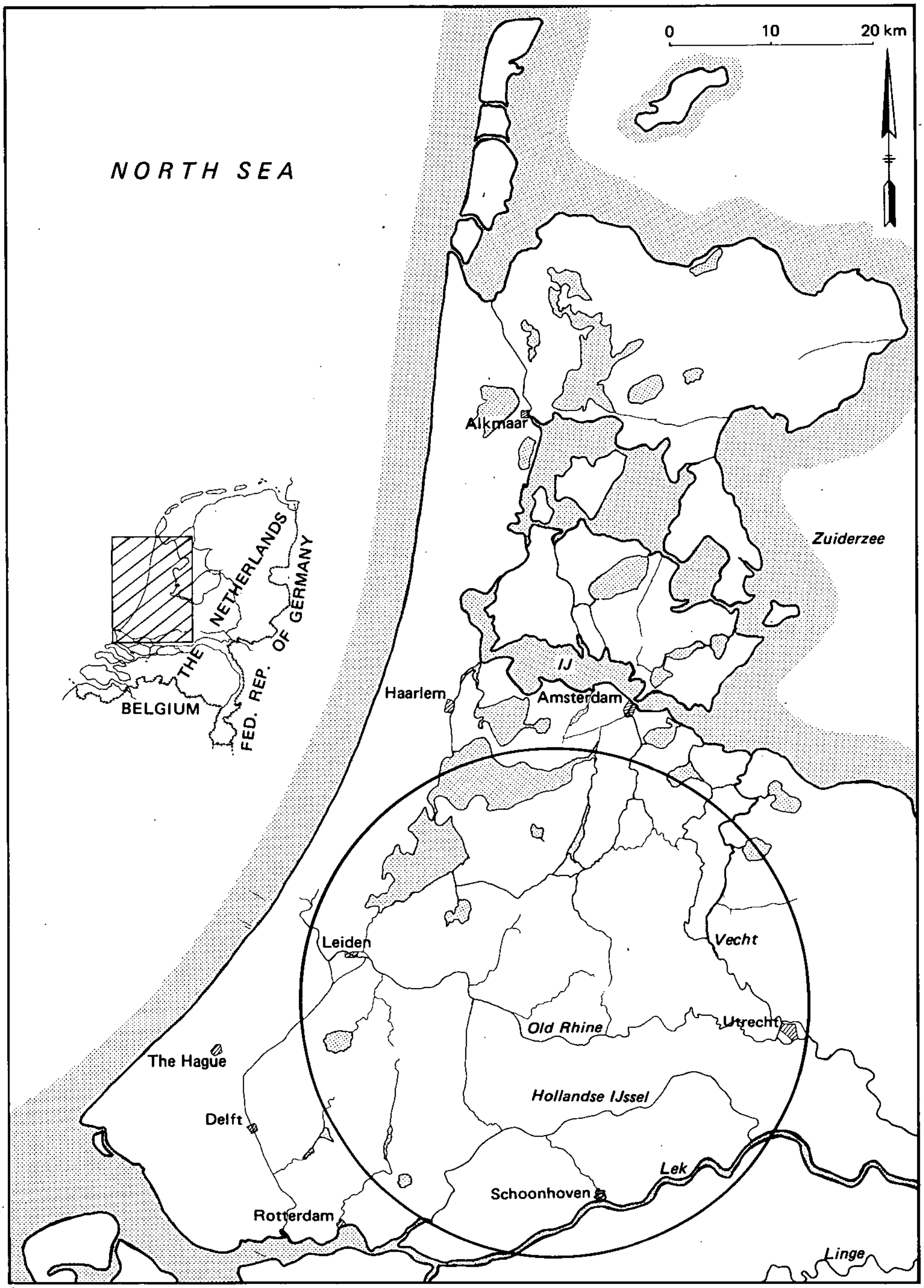


Figure 1 Midwest of the Netherlands, situation about 1300 AD (after Historical Atlas of the Netherlands). The encircled area roughly indicates the region of the Big Reclamation.

ular habitation and reclamation of this enormous central region of the Netherlands consisting of peat, and peat on clay. Initially I was particularly involved in the Dutch part of the area, and I came across a good deal of data which did not match the common notions of the day. I found no less than three chapels mentioned in the central part of that fen area in about the first half of the eleventh century. I also found that several settlements there were still paying *bodding* in later times, a payment which, as already mentioned above, dates at the latest from the beginning of the eleventh century. Although these historical facts were already known, scholars had, until then, justified them as having been concerned with sparse, isolated vestiges of fishermen and fowlers.

I then came across an article written by the German historian, Rietschel, in 1906. Rietschel, who specialized in mediaeval German colonization, discussed the organization of agrarian colonies in the north-west of Germany. He described several contracts, dating from the twelfth century, by which the Archbishop of Bremen and Hamburg, as the ruler of the area, gave wild fenlands for reclamation. The oldest contract - a document dating from about 1113 - described the contract partners as *Hollandenses* (Dutchmen).

These agreements gave detailed stipulations about the organization of the communities to be created in the fenlands, and much data about the system of regular reclamation to be applied. In some cases Dutch technical expressions were used.

Rietschel had deduced from the contracts that these Dutchmen had brought with them, from home, their knowledge of reclamation of the fenlands, and also the whole framework for the conditions of settlement in such an enterprise. Rietschel challenged Dutch scholars to question, through research, his findings. But unfortunately no one made serious efforts to do so. That his challenge remained unfulfilled is hardly surprising, because the earliest comparable Dutch contracts on the reclamation of the fenlands which have come down to us, date from the thirteenth century. Furthermore serious attention being given to Rietschel's request was unlikely in view of the common belief, at the time, that the Dutch fen areas had always consisted of low-lying swampy marshlands. As I have already pointed out, reclamation of these marshes was then considered to have been impossible prior to the building of continuous dykes in the north and south of the plain in about 1200 AD.

I made a careful study of those early German contracts and discovered a recurring stipulation in the seven oldest documents which dated from the twelfth century. It was stipulated that the Dutch colonists would pay a recognition, or *census*, to the Archbishop of Bremen and Hamburg as ruler of the area. This *census* was one denier (a small coin) per farm. The oldest of the contracts also stipulated the exact measurements of the farmlands, 720 by 30 rods[2], separated by shared ditches. I realized that here we had found the first exact description of the Frisian-Dutch system of 'parcelling' the fenlands.

I then returned to the Dutch sources and found that nearly all the settlements in the fens, those dated by a chapel or by the payment of *bodding* were either older or dated from the first half of the eleventh century at the latest, were still paying a *census (tijns)* in the later Middle Ages. These *tijns* were generally paid to the Count, I studied these areas further, and particularly the fenland to the north of the Rhine from where the first Dutch emigrants said they had come. By comparing the modern maps with the old maps I became convinced that here, as elsewhere in the whole plain, the Frisian-Dutch system of parcelling the fenlands had been used consistently. This encouraged a more general study of the system of 'parcellization' in the Holland-Utrecht plain, and I found that the colonists there had set up very large numbers of settlements of constant measurements. In most cases the farmlands were of exactly the same breadth as mentioned in the oldest Bremen contract, but half the length. In some cases the farms were of exactly the same dimensions as their German counterparts following that contract.

With this new knowledge I returned to the map of that *census*-paying fen area in Holland and looked for the three settlements for which I could find, in the oldest accounts of the administration of the Count, the exact amount of the *census* being paid. The findings here enabled me to reconstruct that the people there had been paying the Count exactly the same one denier for exactly the same sized farmland as in the northwest German settlements. Among those three settlements on the map, was one of the eleventh century chapel villages mentioned earlier. This was crucial evidence that the Dutch immigrants had indeed brought, from home, their whole system of settlement and reclamation to Germany. A system which had already been practised as early as the eleventh century in

Holland.

Two reasons highlight the fact that this practice was a highly successful one. First, because the old and modern maps together reveal corresponding groundplans for no less than nine settlements in the area (Figure 2)

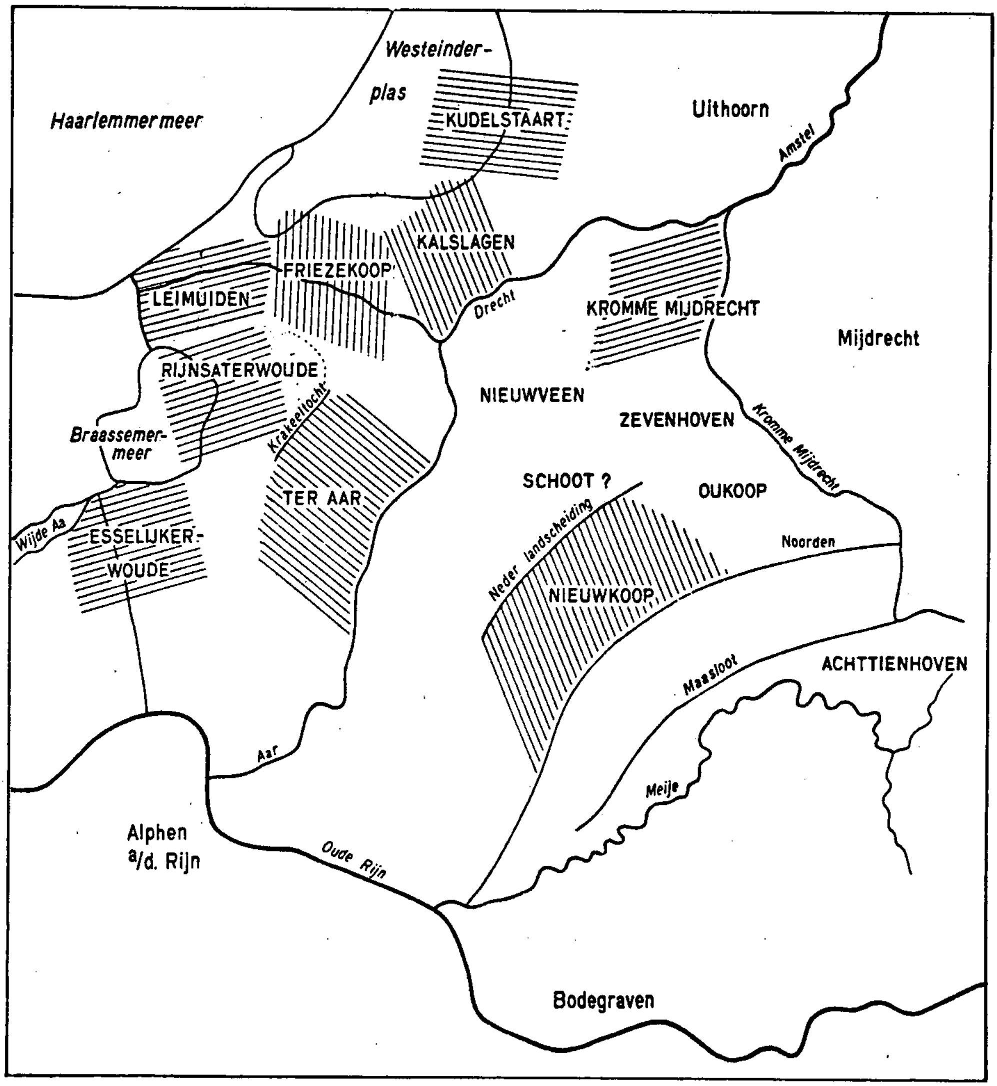


Figure 2 Twelve-furlong settlements in the eleventh and in the first half of the twelfth century

and, secondly, the relatively high amount of the tithes (tenth parts) being paid to the Count from grain crops by each settlement, even as late as the fourteenth century. Those tithes could only mean that the land in the area at that time must have been sufficiently high for growing grain. General experience is that the surface of the fens subside through cultivation. Even today with a continuous and refined drainage, in areas of peat layers of over 10 metres deep, subsidence continues at about 1 centimetre a year (see Schothorst's paper). To overcome this it is necessary to deepen the drainage ditches regularly to maintain sufficiently drained land. Viewed in this light it will be clear that, in the fourteenth century, even allowing that the crop would have presumably consisted of summer wheat, and that the ploughed land would have gradually encroached upon the wild[3], and still very fertile fenland, soil levels must have been considerably higher than today, and higher still at the time of its first occupation about three centuries earlier.

In the 1950's, when I first became involved in these investigations, people in other circles of science were just beginning to think that the level of the Holland-Utrecht fenlands must generally have been considerably higher in earlier centuries. Further research of various kinds[4] has encouraged general acceptance of this viewpoint, and today we speak of these higher fens as a collection of cushions of peat, or raised bogs, as they are generally known. The sources of several small fenland streams pinpoint the places at which we are able to reconstruct the centre of the peat cushions. There are traces of former dykes to the rear of some of the old colonies, and this new evidence explains why they were necessary. Those dykes were essential for defence against water from the higher ground at the centre of the raised bogs.

The findings of more recent research now enable us to understand why the Dutch were able to reclaim their fenlands in those early periods of colonization. We know that not only was the land then much higher, but also that the water of the IJ, to the north, was then only a small freshwater lake. Because of this there was no threat from the sea in the north. The situation had changed since the twelfth century because of some very heavy storm surges, transforming the small Almere lake into a much larger salt inland sea, later called Zuiderzee[5] (see Figure 1). This brought the tides far inland and created the need for continuous dyking to protect both the settlements alongside the water, and also those inland settlements which, over the centuries, had already suffered considerable subsidence in most areas through continual cultivation.

I ask the reader's forgiveness for confronting him with so much detail of the early stages in the reclamation of the Holland-Utrecht fenlands, but there are good reasons for my doing this. In spite of the new and vital historical findings about these fenlands, the well-known fable of how the Dutch snatched themselves from the clutches of the sea with the aid of windmills and dykes persists to this day. Most school books, and also popular literature, continue to ignore the facts and declare the validity of this old tale. Only by taking every opportunity and persistently emphasizing the true facts we can hope to influence minds and win them over to an acceptance of the well-proven, albeit new, views of scholars.

3.3 The technical aspects of the Big Reclamation

My new finding about the exact time in history when the Dutch fenlands were systematically opened up by man, led me to do a further thorough investigation of what we now call the Big Reclamation. This enormous chain of enterprises, which continued until the fourteenth century, brought about the gradual reclamation and habitation of the central Holland-Utrecht peat, and clay on peat areas. I will pursue the subject here by sketching the results of my research which, in recent years, is being carried out in close cooperation with scholars from other fields. There was a period of some free cultivation in this central Holland-Utrecht area, both along the banks of the river Rhine, and at places scattered along the eastern edges of the fenland land-mass. This free reclamation probably took place in the tenth century, following the same system used in the north, after which the scene changed. In about the year 1000 AD, the fenlands came under the effective control of the rulers of the area - the Count of Holland and the Bishop of Utrecht. Under the control of the rulers a systematic disclosure of the wild fenlands began. The work, which continued up to the latter part of the fourteenth century, was pursued in an unbelievably methodical way.
To begin with the starting point, or starting line of a settlement, this was the bank of a smaller river or marsh stream. Series of parallel ditches were dug into the bogs perpendicular or nearly so to the starting line. The purpose of these ditches was drainage, and separation of the different farmlands. The new settlers were required to keep identi-

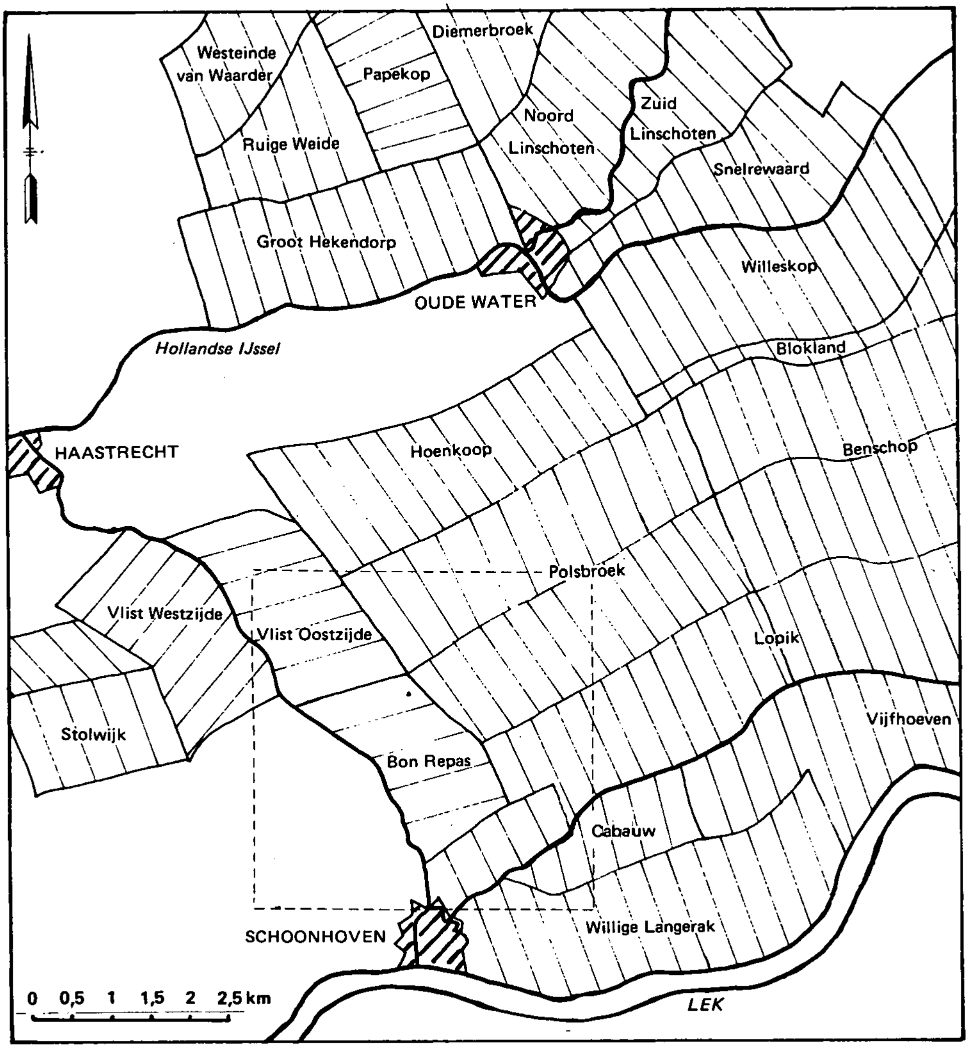


Figure 3 The western part of the Lopiker Waard, northeast of Schoonhoven, showing the typical pattern of the reclamation. The area of Figure 4 is delineated

cal fixed lengths for their farms which, in turn, determined the depth of the whole settlement. This resulted in the formation of territories of villages in the form of strips. When all the fenland along the natural water was occupied, then a new colony would begin by digging a canal *(wetering)* behind a existing colony, and, from there, a new set of parallel ditches each of the same length. This can be seen in some places where there are three or more settlements lying one behind the other, all

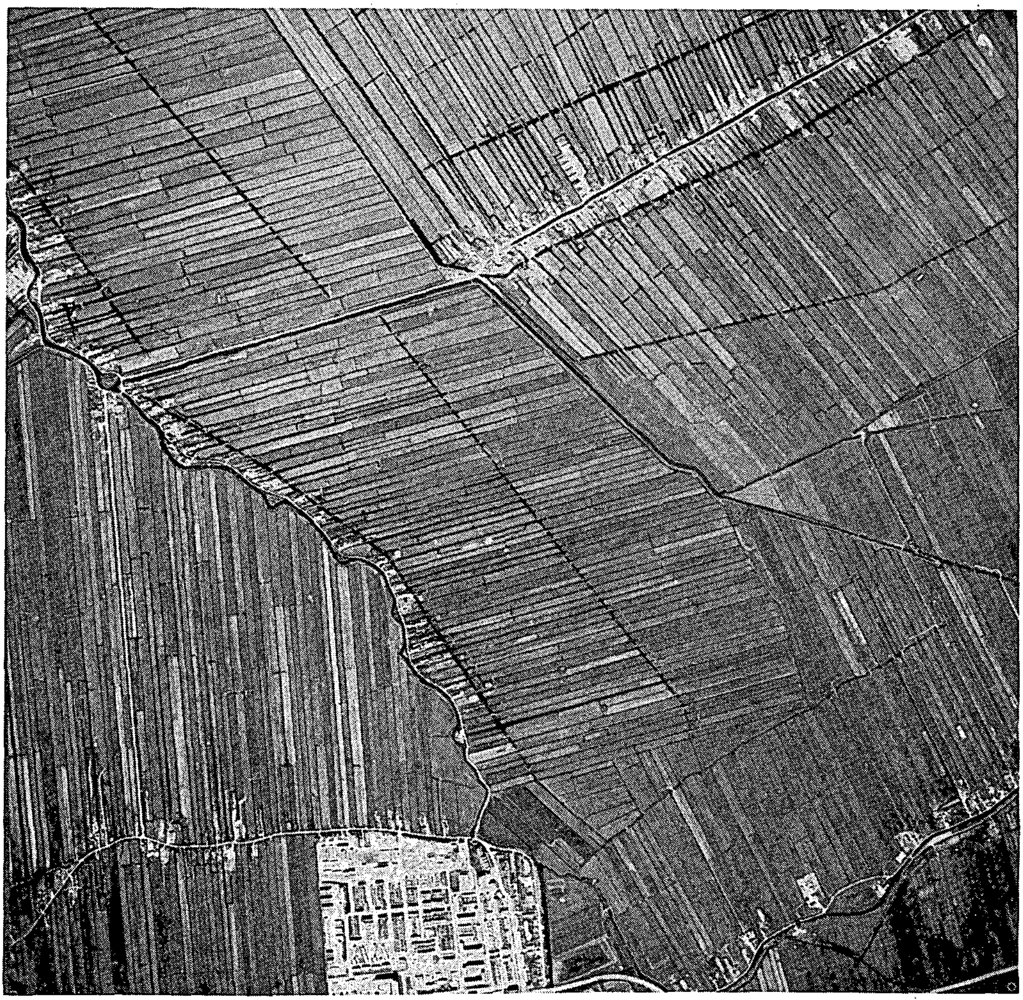


Figure 4 Area north of the recent suburb of Schoonhoven with Bonrepas on the righthandside of the river Vlist and Polsbroek more right (Fototheek Topografische Dienst). For location see Figure 3

placed in the same direction from the starting line (Figures 3 and 4). The frontage length of those strip settlements ranged frome something less than a kilometre to a few kilometres, while their distance into the fenland was of strikingly similar proportions. Several decades of settlements reached from 1250 to 1300 metres into the wild fenland (Figure 2, 3, 4 and 6). The people of those times described these measurements as six furlongs *(zes voorling)* or, originally, six times the way a

plough proceeded without turning. Each furlong measured 60 rods *(roeden)*. Such measurements give further indication that growing of grain was quite usual in the fenlands at that time. We have already met overwhelming proof of this arable farming from the relatively high tithes which were still being paid to the Count of Holland in the fourteenth century, by fenland villages which were founded some centuries earlier. Even then, rough calculation indicates ploughed surfaces of five to ten per cent[6].
It was probably the discovery that grain could be grown in the fen areas that paved the way for the Big Reclamation with its creation of new settlements far removed from those sparse earlier dwelling-places in the geestlands behind the dunes, and scattered along the larger rivers. In a civilization which did not know towns and markets it must have been necessary for every family, and certainly every settlement, to produce the food necessary for daily life.

I have already discussed the fact that the fenlands continue to subside once they had been reclaimed. Nowadays (see Schothorst's paper) we know that subsidence is caused not only by dehydration (i.e., drainage which shrinks the upper layers of the earth) but also through exposure to the air. Oxygen causes the decomposition of the peat itself, which literally disappears under this action. Although this subsidence is a gradual process, its effects on the altitude of the fens have, through the centuries, made it impossible to continue growing grain. Of the two previously practised agrarian activities, only dairy farming remains. In general, grain growing ceased in about the fifteenth century.

Trees in the fen areas were scarce and the colonists would have quickly exhausted the supply of those of decent size. For heating in wintertime, they must soon have turned to the use of dried peat, and even now that early quest for fuel is indicated by the strikingly broad ditches in the neighbourhood of the dwelling houses.

As has already been mentioned, the depth of the settlements into the wilderness was generally six furlongs (1250-1300 metres), although in the oldest of the fenland colonies the depth was twice that size (12 furlongs, or 2500-2600 metres) (Figure 5). This is 12 times 600 feet or 720 rods *roeden* which exactly matches the number of rods shown in the oldest Bremen settlement agreement. We were able to reconstruct the furlong measurement with the help of one particular document, dating from the latter part of the thirteenth century. This document is a report of

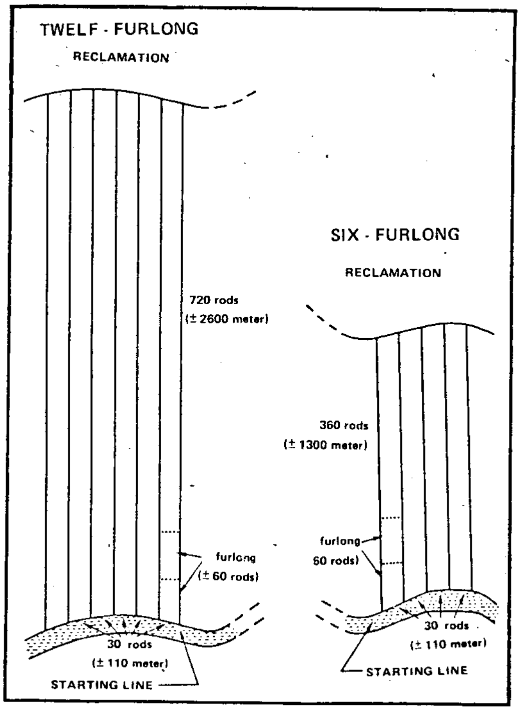


Figure 5 The systematics of the reclamation

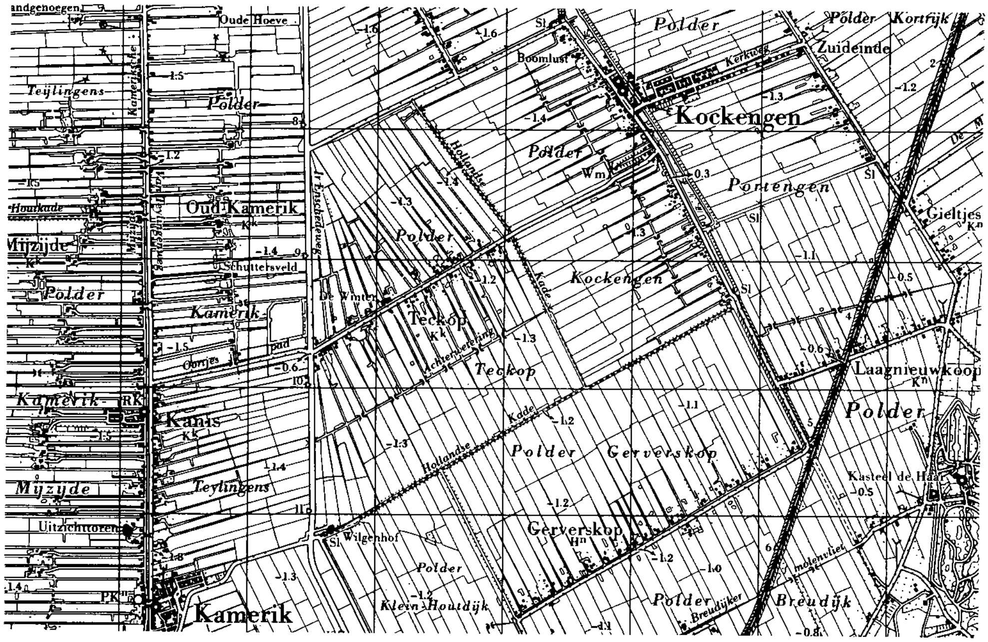
the work of a committee, which was carried out on behalf of the Count of Holland. The committee's task was to establish how much unclaimed land, and how much not yet reclaimed land remained. Much of the land incorporated in the groundplans of the settlements had not then been reclaimed fully. The farmers were therefore required to produce evidence of the rights they claimed to the neighbouring wilderness. In defining those rights the representatives of the colonies generally used the expression of twelve or six furlongs as a measurement of the depth of their territory. In some of these cases it is still possible to measure these distances on the modern map, and thereby to reconstruct the furlong measurement as a distance of 60 rods.

In the first stages of the Big Reclamation the length of every farm along the starting line must, in all cases, have been fixed at 300 feet (about 110 metres). This conclusion is based not only on the oldest Bremen agreement, for the original number of farms is also obvious from the data of several Dutch or Utrecht colonies. For instance, the original strip-form settlements are still extant on the map, and from this information it is sometimes possible to work out the exact measurements. The names of some settlements indicate the number of farms worked there

(*Dertighoeven*-Thirtyfarms). Sometimes we can look at the groundplans and compare them with the number of deniers which were later paid, or the number of farms paying some other form of levy. In all such cases it is possible to reconstruct the original breadth of the farms. Sometimes the map itself allows for conclusions to be drawn, when the equal distances between the shared ditches are so regular that one can, only by determining the skeleton of lines of the settlement, reconstruct the original breadth of the farmlands along the starting line. Although research has shown that other measurements were used in some of the later colonies, it is still usual to find uniformity in the breadth of farms in any one settlement, and especially in areas where the settlements originated. It is fascinating that even nowadays the distances between the farmhouses of some settlements remain at the regular distance of 300 feet. Examples of this are to be found at Gerverscop and Teckop, to the north-east of Woerden (Figure 6). Here, after eight centuries, the hamlets have changed so little that their outlines still bear the traces of their artificial beginnings.

There was not always enough wild fenland available to accommodate the twelve or six furlong settlement. This is especially true of the later stages of the Big Reclamation. In such cases the variation in amounts of available wild fenland resulted in the irregular groundplans of the new colonies. Such settlements (which I call rest settlements) often bear the name of Blokland, which was originally *beloken*, or blocked, enclosed land (Figure 3). In a few cases people followed a different pattern of reclamation. For example in an area in the north of the Holland-Utrecht plain which was encircled by some small streams in such a way that the wild fenland contained within it was of a circular shape. For the purposes of cultivation this land area had been divided like a cake, into wedges (Figure 7). Because of the lack of sophisticated measuring techniques, we may suppose that, whilst the division of land was in progress, a large bonfire was maintained as a marker at the centre-point of this area to ensure an even distribution of the land. In another case I found that the people used a marker already available to them: the fourteenth century boundary between two villages was pointed exactly at the tower of the Cathedral of Utrecht.

In the beginning, as we have already seen, the colonists paid an annual *census* of the minimum value of each farm. This type of payment ceased in



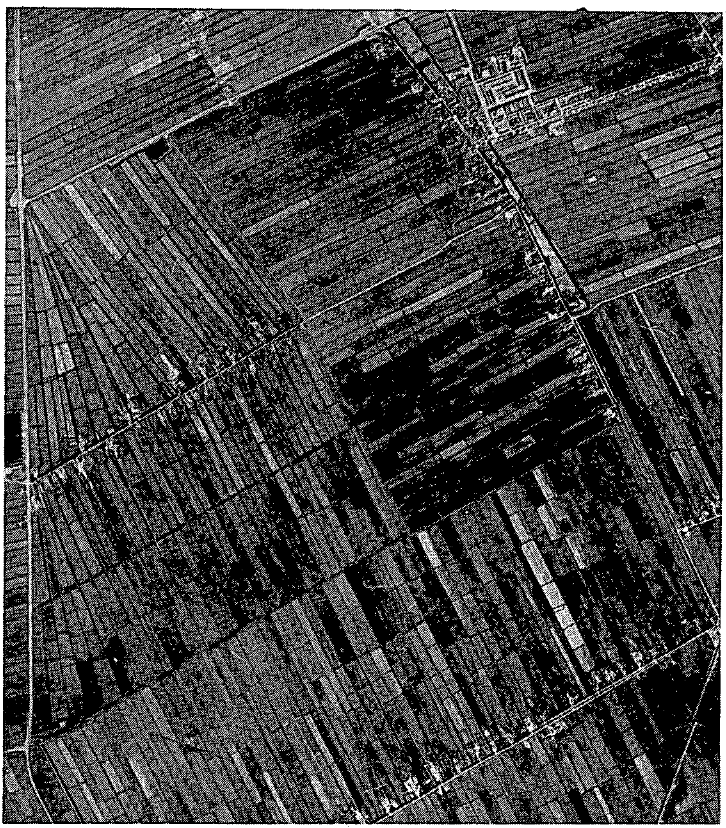


Fig. 6 Topographical map (1 : 50 000) of a region west of Utrecht (above) and an aerial photograph of the middle part of this region (Fototheek Topografische Dienst)
The farm of the frontispice (p.2) is situated in this area

Figure 7 The Ronde Venen (Round Peats) in the northeast of the Holland-Utrecht lowland plain during the peat-digging (1854) and the creation of polders, showing the systematics of the reclamation

about 1150, and during the second part of the Big Reclamation, which, after a break, started in about 1200 AD, the new colonists had to pay considerably higher land taxes, under other names, by the acre. The causes of this break in the enterprise, and the changes which came about in the conditions of settlement will be discussed in the following pages. A very important key for reconstructing the chronology of the Big Reclamation is the payment made for land. In this context let me emphasize that in all cases where post-dated historical sources show a *census* , *tins* or *cins* of low value, then the colony dates from before about 1150 AD. Any colony or settlement paying far greater amounts under other names must date from after about 1200 AD. But we do not have to depend upon data of this kind, for sometimes documentary information about ecclesiastical holdings, or archaeological data give details about the age of the settlements.

The map also provides a lot of information on the subject. The colonies built along streams are recognizable as being older than those colonies whose boundaries are in turn bordered upon them. "Rest" settlements, with their irregular groundplans, are of more recent date than the settlements surrounding them whose groundplans are of regular proportions (Figure 3 and 4).

Where did the colonists come from? A place name like Rinsaterwald - (settlers along the Rhine) - which is one of the oldest Dutch fenland villages, lead us to believe that some colonists came from the old nearby habitations. But it is likely that larger contingents of them came from the Frisian districts in the north (later belonging to the County of Holland) owing to the loss of land there through sea flooding. There are many direct indications of a likely influx of large Frisian contingents of settlers. For example, one of the 12-furlong settlements has the name Frisencoop. Then we have the village of Boskoop, which was originally Buckiscoop: Buckis is a Frisian Christian name. There are also language idiosyncracies in some areas which further reinforce the presumption that large contingents of Frisian settlers were among the colonists.

In the later stages of the Big Reclamation the main bulk of colonists will have originated from the older fenland settlements. With the growing of the population there, the younger members, unable to find farms for themselves, will have had to seek land elsewhere. This is already revealed by the emigration to Germany which had occurred since the twelfth century. The names of the originators of several Dutch settlements in the first half of the 13th century proves that they, too, came from the region of the oldest Dutch 12-furlong settlements.

3.4 The organizational and political aspects of the Big Reclamation

The right to rule the wild fenlands was granted to the lord of the country by Royal disposals in the tenth century. The rulers were the Count of Holland in the west and the Bishop of Utrecht, in the east. For ex-

actly measured ground plans they regulated all that was required for the public order of the territory and the future population, through settlement agreements. These agreements contained regulations covering the local administration of justice; the amount of annual tax to be paid; the number of men to be drafted in the event of war; details of levying tithes; and details of how to rid the land of superfluous water, especially for colonies of the second and third line. As already mentioned, until about half way through the twelfth century every farmer had to pay one denier as *census*. The purpose of this payment was as the recognition of the power of the ruler of the country. It was a sign that the colonists were not coming to create an independent farmer's republic.
Around the year 1150 AD, as I have already mentioned, the Big Reclamation was halted temporarily. This was due to the disastrous obstruction of the mouth of the Rhine on its original lower course through the middle of the plain. Although the river at that time no longer received water from its upper reaches the delta must nevertheless have received a steady and continuous supply of water from the many older colonies on both sides of the surrounding higher fenlands. The disaster was overcome by digging long canals from the Rhine area to the north with sluices giving off to the IJ which, as we have already seen, became a tidal sea branch in the same period. This event in its turn urged continuous dyking at the perimeters of the area. Thus the whole situation changed.
From this time onwards the water problems of the plain required the construction and maintenance of large regional waterworks, and continual efforts to control the invasion of land by water. In the mean time there was relatively little wild fenland available for cultivation. The combination of these two factors resulted in the land of existing settlements, and the remaining unclaimed fenland, taking on a social value. The Count of Holland and the Bishop of Utrecht, whose positions by then were firmly established, no longer asked a symbolic recognition of their authority from new colonists, but asked instead a real *quid pro quo*. This sometimes took the form of a lump sum but, more generally, was in the form of sizeable land taxes levied by the acre. These taxes were known as *erfpacht* or *erfhuur*.
The contracts for people coming from a foreign country contained exact stipulations about all the conditions of living in the new community. These conditions were agreed *expressis verbis*. Where the colonists were

already a subject of the same ruler, or where they were asking only an extension of an existing settlement already under contract, then much was arranged through tacit consent.

The people of those times called these contracts *cope* or bargain, but the word has no connection with the private law concept of bargain or purchase. At that time it meant: agreement, deal, with compensation, whatever it may have been. The names of villages or hamlets over many decades in the Dutch fenlands end with *coop* (nowadays *koop*). We have already met with some of these names. Other examples are: Nieuwkoop (new bargain); Oukoop (old bargain); Willescop (William's bargain); Papekop (bargain of a pope or priest). Names such as these, which can also be found in north-west Germany, keep alive the memory of the birth of these hamlets.

It should also be mentioned here that the colonists often introduced their own place names from home. So the name Horn, at the centre of the area in the neighbourhood of Bremen where (as recent research has shown) the first Dutch colonists must have settled, must have been taken from the neighbourhood of the oldest Dutch fen settlements where the Rhine forms a large bend or "horn". Today the hamlet Hoorn lies at one side of this bend, and on the other side we find the hamlet Oudshoorn which was originally a fen settlement some distance from the river. (The oldest spelling: Woutshorne, Outshorne).

Generally it was the rulers themselves who entered into these *copen* or agreements. In a later stage in Holland, the Count also called upon his lower lords to strike the agreements. For the Bishop of Utrecht settlement agreements were often arranged by the governors (the chapters) of the main Utrecht churches, who ruled parts of the Diocese.

The colonists would usually have closed the agreements as a group, as can be seen in the oldest of the German contracts, and the oldest available Dutch and Utrecht contracts. Sometimes, as may be already concluded by you from some of the cope-names, indivuals entered into an agreement with the Count or Bishop. Such people can be described as entrepreneurs or employers. Capitalistic dealings like these, however, were probably much less usual than they were at a later date in north-east Germany where Dutch colonists, among others, were also active in the later Middle Ages.

The colonists were given the wild fenlands free, not only for reclamation but also for their own disposal either during their lifetime, or at their death: Nowadays we would call this "property". Their obligations to the rulers were political and not excessive and applied to the settlement as a whole and not to the individual colonists. In the first stage of the Big Reclamation there were no direct connections between colonists and the ruler of the country, apart from the payment of one denier as a symbolic recognition of authority. The political relationship was no more than a territorial regulation and people were free to come and go as they pleased. As I see well, this position of freedom, the *landsheerlijke vrijheid*, or country-lordly freedom as I call it, was new and unique in this period when compared with the surrounding countries of the continent. The people in these countries, where lords governed, were generally held in bondage, or part bondage. However, when you were a free man there your freedom was not unlimited or quaranteed by agreement with the ruler, as was the case in the new land. This new freedom had already spread in the twelfth century over the older *bonded* Dutch settlements. Serfdom here had disappeared at a relatively early stage in history.

The marvellous and striking regularity of the overall groundplans of settlements through many decades certainly indicates that a great concept was worked at doggedly and sustained for centuries. It is impossible to imagine that even a powerful administration could have forced the development of this huge fenland area without the voluntary dedication of the people. No, this plan could only have succeeded based on the concept of freedom, which I have just discussed.

The large increase in the number of settlements gave a distinct advantage to the dynasty of the Count of Holland over other members of the ruling classes through the increasing mass of loyal and free inhabitants of the fenlands over which he ruled. Bishops were elected, generally after struggles between internal and external powers, which often resulted in them becoming the tools of others. This type of situation was certainly true of the Bishop of Utrecht.

The freedom of the fenland area developed into a trademark of Holland. It became THE land of Freedom in the eyes of other Europeans. This idea of freedom was introduced by Dutch colonists, along with their technical system of reclamation. It was also taken to many other regions of western Europe, not only to other parts of the Netherlands, but also to northern Germany and to scattered places in England, such as Romney Marsh in Kent, Holland in Lincolnshire and Cambridgeshire.

3.5 Heemraadschappen (Regional waterboards)

The initial reclamation of the wild fenlands took place mainly on the raised bogs in the higher inland areas, where drainage required no more than the digging of ditches, or sometimes canals *(weteringen)*.Nevertheless, during the course of time it must have become necessary to construct small, localized dykes, for when people reclaimed the lower parts of the marshes it would have been necessary to defend it against water from the higher marshes. Furthermore, settlements close to the neighbourhood of bigger rivers would need to be defended against flooding from the river.

In the twelfth century the first regional waterworks came into being. The people managed to dam up small rivers to ensure improved and lasting drainage of the regions behind the dams. Recent research has dated the earliest example of such damming as early as 1122 AD. This is at a site on the Rhine at Wijk bij Duurstede, in what is now the province of Utrecht. The river there was formerly the main course of the Rhine, which had lost its position to the river Lek about three centuries earlier. It is not possible to trace the originators of this work. It could have been initiated by the Bishop of Utrecht or by other interested local rulers or settlements. It is certain however, that maintenance of the work was carried out by these interested local parties, who became welded for that purpose into a lasting bond. This union formed the first special organization for the purposes of dyking and drainage. Thus the first waterboard came into being[7].

The next known dam construction dates from 1165, after the disastrous clogging up to the mouth of the Rhine near Katwijk in Holland, which was built by the Dutch on (what was then) the boundary between Holland and Utrecht, with the intention of shutting off the Utrecht water. This construction caused a state of conflict between the countries, with the result that the Emperor, to whom the Bishop had appealed, ordered the removal of the dam. In the meantime the Dutch settlements involved in the dispute were forced to remove their superfluous water by digging canals from the Rhine area to a lake district more to the north, with an open connection to the IJ. The conflicting parties eventually reached a compromise and a narrow opening was left in the dam. Utrecht accepted responsibility for constructing and maintaining extra canals and sluices on Dutch territory which helped to carry the joint superfluous water to the IJ in the north. We can safely assume that these works led to a lasting collaboration between the involved settlements on the Utrecht side of the border in Holland, and also in western Utrecht. This collaboration was the beginning of what later became the waterboards of Rhineland and Woerden, which are still in existence today.

Many dams were built in the twelfth and thirteenth centuries, and many Dutch towns took their names from these constructions: Amsterdam, Rotterdam, Schiedam, etc. The lower ends of streams were dammed as a defence against the tidal surges of the sea during storms. The construction of primitive culverts or sluices was carried out to rid the land of superfluous water at low tide. During the course of the twelfth century enterprises were undertaken to join together local dykes along the larger rivers and sea-branches so forming the large continuous regional dykes. By about 1200 AD most of the regions in the area were served by their own works which gave some defence against the higher waters outside.

The maintenance of the regional dams, sluices, and dykes, became the responsibility of co-operative bonds formed by the settlements themselves. Each settlement was represented on the board by its alderman. Every village was responsible for the good order of a part of its regional waterworks. This work was called the *slag*. Where dykes or *weteringen* were involved, each village, in turn, divided its share of the overall work between its farmers. Each farm (or *hoeve*) having its own share of the work (*hoefslag* - farm-share) (Figure 8) of the *slag* of the settlement. General (*schepenen*) or special (*heemraaden*) local public works inspectors, controlled the work. The inspectors had fixed inspection days, and had the power to punish those who neglected their work in any way. In the event of permanent neglect, the inspectors could authorize the local sheriff (*schout*) to carry out the work at the offending farmer's cost.

In a few cases early thirteenth century sources mention special overall *heemraaden* of the co-operative bonds. These are the first examples of the waterboards which developed over time into autonomous corporate bodies

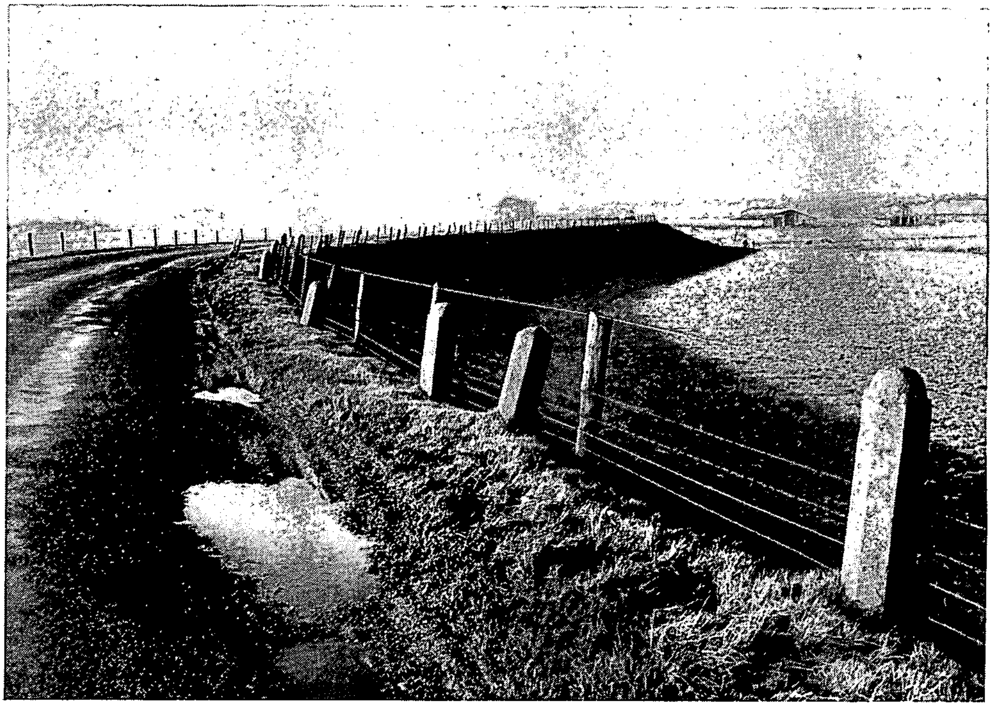


Figure 8 Part of the northern dyke along the Rhine near Amerongen, showing the stone poles which mark the "slagen" (Photo Soil Survey Institute R36-31)

with independent financial means. During the course of the thirteenth century these boards, formed by supervisors/governors under the name *heemraad*, became usual for all of these regional waterboards. Hence the name *heemraadschap*. During the same period the waterboards were successively incorporated into the ruling organization of the Count or Bishop. Regional bailiffs, as representatives of the central rulers, were assigned the role of investigative judges. This had formerly been the task of the numerous local sheriffs. These bailiffs were responsible for the execution of any sentences passed by the boards of the heemraden, and to enforce the repairs of the neglected *hoefslag*. There is also evidence that some waterboards had their own "investigator-executor", or *dijkgraaf* (Count of the dyke) appointed by the Count or Bishop. Although this was exceptional in early times, it became the normal practice in later centuries.

During the course of the late Middle Ages (fourteenth, fifteenth and sixteenth centuries) region after region of almost the whole extent of the Holland-Utrecht plain, developed its own waterboard or *heemraadschap*. As time passed the most powerful waterboards gradually took over the supervision of the local *heemraden:* hence the names *hoog* (high) *heemraad* and *hoogheemraadschappen*.

Throughout the thirteenth and fourteenth centuries most of the *heemraadschappen* were authorized by official charter to fulfil their duties. It is these charters which have led to the widely held belief that the rulers (Count or Bishop) were the founders of the waterboards. However, recent research has shown that the waterboards are generally older than those charters which merely represented official recognition of an existing state of affairs. Furthermore, modern scholars can reasonably argue that in the beginning, the regional *heemraden* were not appointed by the rulers but were chosen by the villages involved. Even where the rulers did instigate the building of a dam or a regional dyke, organization of their maintenance was the responsibility of cooperatives of settlements. Only in times of emergency when the safety of the inhabitants was threatened, or the maintenance of dykes or waterworks was neglected, did the Count or Bishop, as the highest authority, intervene.

3.6 Polders

The late Middle Ages saw the second manifestation of the Dutch waterboard: the polder. A polder can be distinguished in two senses, the technical polder and the juridical polder. Technically speaking, a polder is a combination of lands brought together only by a need for better drainage. Dykes constructed around this land enable the maintenance of a more or less constant water-level inside. A technical polder such as this, but having its own laws and financial organization, is known as a juridical polder.

From the technical point of view, the oldest polders to be found in this country, are those in the Dutch-Zeeland delta, some of which go back to the twelfth century. These earliest polders either gained, or regained, some land outside dykes. Enterprises of this kind were generally initiated by a local ruler, or by a settlement bordering the newly gained land. Responsibility for the land gained or recovered in this way was

allotted to the local administration.
In the late Middle Ages the creation of polders also became necessary in some places owing to the subsidence of land caused by centuries of cultivation. The subsidence was so intensive that it was no longer possible to rely on natural drainage. To overcome this, people created polders for better drainage. The better drainage was achieved by digging small *weteringen* to tidal rivers or river tributaries which had been lowered artificially by damming. The lands combined in polders in this way did not correspond with the original ground plans of the villages, and it was this which prompted the land-owners concerned to organize polders in a juridical sense, which were separate from the local administration. Polders held an independent position both financially and juridically. The supervisors *(poldermeesters)* were selected from amongst the land owners. When land belonging to a polder was lying in one particular settlement only, then the sheriff of that settlement was also active in that polder. However, where a polder encircled lands of several villages, then the sheriff of one of the villages concerned would, as a rule, officiate for what was otherwise an independent polder. Initially, the consent of the ruler was a requirement for the construction of new polders. This situation changed in time as the inland-powers of the heemraadschappen grew, until, eventually, new polders were not permitted without their authorization.
From the beginning, the main decisions in the polders were taken by assemblies of land-owners, which gave the polders a highly democratic quality. This contrasted greatly with the situation in the *heemraadschappen* which, from the late Middle Ages until the French Revolution, were ruled by the rural nobility, abbeys and later, also by prominent citizens. Thus the general public, including the farmers who maintained the waterboard works, had no influence in the decision making processes in the *heemraadschappen*.
The middle of the fifteenth century saw increased activity in the creation of polders. This phenomenon, which until then had been an exception on the mainland, spread rapidly with the introduction of the drainage-windmill. It was possible to use these mills in all wind directions and they were capable of pumping superfluous water from large areas of land to levels of 4 or 5 feet. In this way it became possible to provide effective drainage to land so compacted that it was becoming lower than

the average levels of neighbouring rivers and canals.
Villages which had one or more mills for the whole of their territory had no need of any special controlling organization. Generally, however, the land of the newly created polders did not correspond with the ground-plans of the villages so the land owners concerned would establish a juridical polder.
The invention of the drainage-windmill encouraged a rapid increase in the number of polders created. These developments, which continued up to the seventeenth and eighteenth centuries, transformed the detailed drainage system of almost the whole of the Holland-Utrecht plain. In a short time we also had a network of regional *heemraadschappen* as a network of polders, over the whole area.

3.7 Struggle for life

The dykes, *weteringen*, culverts and sluices which have been discussed so far, were necessarily small, owing to the use of manual labour in their creation. Their maintenance was an unremitting fight against nature. It was a fight which was often lost, with disastrous results, so that after a dyke-breach whole areas would regularly have to be abandoned, sometimes for long periods. Evidence of this can still be seen in areas where stretches of dykes, which no longer serve any purpose, are situated in the middle of areas of land. There is also evidence of scouring holes (small lakes) behind these dykes - the so-called *wielen* - at the sites of earlier breaches. These relics remain as a reminder of those earlier breaches in the dykes. They serve to keep alive our memories to the continuing struggle for life in this low country.
This constant critical and perilous situation urged that the regional boards should have effective juridical means to realize new waterworks, and to control the continual maintenance of those works. Hence they have developed their own laws *(keuren)*. Since the later Middle Ages these laws have, time and again, been affirmed and sometimes enlarged upon in official documents of the rulers. The polders also created their own laws. However, since about the fifteenth century, the polders of central Holland were almost entirely subject to the *hoogheemraadschap* laws.
One of the most striking changes in *hoogheemraadschap* law during the

course of the centuries concerns the renovation of dykes, which had hitherto been an individual responsibility. As early as the thirteenth century, in some *heemraadschappen*, people already decided that full renovation of breached dykes was to be realized by the whole of that waterboard community. This later became a rule in every waterboard. By degrees over later centuries, responsibility for the regular upkeep of dykes, dams and sluices (which, as has been mentioned, had been 'weighted' on villages and farmers) was also taken over by the waterboards themselves. The boards of the *heemraadschappen* possessed great power. The ultimate punishment it could demand, was the death of an offender. In the later Middle Ages, the *heemraadschappen* were responsible for all justice in the area of water administration and appeals against a decision made by local authorities, or by polder authorities, would be referred to it. By about the end of the Middle Ages it became possible also to appeal against the decisions of the *heemraadschappen* through the normal central high courts. The laws of the independent *heemraadschappen* were refined and extended as time passed. Occasionally rules were 'borrowed' from corresponding institutions, especially the older ones. The whole of this highly developed branch of law remained fully independent of the common law. So Roman law also had no influence in this unique field.

3.8 Heemraadschappen and polders up to the twentieth century

From the beginning of the seventeenth century there was yet further increased activity in the creation of polders in the technical sense. This increase was due to the technique of draining larger natural lakes with the aid of groups of windmills which passed water in successive steps to the surrounding waters. By this method it was possible to drain bigger lakes with depths of 4 or 5 metres. In the following centuries, this technique was also applied to most of the many artificial inland waters *(plassen)*, some of which were very large, owing to the peat digging and dredging carried out in the quest for fuel for towns and industry.

The new land, gained by draining the bigger lakes in North Holland, was in each case formally organised simply as polder in the juridical sense. In point of fact however the polder boards very soon established the social infra-structure by which the new communities became new villages. By contrast, the regained *plassen* which were also established as polders in the juridical sense, remained in all other aspects under the administration of the surrounding villages.

The number of polders was still increasing during the time of the French occupation (1795-1813). At the instigation of the French the general governing tasks of the old village organizations, under the name *ambacht* (Dutch) or *gerecht* (Utrecht), were taken over by municipal (inhabitants-) organizations *(gemeenten)*. This reduced the original local organizations to waterboards throughout the Netherlands, and thus increased the number of waterboards to over 3,000.

During the period between the French Revolution and the Second World War, pumping equipment and techniques for the construction of dykes were modernized, and nearly all the old water windmills were replaced by pumps operated by steam engines. The new sophisticated methods made it possible to drain the very large Haarlemmermeer[8] which in earlier centuries had been formed from three smaller lakes by erosion.

The new findings allowed the *heemraadschappen* to regulate the levels of their general water systems more effectively with mighty pumping stations. Because of this they do not depend on low tides in order to expel the superfluous water from the polders. After 1918 the steam engine pumps were gradually replaced by diesel-oil and electric pumping equipment.

In about 1840 the juridical powers of the waterboards came to an end. Changes in the Dutch constitution during the course of the nineteenth century gave the provincial governments powers to organize the waterboards and to create new laws and regulations for them. This led to a new and more democratic structure within the *heemraadschappen* so that the greatest powers were held by assemblies of representatives who were chosen by the landowners themselves. The provincial governments were also able to reduce the number of waterboards to about 2,700, by abolishing some of the smaller boards and combining the tasks of others.

A number of specific national laws improved and strengthened the functioning of both provincial authorities and the waterboards. Some limitations were also imposed on their powers.

The idea of organizing the lower authorities on a larger scale has grown since the end of World War II. This movement has also touched upon the world of the waterboards, and was accelerated by the huge flood disaster of 1953. Its aim is to improve the whole of the waterboard administration and to provide better measures to prevent any such disaster in the future. Since that time it has also been considered necessary to staff all these public institutions on a full-time basis. During the last decennia all of this has caused intensive provincial activity in re-organizing the waterboards. Nearly all the polders have now been united into large waterboards (*polderdistricts*), or have been incorporated into the *heemraadschap* of the region. The number of waterboards has thus been reduced to about 200 throughout the country. In recent times most of the *heemraadschappen* have also been charged with control of the quality of water and of purification of sewage. Sometimes, as in the southern parts of South-Holland, the provincial government created a special waterboard for that purpose, to work independently of the existing *heemraadschappen* of those regions. In contrast, the province of Utrecht does not charge waterboards with these new tasks, but organizes its own control of water quality, and its own purification of sewage.

The waterboards of the Netherlands are a great phenomenon. This is especially true of the lower lying regions of peat, and clay-peat areas. Many agricultural industries of the Netherlands, such as bulb growing (Bollenstreek), potting plants (Aalsmeer), vegetables (Westland), and ornamental shrubs (Boskoop), as well as the grass required for dairy farming, are dependent upon the proper control of waterlevels. Indeed, the very existence of the major part of the Netherlands, which now lies below sea level, depends entirely upon the control of the water, through its mighty dykes and water pumping equipment. It is important that the very sophisticated methods of controlling this natural force rest with the experienced waterboards, whose skills have stood the test of time. It is to their credit that these public bodies have managed to keep politics out of their organizations. Their efficiency reigns supreme, but their work remains under the direct control of the chosen representatives of the farmers, smallholders and other involved taxpayers.

Notes

[1] That part of Holland which lies north of a rough line from Aalsmeer to Hillegom just south of Haarlem.

[2] 1 rod (Dutch *roede*) is equivalent to about 4 yards (3.7 metres).

[3] Extension of agriculture into the wild fenland was, of course, limited to the original amounts of land agreed by the *cope*.

[4] Especially by specialists of mediaeval history, physical and agrarian historians.

[5] The building of the enclosure dam between North Holland and Friesland in the north of the Zuiderzee in 1932 converted this sea into the freshwater IJsselmeer lake and allowed reclamation of land on a large scale.

[6] For some settlements, of which I could reconstruct by maps the original ground plan and consequently the surface, we also know the exact amount of money the Count received from the collectors of the tithe. In those same accounts there are records of the amount of money paid by the Count for the mentioned weights of grain for the use of his court. By this datum it is possible to work out what a tenth of a settlement consisted of in quantity of grain, and to know how much grain was actually grown on each settlement. Once you know the general yield of summer wheat per acre it is possible to reach the rough estimation discussed in the text above.

[7] The later *hoogheemraadschap van de Lekdijk Bovendams*, nowadays the *waterschap Kromme Rijn*, where in fact the dam is at the same spot as the famous early Mediaeval trading centre of Dorestaad.

[8] The Haarlemmermeer was situated between Haarlem and Amsterdam in the north and the surroundings of Leiden to the south.

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4 REVIEW OF CHAPTER 3: A COMPARATIVE NOTE ON THE EXPLOITATION AND DRAINING OF THE PEAT FENS NEAR THE WASH

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4.1 Settlement

The peat fens were some distance from the sea. Silt fens had built up on the seaward side, with banks of clay and silt clear of all but the highest tides, and saltmarsh still further seawards. Through this a river system tried to drain an enourmous catchment area in face of tides that could surge, and could scour and drop silt and clay. Changes in relative land and sea-level had made matters worse, almost eliminating any gradient in the river system. The whole was unstable.

Occupation of these fens was remarkably tentative, perhaps primitive, until Cornelius Vermuyden showed us how. We know a good deal of early settlement in the fen area thanks to air photography of sites that fell under the preservation of floods and remained so until relatively recently. In the pre-Roman Iron Age only the landward edge above the peat was settled. In Roman times by the middle of the second century settlement was dense, not only on this skirtland, but also on the fen islands, where the domed tops, usually of gravel deposits, stood proud of the waters, and also on the silts. The archaelogists have remarked a social difference in the Roman settlements of the two kinds of fen. On the silts were small villages apparently devoted heavily to the making of salt. Among and alongside the peats were single family farms, never quite running on to the peat soil itself.

The salt-making settlements on the silts relied on the peat for fuel and sheep-pasture. The little farms could both grow some grain and raise beasts on the lush grass that grew on the peat. It begins to look probable that this early exploitation of the fens in Roman times may have been at the behest of the Imperial government, since the purpose of the canal then constructed, the Car Dyke, seems to have been to convey supplies from the fenland to the northern legionaries responsible for the defence in depth against the Ancient Britons. The canal avoided the storms and pirates of the North Sea.

Some people still try to argue that the Cambridgeshire Car Dyke was an early attempt to drain the fens. As drainage it was a nonsense: worse, it was a disaster. The whole system collapsed about 230 A.D., and the water ran the wrong way until the canal was reconstituted about forty years later. Bromwich (1970), who worked all this story out, will allow the possibility that the reconstitution of the Car Dyke may have had a slight secondary purpose in bringing back better drainage. When it finally broke down again in the fifth century, the water cut its own way out of the difficulty, creating the Old West River, making the Isle of Ely an island, and leaving the fens apparently deserted.

In spite of the interest shown in recent years by historians of the Dark Ages in the possibility of continuity of settlement through the period of the fall of the Roman Empire, no one has yet produced any probable examples from the Fens. The survival of pockets of Celtic speaking inhabitants has been discussed by Darby. St. Guthlac's Welsh education enabled him to understand the tormenting demons who visited him on his island in the deep fen. But this is not much to go on, nor is the evidence of anchorites and hermits founding their cells on fen islands in the seventh and eighth centuries, enough for us to estimate the scale of settlement at that period. They did, however, leave a tradition that led to the development of the great Black Monk houses of later times, following perhaps a double re-founding after Viking destruction.

The Domesday Book gives us a measure of the degree of development of settlement as well as its pattern by 1086. The process of filling up has begun and is far from complete. The fen islands are settled, if their villages are still small. Some of the future skirtland villages in Huntingdonshire are not mentioned, although negative evidence of this kind is unsafe in Domesday: they may be subsumed in other places. The corresponding zone in Cambridgeshire is complete. Fenland parishes are often as large as the apparently well-established parishes in the uplands. The silt-land was well developed. Wiggenhall and the others of this group had yet to split up, and most of the daughter villages had yet to separate. Outwell and Upwell had already begun the adventurous experiment of building out on levees of the Old Croft to find a firmer foundation in the fen. The overwhelming impression from the Domesday is that population expansion and new settlement will soon be filling up all the available sites suitable for villages, even if pressure is not yet acute.

A good deal of the Hundred Rolls of 1278/9 survives for Cambridgeshire. Where it does it gives similar information to Domesday but in much greater detail. The comparison is dramatic. Professor Smith calculated that for the fen-edge parishes where we have both sets of figures, the increase is 242%. Elsewhere the increase, although very large indeed, is not as great as this. In 1279 many villages have passed the probable number of inhabitants that they were to have at the first Census of 1801.

There is evidence of new intakes, fields and villages: Mepal, Manea and Benwick have appeared in the twelfth and thirteenth centuries. Hamlets have emerged on the former wastes. And in the latter century Prickwillow and Shippea have been built on roddons, the raised silt beds of streams that had moved to new courses, not very firm as the peat was still under the superficial silt layer.

4.2 Reclamation

We learn most of the detail of reclamation from seigneurial records, and may easily exaggerate the part played by lords as compared with peasants. But from Professor Miller's researches there can be no doubt that the bishops of Ely in the twelfth and thirteenth centuries played a considerable part in initiating assarting in order to increase their own incomes. The Bishop's new manor of Wiggenhall seems to have been built up from assarts. Most of the land newly won for the bishop passed into new tenancies rather than be absorbed into the demesne, although a substantial amount followed that course, too.

By the survey of 1251 losses in some areas from the bishop's demesnes were almost balancing the gains elsewhere, and the second half of the thirteenth century looks more like a period of stability than expansion.

But even when the Black Monk houses of the fenland were not initiating reclamation, they were active in seeing that the duties of maintenance of walls and ditches, that they helped to allocate according to the custom of the fen, were still carried out.

Some reclamation took place on the lord's initiative, and some on the peasant's. Sometimes the peasant got the lord's permission beforehand, sometimes retrospectively, and probably sometimes not at all. Sometimes drainage was carried out by a whole community, and sometimes by a group of communities. This was especially so on the Marshland, and as a result its parishes were, until recently, in detached parts. Perhaps the most common way of getting fenland reclaimed is illustrated by a lease of a fen from the Abbot of Ramsey in 1196. The lease was to last for twelve years, after which the land was to be handed back with all the improvements made in the meantime. Never during the Middle Ages was there an authority which could initiate and carry out an overall policy for reclamation. The biggest work of which we hear is Morton's Leam, a cut twelve miles long, forty feet wide and four feet deep. It took the initiative of a bishop to carry such a large work through, although the sea banks when added together formed a very major work.

Such exercise of authority as took place over the fens in the Middle Ages attempted to correct failure to perform duties, or breach of custom. According to circumstances, this might involve almost any court from the manor up. Special Commissions could be instituted for particularly serious matters, and from the late thirteenth century these developed into what became recognised as the system of Commissions of Sewers. Even then such Commissions never clearly established their right to order new works.

The fens were only waste in the technical language of the time, meaning common lands. Not only were they extremely valuable for their normal produce, but using them improved them in the sense of fitting them for other more intensive uses. If the reeds growing at the edge of a mere were harvested and cut every year, that place would find the natural sequence of the fen deflected so that it grew only reed. If the cutting were only done every three years, sedge would be selected. If the fen were not cut at all it would develop Carr, a covering of alder, buckthorns, guelder rose and silver birch. Mowing and feeding, together, would produce lush grass in time and turn the fen into natural water-

-meadow, able to give two hay crops a year. Thus to use his common rights at all effectively, a peasant was almost willy nilly involved in the kind of piece-meal reclamation around the edge of the fen that went on all the time, and left the patterns like a skirt of spider's web around so many of our old villages. Pasture on peat land that had been fed for years by beasts, would handsomely repay breaking in to the plough. Breaking in normally took the form of paring the turf and burning it to get rid of the hassocks. After that the first crop was often oil-seed or oats, and other corn crops might follow for years on end without fallow or rotation. The normal fenland village would have its open arable fields above the flood line. Assarts and improvements that created fresh arable land might be amalgamated with these, or might be kept separate. Uncertainty might prevent new grounds from coming under the regular rotation, and frequent winter flooding might bring fertility for any crops that could be grown. The Adventurers' Grounds at Waterbeach, for instance, seem to have grown oats, supplemented by a little peas when the flood seems to have receded later than usual, for two centuries before enclosure.

Since the degree of flooding was so variable, the fenlander was repeatedly involved more deeply in the drier years, and forced to look to banks and drains to save his gains from the good years when they passed. At Willingham the problem of having to find money for expensive flood protection works, just at the times when the farmer had lost most of his income under the water, led them to attempt permanent provision. This they did by the simple expedient of shortening the measuring-rod used for dividing up the hay. The portion then left over was sold to defray the costs of flood defense.

But wholesale reclamation did not arise naturally from the problems and their solutions, as much as from the opportunity which the fens seemed to offer of fortunes to be found by speculation. Towards the end of the sixteenth century the nature of the discussion changes, and speculators begin to promote schemes to make fortunes by draining the fens. The background to the Great Draining when it came was that strange period of gambling in grandiose projects, anything that could be imagined as a way of making money. The Russell family, holders of the only really great estate in the Fenland, combine the old and new interests, the landlord thinking of flood protection and improvement of his estate, and the speculator. As early as 1590 they had brought over Dutch experts to survey the possibilities of effectively draining their own estate at Thorney.

Francis, fourth Earl of Bedford, undertook, by the so-called Lynn Law of 1630 to undertake the draining of the southern Fens for 95,000 acres of the land to be reclaimed by this. The technical expertise he obtained in the person of Cornelius Vermuyden, the Dutch drainage engineer. Halted by the Civil War, resumed in the Commonwealth and again in the Restoration, much of Vermuyden's scheme was carried out, but what was omitted at the time looks very like the solution of the cutoff and relief channels of 1954-64.

Even as Vermuyden was working with some success, there was a worsening in the long-term outlook. As draining became increasingly effective, and as drying fen was cleared, shrinkage and wastage of peat accelerated. Physical shrinkage of the peat as the water content decreased, oxidation as more was exposed to the air, bacterial decomposition, and soil erosion all played their part. For a time fenmen thought that their watercourses were 'growing from the bottom' as their beds grew first level and then superior to the surrounding peat fen.

The whole drainage system now divided into two, the high level trunk system for getting the water out to sea, and the low level system for lifting it out of the fields into the drains.

The high level system Vermuyden improved by straightening the rivers thus steepening the gradient, and increasing the rate of flow and the capacity to scour. He provided Washes, reservoirs for floodwaters that spilled over by setting back embankments from the main river. These would hold an immense amount of water until conditions became fit to discharge it again.

The peat continued to shrink, and more and more water had to be lifted from fields into rivers that now ran above them. What appears to have been the first windmill pump in our area was seen in 1604 at Over, but it is in the last quarter of that century, when the fruits of Vermuyden's work could be felt, that windmills proliferated. The process has been irreversible. Double lift windmills, steam engines from 1817, and diesels from 1913 and electric pumping to-day have come in in their turns to cope with the increasingly heavy demands for lifting water, as the level of the reclaimed fen has sunk.

4.3 Authority

From the Lynn Law of 1630, through the so-called Pretended Act of 1649, to the General Draining Act of 1663 a unified and comprehensive scheme for draining seemed possible. But division into North, South and Middle Levels made it easy to remove its powers piecemeal. The North Level was separated in 1753, the Middle Level in 1810, and although the Bedford Level Corporation was not finally abolished until 1920, most of its remaining powers by 1830 had gone to the Eau Brink and South Level. Before the middle of the eighteenth century local internal drainage boards were being set up by Parliament. These created what was probably the nearest English equivalent to Polders. An authority was created for the area concerned, with power to raise funds and carry out drainage schemes. The area would be banked round, and drained by ditches, tending towards the rectangular. A pump would be provided to lift the water from the ditches into the main drain outside. Such a scheme satisfied the natural instincts of the fenman, to pass the water on to the next parish as fast as possible. There are tales from the old days of the fens of attempts to relieve one's own banks by blowing those of the neighbouring parish, and of men disappearing for ever when found out of their parish in times of flood with gunpowder concealed on their persons. It was against such deep-rooted anarchic tendencies in the fens that the necessary unity was hard won.

By the passing of the Bedford Level Corporation in 1920, the distribution of authority was probably not much better than it had been in the Middle Ages when at least some religious houses and dignitaries were capable of mounting works greater in scope than the single manor or village. There were for instance no less than six separate sets of Commissioners responsible for the banks of the river Ouse. A series of measures have re-organised drainage authorities in recent years, setting up first river catchment boards, and finally Regional Water Authorities. So the present Anglian Water Authority is responsible for drainage in Essex as well as in the Fens, and for such duties as water supply and sewage treatment as well as drainage. Nevertheless, the Great Ouse Flood Protection Scheme, carried out from 1954 to 1964, seems to have produced the most effective drainage in the history of the Fens. The menace of floods appears to have receded; the menace of peat loss becomes more serious every day. The rate of peat shrinkage varies according to situation and the proximity of draining schemes, but we can see some measures of it over quite a long period from the Holme Post, a cast iron post sunk into the peat, level with the surface in 1851 when Whittlesey Mere was drained.

	Holme Post
Year	Height exposed
1851	0 inches
1860	57 inches
1870	92 inches
1875	98 inches
1892	122 inches
1932	128 inches

The rate of disappearance of the peat depends partly on the effectiveness of the drainage to which it is subjected, and the method of husbandry used.

We have been very concerned for some years with the long-term prospect for fenland farms as peat vanishes and infertile sub-soil is exposed. Professor van der Linden found that this process had reached the state where wheat could no longer be grown in the area which he was studying, by the end of the fifteenth century. The Dutch-Frisian pattern of settlement had been much more thorough and much earlier, and the original peat areas had been probably much greater. The surface of the peat, which was exposed so much earlier to drainage, must have been originally much higher than we see it to-day because of the length of time during which it lasted. The scale of reclamation in what appears to be a massive project of medieval colonisation, could scarcely have been carried out then if it had depended on pumping. It would be hard, if not impossible, to anyone familiar with the English Fenland not to be convinced by Professor van der Linden's exposition.

The patterns revealed on the map are so different from English patterns, and suggest the division of virgin lands into single family farms, each in its own ring-fence, and of a standardized shape and size. The English medieval fenland holdings, in so far as we know them, were hardly standardized at all, although there was some tendency towards a standard holding for each class of unfree peasant within the manor. There was much less equality than on the Dutch colonial lands. An English peasant's holding in the fenland would almost certainly consist of a homestead, with probably a very small toft and croft, on firmer soil, if only a roddon (the raised silty bed of an extinct watercourse), a modest holding of arable, probably intermixed with neighbours' land in some sort of open field system (although assarts outside such a system might have produced a different pattern), and outside and beyond this, extensive and valuable common rights in all the rich products which the fen had to offer. There have been recent attempts to deny that England ever had a peasantry, but in the fenland the English cultivator seems to deserve this description better than his Dutch counterpart.

Hall (1978), the Archaeological Officer for the Fenland, discovered a type of earthwork, different from anything noticed hitherto, which appears to result from planned reclamation in the thirteenth century. The scale is smaller than the blocks produced by the Dutch-Frisian system, and the individual strips are not complete farms.

The ditched strips which Mr. Hall discovered in Elm Parish were only about 12 yards wide and varied from 200 to 1,100 yards in length.

The pattern on the map suggests that they are a large area of reclaimed land added on to an older arable system with a lay-out more familiar in England. We have no evidence as to their method of cropping, or whether they were absorbed into any kind of common field system. In the meantime we await further discoveries by Mr. Hall, to help us understand whether the similarities or the differences between English and Dutch methods of reclamation have most to tell us.

Acknowledgement

The map was kindly made available by Mr. David Hall and the Cambridgeshire Archaeological Committee, to whom we are most grateful. A full account of Mr. Hall's findings has been published in Landscape History (1981).

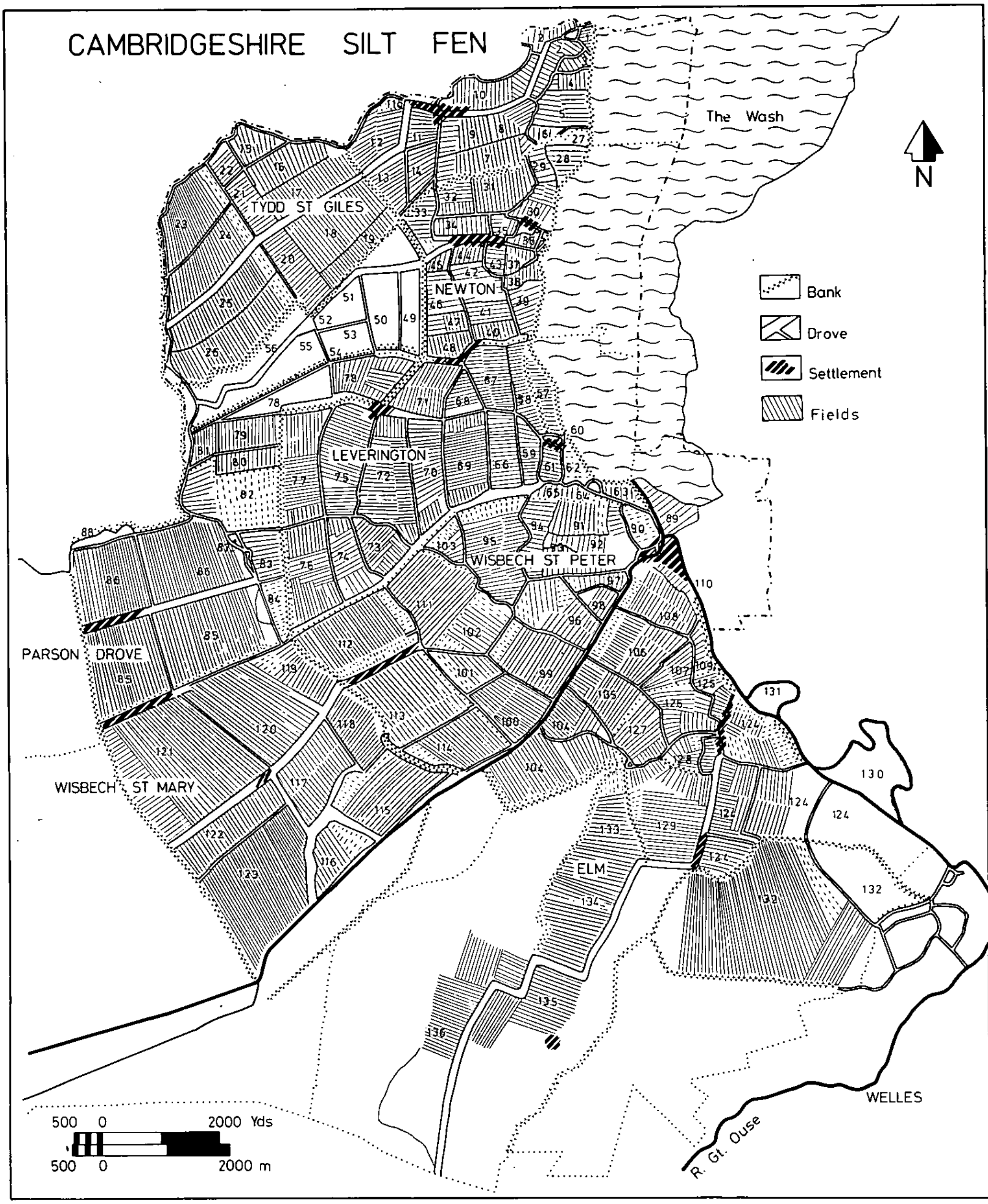

Figure 1 The long ditched strips appear to be a reclamation pattern virtually identical with those established in Van der Linden's paper as belonging to the early Middle Ages in the Netherlands. They contrast strongly with the patches of ridge and furrow of a more familiar type.

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5 SOILS AND THEIR GEOGRAPHY

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5.1 Introduction

A series of factors, mainly dealt with in the other papers, are responsible for the complicate soil pattern found in the western part of the Netherlands. This area is roughly situated between Amsterdam, The Hague, Rotterdam and Utrecht (see Van der Linden's Figure 1). It is a quiet, predominantly rural and, for Dutch circumstances, little urbanised area, it is popularly known as "The Green Heart of Holland". Agricultural activities are mainly dairying, further arable on the calcareous soils of the drained lakes, flower bulbs on the excavated dune sands in the west, flowers in greenhouses both on the peat lands and on the calcareous soils of the drained lakes, and ornamental shrubs on the peat lands of Boskoop. Catchwords summarising items discussed in the other papers are: deposition of marine sediments four to five meters below todays sea level, gradual rising of the sea level, nearly closing of the coastal barriers, paludification of the enclosed lagoon, upward growth of the peat, differentiation in big islands of raised bogs surrounded by wood peats with peat streams draining into a lower branch of the Rhine, the Big Reclamation, drainage by gravity, subsidence, drainage by pumping (windmills), development of Drainage Boards, peat cutting, man-made lakes, draining of the lakes. The Figures 1, 2 and 3 are another attempt to elucidate the natural and human activities which made western Holland.
The topic of this paper is to describe the soils and their geography, which properties can only be comprehended if their intricate history is known.

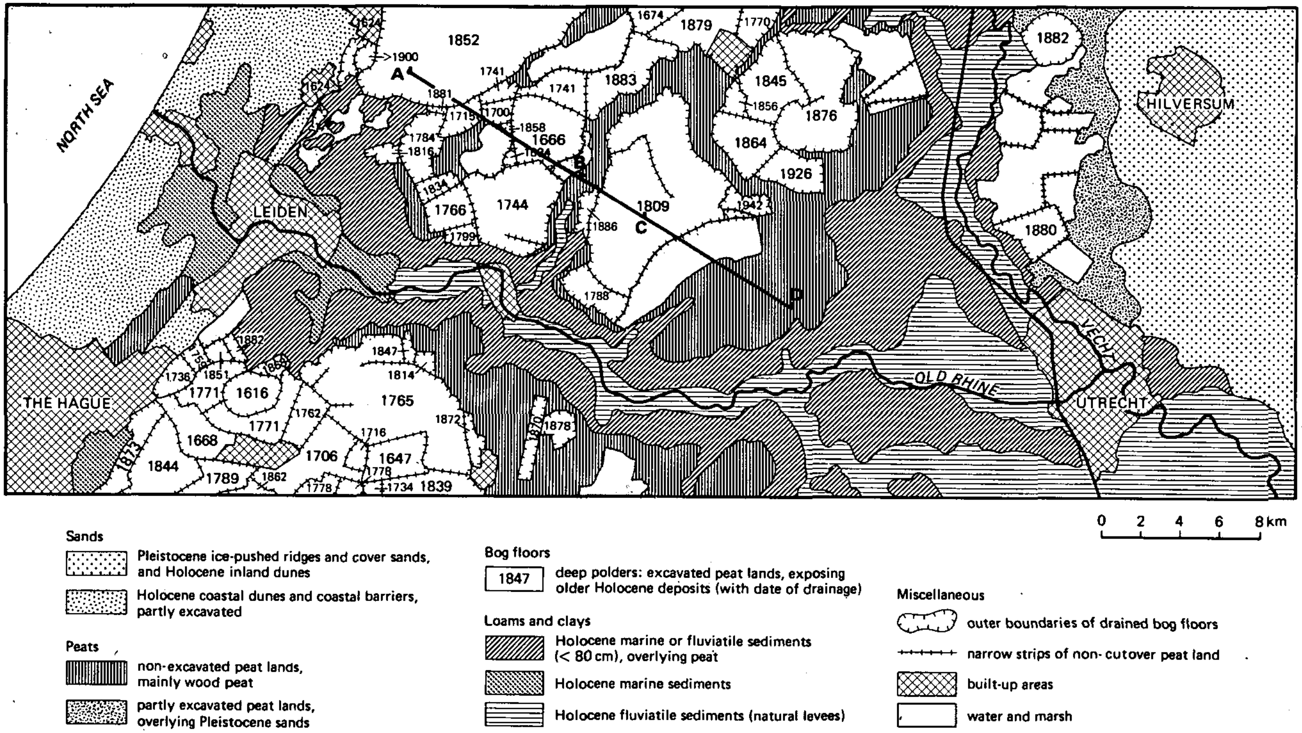


Figure 1 The main area of the drained bog floors and the remaining non-cut over peat areas between The Hague and Utrecht; Amsterdam is just north and Rotterdam further south of this area. A–D indicates the location of the transect from Figure 2, and B–C could be the location of the story given in Figure 3. This rough physiographical map is generalised from the Soil Map of the Netherlands, scale 1 : 50 000, sheets 30 E, 31 W and E, and 32 W.

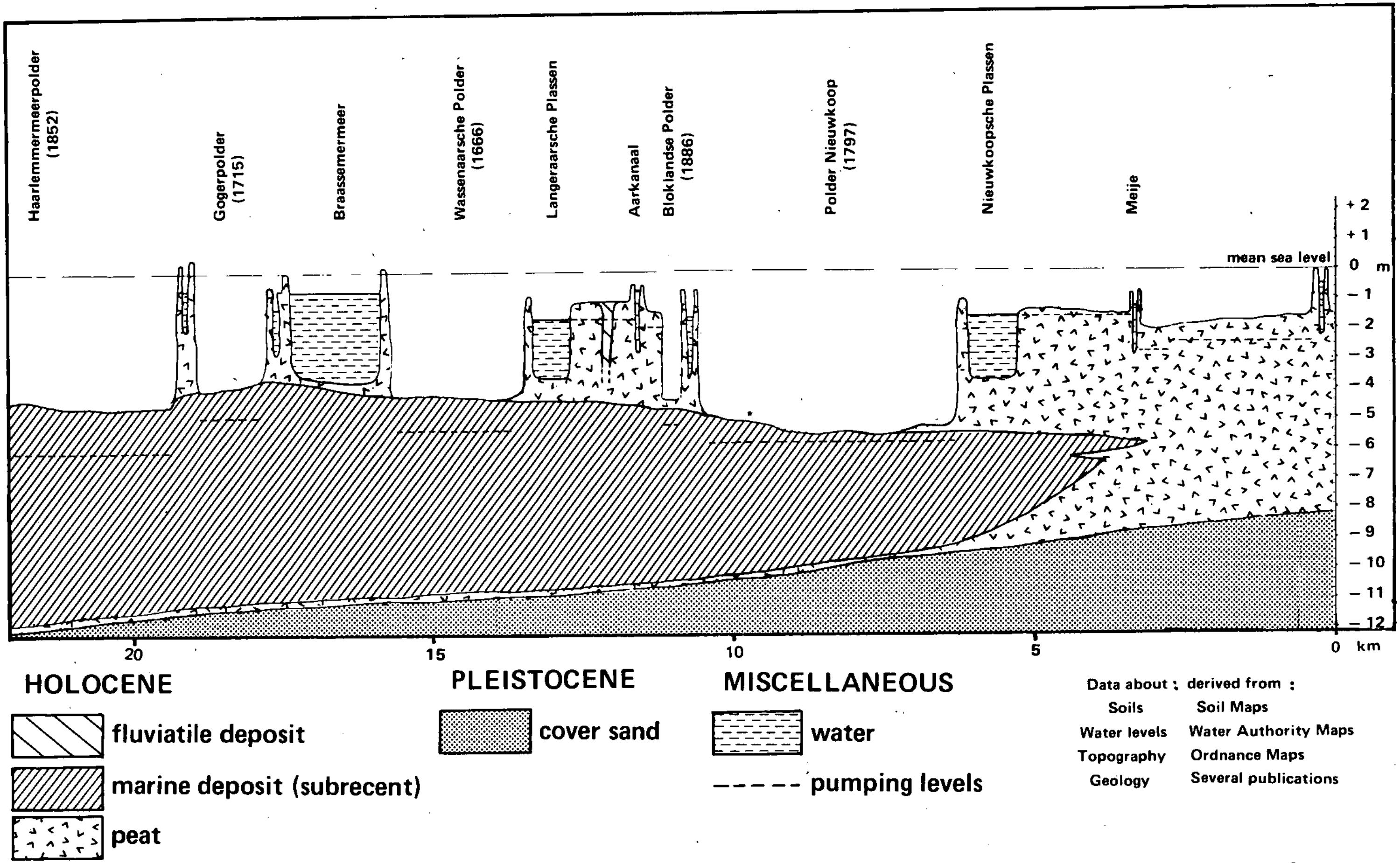
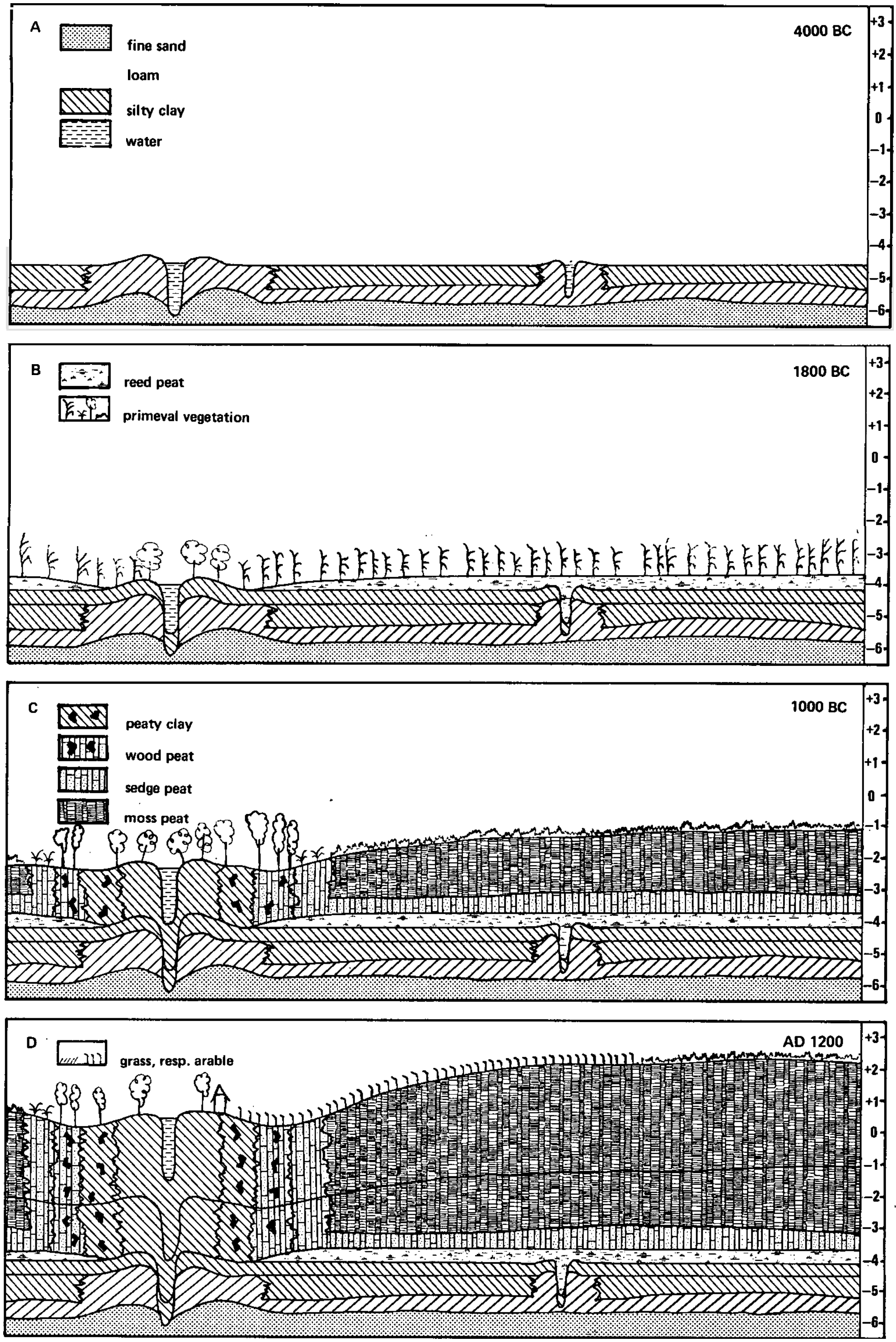
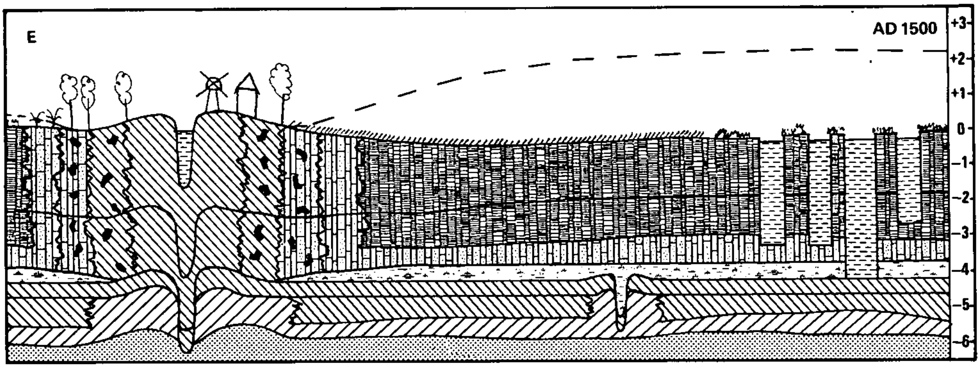


Figure 2 Transect indicating the elevation of the pumping levels, of the non-cut over peat lands and of some reclaimed bog floors and their reclamation dates (cf. Figure 1).



A
fine sand
loam
silty clay
water
4000 BC
B
reed peat
primeval vegetation
1800 BC
C
peaty clay
wood peat
sedge peat
moss peat
1000 BC
D
grass, resp. arable
AD 1200
+3
+2
+1
0
-1
-2
-3
-4
-5
-6



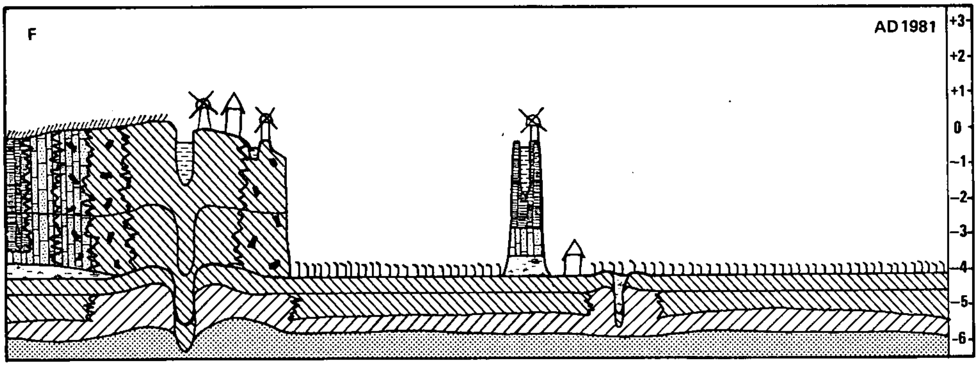


Figure 3 Sketch of the genesis of the area of Figure 1. The elevation is indicated in metres plus or minus todays sea level.

A. Calais deposits (cf. Bijlsma, Table 2) with tidal creeks.

B. the sea retreats, reed peat blankets the flats and many small creeks, the bigger ones drain the bogs into the Rhine.

C. the fens change into raised bogs, eutrophic river influence alongside the peat drains, which are laterally filled in with fine-textured sediments during high discharge of the Rhine, their upward growth keeping pace with the raising bogs.

D. the beginning of the Big Reclamation (cf. Van der Linden's paper): peat streams fringed by gallery forests act as starting lines for the settlers, the higher situated raised bogs could be easily drained by gravity and reclaimed as arable lands.

E. due to subsidence (cf. Schothorst's paper) drainage detiorates, introduction of pumping (cf. Van der Molen's paper), arable land changes into grassland, starting of peat cutting.

F. todays situation: the ash-poor peat has been cut for fuel De Zeeuw, 1978), the resulting lakes are drained and reclaimed.

5.2 General soil conditions

The area of Figure 1 has roughly six soil-landscapes:

a. the Pleistocene area in the east,
b. the coastal-dune area in the west,
c. the estuarine soils in the mouth of the Old Rhine,
d. the riverine soils of the Old Rhine and the Vecht,
e. the non-cut over peat lands, and
f. the area of the deep polders.

The first four areas will be dealt with cursorily, the peat lands and the drained bog floors will be discussed in more details in next chapter.

5.2.1 Pleistocene

The Pleistocene deposits (all sands) in the east dip below the Holocene deposits at about todays sea level, they slope gently to the west (Fig. 2), and pass the coast at about 18 m below sea level (cf. Bijlsma's Fig. 2). Hilversum is situated on an outcrop of preglacial river sediments, pushed up into low hills by the Saale ice (20 m above sea level). The footslope of these hills and all pleistocene sands below the Holocene deposits on Figure 1 consist of cover sands, a fine aeolian sand.
The soils are podzols (spodosols). As far as the ground water is deep, land use is mostly pine forest and some heath land, as far as the ground water is shallower, these podzols are in arable and grass. Locally the cover sand is eroded and blown into inland dunes.

5.2.2 The coastal dune area

On the inner side of the beach there is a narrower or wider strip of coastal dunes, rising locally to 30 m above sea level. In most coastal areas sea defences are artificial (dikes or sea walls), but the Green Heart of Holland is safeguarded by these dunes. Except some roads and footpaths it is forbidden area. The still moving outer dunes are more or less fixed with marram grass (Ammophila arenaria) which can stand, even needs, shifting sands; the inner dunes carry a natural vegetation, diffe-

rentiated after lime content exposition etc.
The inner dunes are much lower, often superficially decalcified. These dunes and also older coastal barriers not or hardly covered with dunes, are mostly excavated down to about half a metre above the everywhere present fixed boezem level (which is 60 cm below sea level). There is a continuing need for sand in urban areas (road building, sand-lime bricks) but it was also used on dairy farms in the stables (see below).
These excavated humus-poor sands are excellently suited for bulb-growing, and the famous colourful Dutch bulb fields are nearly exclusively situated on these soils. The intermediate beach plains between the excavated dune ridges are often peaty or covered with thin estuarine sediments from the mouth of the Old Rhine, and used for dairying.

5.2.3 The estuarine soils

These are situated around Leiden, the upper part of the parent material was deposited in the few ages before the clogging of this Rhine mouth in the middle of the twelfth century (cf. Van der Linden's paper), so it belongs to the Dunkerque III Deposits (Table 2 in Bijlsma's paper). Locally this material was used for firing tiles and bricks in brick kilns. The area northwest of Leiden is raised with dune sand mixed with mud and manure thus improving drainage and texture for horticultural purposes. Land use is mainly grass, some arable and on the above-mentioned improved soils horticulture (flowers, both in the open and in greenhouses).

5.2.4 The riverine soils

The rivers Old Rhine and Vecht (Fig. 1) originally were lower branches of the Rhine (today the Rhine water reaches the North Sea 50 km more south). Both have narrow levees with brown medium- and mottled grey fine-textured soils overlying coarse riversands. Laterally these soils grade into shallow silty clays overlying wood peat. On most places alongside these rivers this levee belt between the clay-over-peat soils is only 500 m wide. In the eastern part of Figure 1 the levee of the Old Rhine is excavated over a relatively large area to a depth of about 1 m, the material was used in brick kilns.

Most of the soils are used for dairying, some for horticulture. The excavated soils are drained and used for orchards, there are some problems with magnesium because of the high lime content (up to 20%).

5.3 The peat lands and the drained bog floors

The area of Figure 1 encloses about 150 000 ha of land. Roughly 20 000 ha is urban area, originally nearly all on either the inner coastal barriers, or on the levees of the Old Rhine and the Vecht, or on the Pleistocene sands. The more recent urban developments spread over the clay-over-peat and the peat areas with all their problems (cf. Van den Kerkhoff's paper). About 15 000 ha is non-excavated peat lands, mainly wood peat and another 25 000 ha has a peat subsoil within 80 cm depth of marine or fluviatile upper sediments, and about 30 000 ha of Figure 1 consists of drained and reclaimed bog floors. Some data about the reclamation history of all reclaimed inland lakes (either caused by peat cutting or by peat erosion) are given in Table 1.

Table 1 Polders reclaimed from shallow lakes (bog floors) in the provinces Noordholland, Zuid-Holland and Utrecht (excluding polders in the former Zuyder Zee). After De Bakker, 1979

Enclosure between:	1500 – 1550	1550 – 1600	1600 – 1650	1650 – 1700	1700 – 1750	1750 – 1800	1800 – 1850	1850 – 1900	1900 – present4)
Acreage (ha)	82	2228	26985	1495	3456	21882	9585	42007	1648
Number of polders	2	17	48	4	7	24	1	68	8
Average acreage1) per polder (ha)	-	147	688	374	494	912	682	7352)	206
Largest polder (ha)	65	620	7100	960	1125	3975	4355	181003)	50
Smallest polder (ha)	17	5	6	170	270	85	5	4	34

1) Excluding polders less than 25 ha.

2) Average acreage excluding the polder of 18100 ha: 425 ha.

3) Second largest polder: 3015 ha.

4) Last polder was reclaimed in 1942.

5.3.1 The non-excavated peat lands

As is stated earlier in this paper and also in the other papers, the ash-poor moss peat and also nearly all sedge peat has been excavated for fuel (see also De Zeeuw, 1978). The non-cut over peat that is left, is nearly exclusively the clayey wood peat. The hundreds of years drainage (although shallow, cf. Schothorst's Introduction), the manuring, liming and fertilisation, have changed the upper part of the soil considerably. This process has been called "earthifying" (= to change into earth) by the Dutch, and it is comparable with what the Poles call moorsh- or muck-forming process (Kowalinski, 1964; Okruszko, 1972).
The Dutch never did investigate this process chemically, but did a lot of micromorphological work (e.g. Jongerius und Pons, 1962). A peat soil is called an "earthy peat soil" in the Dutch soil classification system when the Al horizon is thicker than 15 cm and has hardly recognizable peat structure (De Bakker en Schelling, 1966).
A second process on these earthy wood peat soils in this part of the Netherlands is a manuring practice (now obsolete). Sand from the excavated dunes was used in the stables and mixed with mud and manure spread over the land, was caused a higher sand content in the topsoil (the left soil from Fig. 4 and the first soil in Table 2).
From the 15000 ha of peat soils on Figure 1 12000 ha have this sandy-mucky man-made topsoil.
In a small (500 ha) horticultural area west of the lake which is situated south of the large polder reclaimed in 1852, the soils have a topsoil thicker than 50 cm without recognizable peat structure. Under intensive horticulture using all kinds of compost, manure, sand and organic mud dredged from the ditches a thick sandy-mucky (25% o.m., 15% clay, 50% sand) layer was made on top of the original carex-phragmites peat.
These peat lands are mainly used as grassland for dairying. There are a few horticultural centres where flowers in greenhouses are grown (carnations, roses and chrysanthemums) and also vegetables. An important crop near Aalsmeer are lilacs, and in Boskoop ornamental shrubs.

5.3.2 The reclaimed bog floors

From the about 100 000 ha of reclaimed bog floors (Table 1) 30 000 ha occur on Figure 1. From this area 20 000 ha are mineral soils developed in Calais deposits, 500 ha have less than 40 cm peat and 500 ha have more than 40 cm peat, left behind by the peat cutters in the deeper sites of the former tidal flats. The mineral soils mostly have a dark humose topsoil and the texture varies between sandy loam and silty clay. The shallow peaty soils often overly a silty clay which is very acid. Two soils (Fig. 4 and Table 2) will be discussed shortly.

Table 2 Some analytical data from the soils from Figure 4 (De Bakker, 1979).

	org.m. %	C/N	pH-KCl	$CaCO_3$ %	clay %	silt %	sand %
Peat soil							
topsoil	45.3	13	5.2	n.d.	33	42	25
subsurface	23.1	10	5.2	n.d.	54	31	15
subsoil	67.4	20	5.8	n.d.	46	49	5
Acid sulphate soil on bog floor							
topsoil	22.0	12.6	5.6	0.3	43	50	7
subsurface	8.8	n.d.	3.4	0.1	56	43	1
subsoil	6.8	n.d.	3.7	0.2	57	43	0
loamy calcareous soil on bog floor							
topsoil	7.5	11	7.0	1.8	23	36	41
subsurface	4.0	10	7.1	7.9	23	41	36
subsoil	1.1	n.d.	7.4	13.0	10	19	71

The middle soil from Figure 4 is an acid sulphate soil, soils discussed at length during a congres in Wageningen (Drost, 1973). Below a thin layer of peaty clayey material, a limnic deposit dating from the lake-stage (after peat cutting and before drainage) often a remnant of peat (mostly reed peat) is present, overlying a mineral subsoil. The upper part is

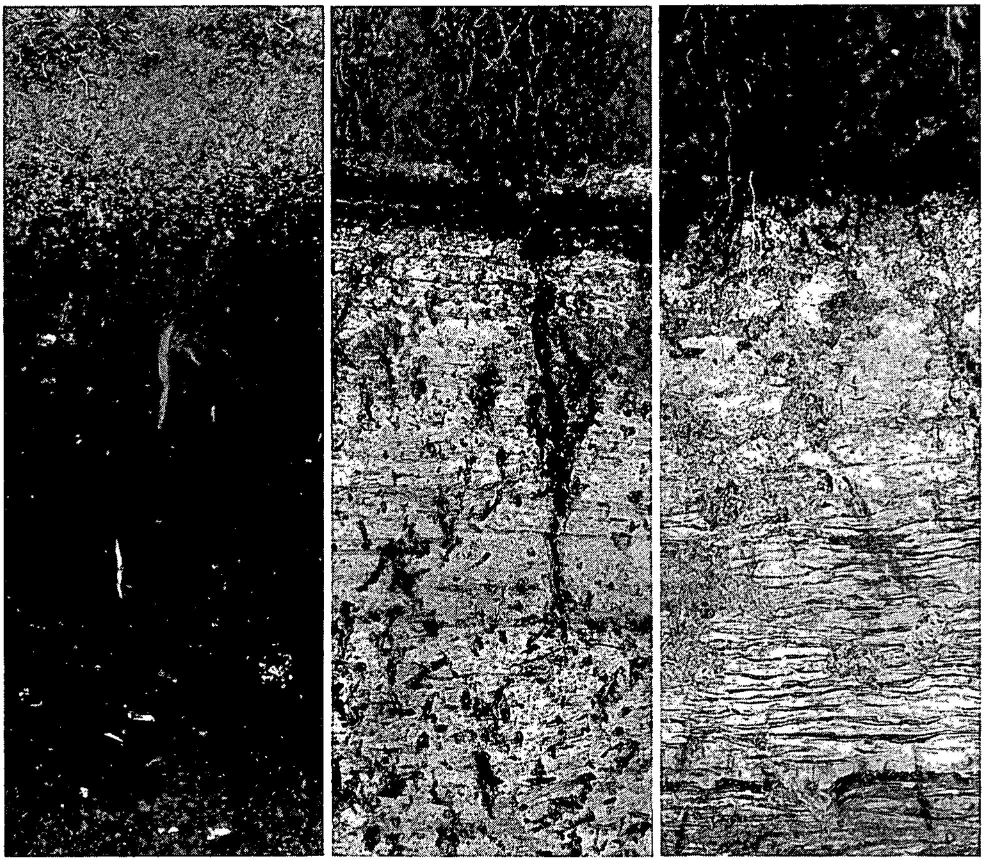


Fig. 4 Three soils (depth 1.20 m) from the area of Figure 1.
Left: a non-cut over wood peat soil, with a sandy man-made topsoil, a clayey mucky subsurface layer overlying wood peat, oxidised to a depth of 65 cm.
The other two soils are from the bog floors, the drained cutover moss peat areas. They are developed from marine sediments deposited 4000 to 5000 years ago.
Middle: an acid sulphate soil, with a topsoil derived from peaty lake mud overlying a thin remnant of peat, on a very acid, partly oxidised silty clay (cat-clay) rich in sulphates with a non-oxidised soft subsoil rich in sulphides.
Right: a loamy soil, with a mixture of marine calcareous loam and peaty lake mud on top, and a loamy calcareous stratified subsoil. (Photos Soil Survey Institute R29-20, -6 and -5).

oxidised, and the sulphides present in the old marine silty clay oxidised into jarosite and sulphuric acid, thus producing an acid layer, called cat-clay by the Dutch farmers. Still deeper the subsoil is still unripened (soft, water rich and non-oxidised) a potential cat-clay.
Such soils are used exclusively as grassland, in the last decades these topsoils have been considerably improved by liming, their subsoils still being acid (Table 2).
The non-acid soils partly are calcareous and medium-textured, like the third soil from Figure 4 and Table 2. The upper part consists of lake mud mixed by ploughing with the calcareous subsoil. This is finely stratified, and often highly calcareous. However they have a different genesis, these soils in some properties are comparable with hydromorphic chernozemic soils: base-saturated, loess-like in texture, dark humose topsoil, low C/N ratio, krotowinas in the subsurface soil.
These soils are all tile-drained and excellently suited and used for a wide range of crops: wheat, potatoes, sugarbeet, barley, colza, peas and in the last decade an important crop is maize for silage. They are also first-rate grassland soils. As Hidding states in his paper some rose growers have moved from the peat lands to these drained bog floors, also other horticultural crops are grown on these calcareous soils.

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6 REVIEW OF CHAPTER 5

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The review of the paper was based on the following assumptions:

1) Soils of the Netherlands' region in question belong to those utilized at the longest and most intensively in Europe. They occur in areas subjected to various forms of a strong anthropogenization.
2) Soils developed from peat are very labile and undergo far advanced transformations under the effect of various human activity forms in the natural environment.
3) Peat soils characterized in the paper represent the types which are developing and will develop on peatlands in consequence of different kinds of human activity.
4) Recognition of these soils, their classification and evaluation are of significant importance from the viewpoint of forecasting conditions for agricultural or horticultural production on peatlands in the future.

The author of the paper reviewed distinguishes in the area in question two groups of soils. They are:

a) soils of non-excavated peatlands,
b) soils of the reclaimed bog floors.

He distinguishes with in the first group:

- peat soils transformed by a natural soil process, stimulated by their agricultural utilization,
- peat soils transformed both by the soil process an by different materials added to them, first of all, manure with sand.

In the second group the author distinguishes:

- soils formed from the mineral substrate rich in humus, but without any peat admixture,

- soils formed from the mineral substrate and remnants of peat as well as from mud from the lake formed after peat cutting.

Soils of this group differentiate into types depending on the kind of mineral substrate, on which they developed. There are quite different soils formed from oxidised and silty clay, known as cat-clay, as well as those formed from a calcareous, medium-textured material, which with regard to their properties approximate hydromorphic chernozemic soils (named also black soils).

Comments to the soils presented in the paper are as follows:

First of all, it is to stress that among classifications of peat soils applied in the world only two classifications - Dutch and Polish - distinguish, formally since many years, two main types (Okruszko and Piaścik, 1979):

- soils of undrained peats, being in the peat accumulation phase,
- soils of drained peats subjected to oxidation, in which drying up and disappearance of the organic matter of peat is taking place (decession phase in the peatland evolution).

Similar view as regards the classification principles of peat soils, although formulated still too generally, is represented recently in British, Soviet, GDR and Hungarian classifications.

This question is of significant scientific and practical importance and requires an explicit formulation, particularly in view of assuming by particular countries the classification after the USA Soil Taxonomy.

The basis of the USA classification is, besides geographic situation, the peat mass humification state in the subsurface tier at the depth of 30-90 cm (in sphagnum peats 60-120 cm) and in the bottom tier (90-130 cm or 120-160 cm) taking into account to a quite little extent the topsoil tier (0-30 cm) character. However, the properties of the latter determine the root growth conditions, and consequently the level of crop yields, as well as tillage and utilization conditions of these soils.

This problem was discussed in detail by Dinç, Miedema, Bal and Pons (1976), who stated: 'we consider the classification system of the Soil Taxonomy for the Histosols very unsatisfactory' (page 262). I support this opinion. I regard as indispensable to take into account in the classification of peat soils the soil process running in them and transforming these labile soils since the moment of their first drainage.

It is also necessary to determine in detail the kind of soil material occurring in the topsoil tier.

Investigations of peat soils in the aspect of the process occurring in them after drainage, defined by us as 'moorsh-forming' soil process, are carried out in Poland intensively for 30 years.

Results of these investigations prove distinctly the purposefulness of taking into account in the classification:

1) soil transformation state under the effect of moorsh-forming process, what is expressed by the thickness and character of the peat mass and its transformation state in the topsoil layer; this is correlated with the kind of peat, from which the soil is developed, first of all with its decomposition degree and with the drainage depth of the given peatland,
2) occurrence in the topsoil layer of soil material other than peat, formed in consequence of natural phenomena (e.g. inundation) or under the human activity effect (adding sand to the topsoil, manuring, spreading of mud, etc.),
3) magnitude of the fresh humus influx (from decomposition of plant matter, mainly roots of plants), which determines the soil structure and air-water conditions in soil connected therewith.

The soil process running in the drained peat soil changes its physical properties (Table 1) and chemical composition (Tables 2, 3), mainly in the topsoil layer.

Table 1. Characteristics of physical properties of moorsh-peat soils

Soil		Layer in cm	Ash content %	Bulk density g/cm^3	Total porosity % of volume	Volume of pores		
						macro	meso	micro
Weakly moorshed soil from		0- 30	18.2	0.200	88.0	15.1	53.1	19.8
fibric peat	Mt I aa	30- 80	8.1	0.122	92.3	25.4	55.5	11.4
Typic Medifibrist	n = 4	80-130	10.1	0.119	92.4	25.8	53.7	12.9
Weakly moorshed soil from		0- 30	17.5	0.201	88.0	16.7	49.0	23.3
medium decomposed peat	Mt I bb	30- 80	10.5	0.135	91.4	23.6	53.4	14.4
Typic Medihemist	n = 4	80-130	11.2	0.128	92.0	26.0	50.4	15.6
Medium moorshed soil from		0- 30	20.4	0.237	86.2	14.5	47.0	24.7
medium decomposed peat	Mt II bb	30- 80	11.6	0.156	90.3	18.9	52.9	18.5
Typic Medihemist	n = 5	80-130	10.7	0.134	91.6	23.0	49.8	18.8
Medium moorshed soil from		0- 30	15.5	0.220	86.8	19.3	39.9	27.6
strongly decomposed peat	Mt II cc	30- 80	13.1	0.155	90.5	21.7	46.7	22.1
Typic Medisaprist	n = 6	80-130	19.3	0.164	90.4	21.1	49.4	19.9
Strongly moorshed soil from		0- 30	17.6	0.304	81.8	23.9	24.7	33.2
strongly decomposed peat on		30- 80	12.4	0.179	89.0	23.0	39.8	26.2
medium decomposed peat	Mt III cb	80-130	8.3	0.107	93.1	21.1	59.9	12.1
Hemic Medisaprist	n = 5							

Table 2. Mineral elements enrichment or impoverishment coefficients of the 0-5 cm soil layer in relation to the layer on the depth 45-50 cm as a result of moorsh process in peat soil (Sapek, Gotkiewicz 1977)

Element	Peatland utilization			
	Grassland		Arable land	Forest
	not fertilized	fertilized	fertilized	not fertilized
Ash	1.31	1.11	1.08	1.56
K	3.39	2.62	3.33	3.50
Mg	1.06	0.93	0.65	1.30
Ca	0.59	0.48	0.40	0.71
Fe	1.30	1.17	1.24	1.65
Al	5.00	3.90	3.20	3.68
P	3.70	3.55	2.66	3.90
Cr	1.70	1.70	1.14	1.84
Mn	2.20	1.65	2.24	3.40
Zn	4.15	2.65	1.60	6.00
Cu	1.40	1.04	4.20	0.89
Co	2.50	7.50	3.50	7.70
Ni	0.91	0.96	0.72	1.57
Pb	35.5	80.0	10.90	31.8
Cd	64.0	91.0	6.75	28.6

Table 3. Characteristics of humus compounds in the profiles of moorsh-peat soils (Okruszko, Kozakiewicz 1973)

Compounds		Layers in the soil profiles				
		0-10	10-20	20-30	50-60	80-90
Fulvic acids in % of C:						
in weakly moorshed soils	n=7	15.3	11.8	9.2	9.3	8.4
in strongly moorshed soils	n=3	15.3	17.5	17.6	18.4	13.2
Humic acids in % of C:						
in weakly moorshed soils	n=4	39.9	39.4	40.1	36.7	34.7
in strongly moorshed soils	n=3	44.5	48.4	52.8	55.2	53.2
Ratio of humic to fulvic acids in soils:						
weakly moorshed		2.3	3.2	3.4	3.5	3.6
strongly moorshed		2.6	2.7	3.0	2.9	4.0
Hymatomelanic acids in % of D.M.	n=3	0.0	0.35	1.14	3.13	3.92
Total N content in % of D.M.	n=7	4.84	4.41	4.29	3.88	3.75
C: N in soils	n=7	11.8	13.2	14.2	16.0	17.2
in humic acids	n=9	11.8	12.1	12.5	13.2	13.2

n=number of samples

A very important factor in the differentiation of peat soils is the peat thickness reduction as a natural process connected with subsidence or caused by man (peat excavation), or other phenomena, as fires, eolian erosion, etc. They lead eventually to developing soils formed from peat and mineral substrate. The area of such soils is widening proportionally to the utilization time of peatlands.

Results of the Polish investigations in this field approximate those presented by De Bakker in the paper reviewed. We have found the formation of kinds of black soil (hydromorphic chernozemis soils) on mineral loamy substrates rich in $CaCO_3$. They are very fertile soils, of a high value for agriculture. In case of sandy substrate poor in lutum, soils defined in Poland as "moorshy" or mucky-like ones, composed of sand and humus, are forming. The humus content in such soils amounts to 10-20%. This amount of the organic matter gives them other properties than those characteristic for humic sandy soils with a humus content of 5-10%. In Dutch literature (De Bakker 1966) such soil materials are defined as peaty sands. Humus of the soils is liable to drying up and after drying it can be separated on sieves from sand. They do not form any complex compounds with mineral part of the soil. They can undergo irreversible dehydration. These soils, when intensively manured and utilized, can give high yields, on the necessary condition of application of organic fertilizers or green manures, increasing the fresh humus amount in them. This kind of soils is not mentioned in the paper by De Bakker. It can be presumed that they would occur on reclaimed bog floors on sand.

The question of the mud participation in the formation of organic soils deserves attention. Mud is formed on the area of cut-over bogs occupied by marshes. This soil formation differs from peat with regard to genesis, character of its mass and properties. There are hitherto only few data in the literature concerning mud, what was stressed in our previous works (Okruszko 1979, 1980). Mud is not of a fibrous structure typical for peat; it is formed in a hydrous medium with humified organic matter mixed with mineral sediments. Hence it is rich in complex organic-mineral compounds, and thus resistant, contrary to decomposed peat, to irreversible dehydration.

Organic soils presented in the paper by the reviewed author (and in his other works), formed under conditions of a long-term and differentiated utilization of peatlands, allow to conclude that the question of their classification would require to be worked out on an international scale. It is necessary to establish the criteria of characteristics and classification of organic soil materials. It concerns basic initial homogenic materials, such as peat, mud, gyttja, as well as heterogenic ones, consisting of the mixture of basic soil materials. Also secondary soil materials can occur in consequence of transformation of the initial materials in the system of soil processes and under the human activity effect. Also definition and characterization of soil processes occurring in organic soils and leading to their modification, being of importance for properties of soils and productive value, are necessary. It is the task, which should be undertaken by the IPS jointly with the International Soil Science Society.

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7 WATER MANAGEMENT IN THE WESTERN NETHERLANDS

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7.1 Introduction

The water management system of the Western Netherlands is almost entirely artificial; moreover, it is extremely complicated. At first sight the country looks flat and rather monotonous. But it is not; even at short distances there are differences in land- en water-levels amounting to several meters.
A second peculiarity is that almost all lands are lying below sea level, the deepest places being more than 5 meters below. Finally there appears to exist a great variety in water management systems and in water levels and an almost complete control of these levels.
The water management system, as it appears at present, is the result of human interference with nature, a process that has lasted continuously for nearly 1000 years. Through this age-long activity, man has transformed the region completely, even to such an extent that it is very difficult to reconstruct its initial, natural state and even more so to imagine its original outlook.
Nevertheless, to understand the present situation, we need a picture as accurate as possible of the original situation. In recent years new findings, both from history and from soil science, have contributed new knowledge of this remote past. But still many points are not clear.
After a short description of this initial state, we will deal with the successive stages of development, because almost every generation has left its marks on this landscape.

7.2 Situation around 1050 AD

In Roman times, the Rhine river, coming from Germany, formed the limit of the empire. In our region, its principal branch flowed along the Roman settlements of Utrecht and Leiden and reached the North Sea slightly further to the West, near Katwijk. This branch is no longer in actual contact with the Rhine river, though it is still called "Oude Rijn" (Old Rhine).
Another branch, the Vecht, flowed from Utrecht northwards. Several smaller rivers and creeks were associated with these two large streams. Around the year 1000 AD this Oude Rijn-Vecht system had already considerably declined. At its waning stage a dam was constructed further upstream, which finally severed its connection with the main river.
Along the Oude Rijn and Vecht, and dating from times that these rivers still carried sediments, broad natural levees occurred, consisting of loamy soils with sandy subsoils. Also along the associated smaller streams and creeks, narrow clay strips had been deposited. As a consequence of the clogging further upstream, water levels in these rivers became lower, and settlement on these clay strips became more attractive. We may, therefore, expect some cultivation of these strips along the rivers, with wilderness beginning immediately behind. This wilderness consisted of peat. Where occasionally flooded by river water, eutrophic to mesotrophic peat, mainly woody peat, was forming, which was admixed with some clay. Further away, oligotrophic sphagnum peat formed exten-

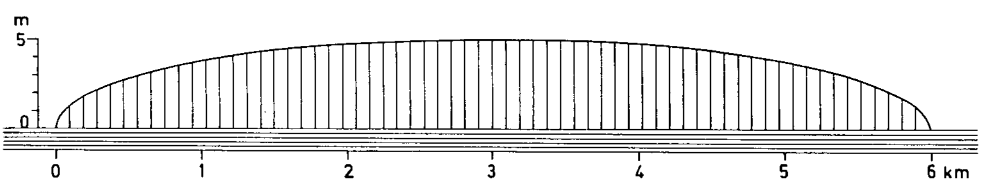


Figure 1 Average cross-section of 64 raised bogs in northwestern Germany (height scale exaggerated 125 times). After Eggelsmann (1980).

sive raised bogs, which in their centers were probably several metres above the riverine lands (cf. figure 1).
In view of these circumstances, only few people lived in the area, most of them along the main rivers Oude Rijn and Vecht.

7.3 Early water management

The wilderniss belonged to the government, in this region the Countship of Holland in the West and the Diocese of Utrecht in the East.
Since about 1050 AD both governments conducted an active policy to reclaim and colonize the area. In a systematic way concessions were given out to colonists, block by block. In such a block each homestead obtained a stretch of land along a river or creek and the right to reclaim a well-defined tract of wilderness behind this stretch. Reclamation of this tract has probably been a long process. It was carried out by cutting ditches from the river into the peat and it finally led to long, rather narrow strips of land, separated by parallel ditches. Neighbouring farms all have the same length, their ends indicating the limit of the administrative unit to which they belong, which unit was coincident with the old concession (see Van der Linden's paper).
As the raised bogs were elevated above the river level, their drainage was easy. Probably it was even facilitated by the outlet towards the river system of Oude Rijn and Vecht, which had lost its upstream connection with the main river and which , therefore, must have had relatively low water levels.
But this favourable situation did not last. The Oude Rijn river, conveying much less water than in earlier times, could not maintain its mouth through the sandy dune area near Katwijk. It finally became clogged at this point around the year 1150 AD. This completely disturbed the drainage of the area, where just at this time, colonization was in full swing. Consequences were grave. The Count of Holland, in order to protect his area against water from the neighbouring territory, built a dam near his boundary with the Diocese of Utrecht, thus totally blocking the discharge from these upstreams lands.
As a consequence several settlements in this part of the area had to be abandoned. Moreover, this drastic measure did not give much relief to

the Count's own area either and no further concessions could be given out. The conflict between Holland and Utrecht rose to the highest level of decision: Emperor Frederik Barbarossa visited Utrecht in 1165 and in 1202 a treaty was signed between parties. The Emperor ordered the dam to be removed, but to revive the old river - now closed at both ends - a series of canals were dug. These canals lead the water northward, via a chain of natural lakes and finally to the sea near Haarlem. Of these works, part had to be financed by Utrecht.

This large-scale solution ended the time of incidental and local measures and introduced general water-management in areas of over 100 000 ha. The authority, responsible for water-management in the area, Rijnland, is known since about 1200. Not only was the entire drainage system reconstructed, but soon it was also separated from the sea by damming river mouths and by construction of protective dikes along the coast. Names of Amsterdam, Rotterdam and - for our region - Spaarndam bear witness of these activities. These dams and dikes could keep out high tides, and especially the dangerous storm surges. Sluices in the dams provided drainage at low tide. There are two types of such sluices: outlet sluices, which provide drainage only and shiplocks, which also allow the passage of ships. Such a shiplock in the Spaarndam near Haarlem was mentioned in 1255: the merchants of the City of Haarlem, deprived of their shipping wanted to construct a shiplock, but the officials responsible for the dam objected fiercely. The Count of Holland, who had already given permission for the construction, had to promise that no steps should be taken without consulting the officials of the Spaarndam.

This unified system of former rivers, natural lakes and canals is known as a *boezem*. Separated from the sea, it allowed to establish a water level slightly below mean sea level, because water could be discharged at low tide, whereas at high tide the sluices were kept closed.

The improved drainage allowed to resume the reclamation activities in the interior and already around 1300 AD almost the entire area had been given out and colonized.

In the remarkable short time of a few centuries, a vast wilderness had been transformed into a well-populated agricultural region. Drainage must have been rather good: from taxation accounts it is known that considerable sums were raised from taxes on grain grown in the area.

A problem is still how the early colonists managed to overcome the inherent infertility of the sphagnum peats, which covered about half of the area. They will certainly have spread the soil dredged from ditches over the land and will have used manure. There are indications that they even dredged into the underlying old sea clay, perhaps for the purpose of improving an infertile soil.

7.4 Gradual deterioration of the drainage

After reclaiming peat soils, the elevation of the soil surface is lowered, a process known as subsidence (see Schothorst's paper).
In the 800 years passed since their reclamation, this process has lowered the surface considerably. Instead of a few meters above mean sea level, these lands are now a few meters below.
This subsidence caused a general deterioration of the drainage.
Arable cultivation in the area ceased during the 15th century and the present land use - almost exclusively grassland - dates from this time.
Under grass, oxydation is much slower than under arable farming. Moreover, grassland can stand higher groundwater levels. In turn, these high levels also retard the oxydation process. But nevertheless, the final outcome, though delayed, is a return to swampy conditions. In Italy, in the Gran Bonifica Ferrarese near the mouth of the Po river, peat soils reclaimed in the 15th century had to be abandoned because of subsidence and impeded drainage. They were not used for agriculture until steam engines were put to the job late in the 19th century. In the Western Netherlands, on the contrary, abandonment was avoided and the area entered a new period of development.

7.5 Separation of *boezem* and *polder* lands

The water levels in the boezem system had not changed much since the separation from the sea in the 13th century. At first all lands drained towards this level, but with increasing subsidence this became increasingly difficult. Since the 15th century, therefore, a second separation was made: small tracts of land, named *polders*, were separated from the boezem and within each tract a controlled water level was established lower than the boezem waters. Whereas the boezem area covered over 100 000 ha, these individual units seldom exceeded 1000 ha and were often much smaller.

Control of polder water levels could not be achieved with sluices. The boezem system had no tides, but only irregular variations. Drainage at low water in the boezem, therefore, was not reliable enough. Instead, pumps were introduced.

The first hand-driven or horse-driven pumps were probably used for drainage of foundation pits and other areas of limited extent. The windmill, however, was able to provide energy for pumping water from larger areas. Such windmills are mentioned slightly before 1500 AD and a century later they were in common use (figure 2). Then separation of boezem and polder waters was already almost completed. Only a few areas with sandy soils - where no subsidence had occurred - continued to drain directly on the boezem waters. A typical example are the sandy fields in the western part of the areas, which are now used for growing flower bulbs.

Figure 2 Windmill formerly draining a peat-polder area West of Utrecht (Photo Soil Survey Institute R 31-155).

7.6 Peat as a source of energy

As was known from ancient times, peat could be used as fuel. The Roman writer Pliny the Elder described such use from the Northern Netherlands. In the 10^{th} century, a Moorish envoy, visiting our area tells how a certain kind of soil was shaped into blocks and dried in summer and how it was used instead of firewood.

Initially this peat was used locally, but soon it also provided the growing cities with fuel. The rapid growth of cities in the 17^{th} century, together with the development of industry, created a growing demand. This led to systematic exploitation of peat on a large scale. Peat continued o be the main fuel in the country till the 20^{th} century. In the Western Netherlands where most of the population was concentrated, this resulted in the removal of all peat suitable as fuel, i.e. all peat with low ash content. Especially sphagnum peat had the required properties. By granting concessions for peat digging to private enterprises, polder after polder was exploited.

Figure 3 Some days after dredging the peat, the partly dried sludge is scratched with a rake to indicate the size of the blocks to be cut after further drying (Photo Soil Survey Institute 22405).

Originally the peat was dug from small pits, which could be done to a slight depth only. Since about 1530, however, a new method was employed: dredging. The dredged material was spread on narrow strips of land where it was dried in summer (figure 3). Such strips often took the place of former ditches, which were filled in with useless topsoil. As the polder level was not changed during the operation, an artificial lake remained. For such lakes, invariably the Dutch word *plas* is used, in contrast to natural lakes, which are called *meer*.
Of the once-abundant sphagnum peat, almost no trace remained. Only under old villages, roads and dikes layers of compressed moss peat bear witness of its former existence. Its extension, however, is easily guessed from topographic maps: all lakes named *plas* have once contained sphagnum peat. They are invariably far from the rivers and creeks of the boezem system. Closer to rivers and creeks, woody peats are still present. During their formation, they were admixed with clay and therefore became unsuitable as fuel. Regions where the old medieval polders still exist are usually underlain by this type of peat.
After removal of all valuable peat the concessionaires moved to another polder, leaving behind a landscape like figure 4 and a fund for future reclamation of the lake. One of the conditions was that for each standard volume of peat removed a certain sum should be trusted to such a fund. When time had come to start the reclamation, inflation had usually reduced the value of these savings to an amount insufficient to cover the expenses.

The wealth of the Netherlands in the 17th and early 18th centuries is probably due in part to this cheap and abundant source of energy. Its exploitation, however, destroyed large areas of agricultural land and left behind lakes of little economic value.

7.7 Natural lakes

The artificial *plas* lakes were not the only ones in the area. Several large and small natural lakes existed; they are always named *meer*. The largest of these was Haarlemmermeer, which gradually expanded at the cost of its surroundings. It was called *land-wolf* because its peaty

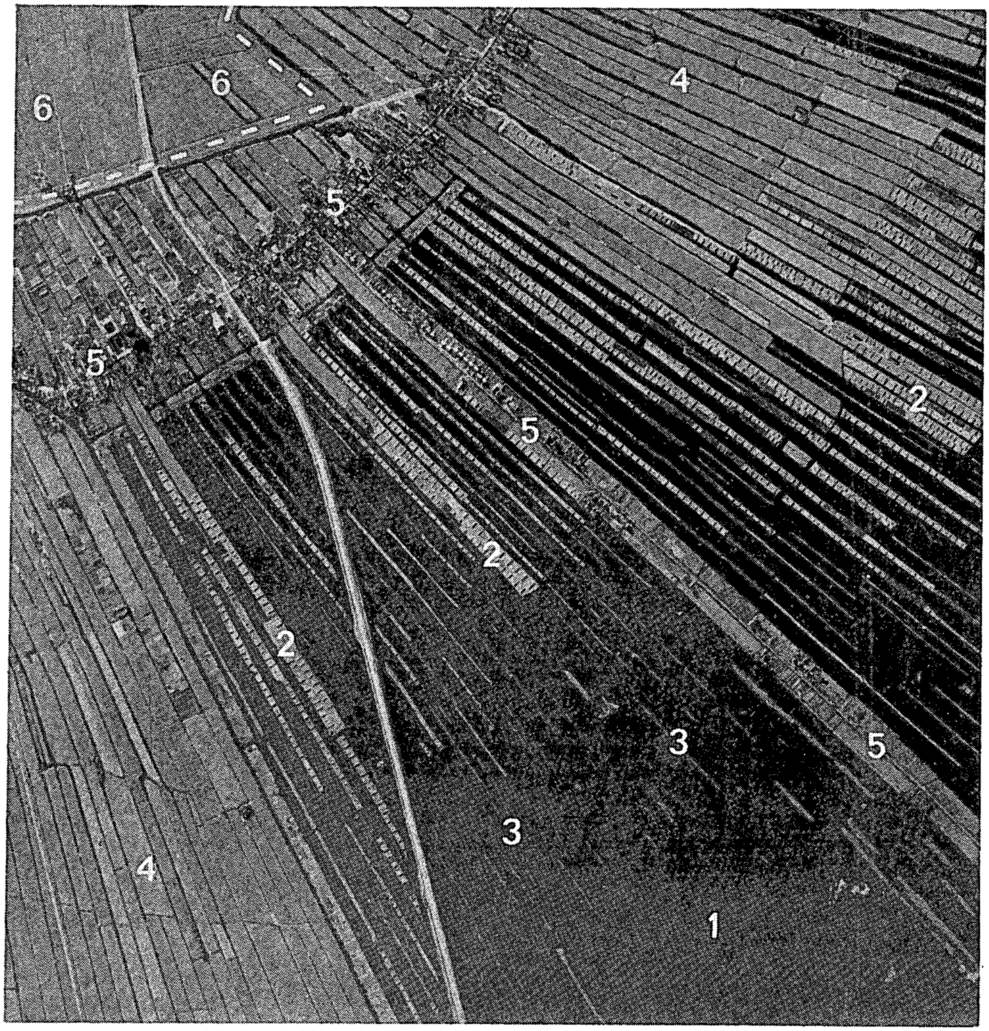


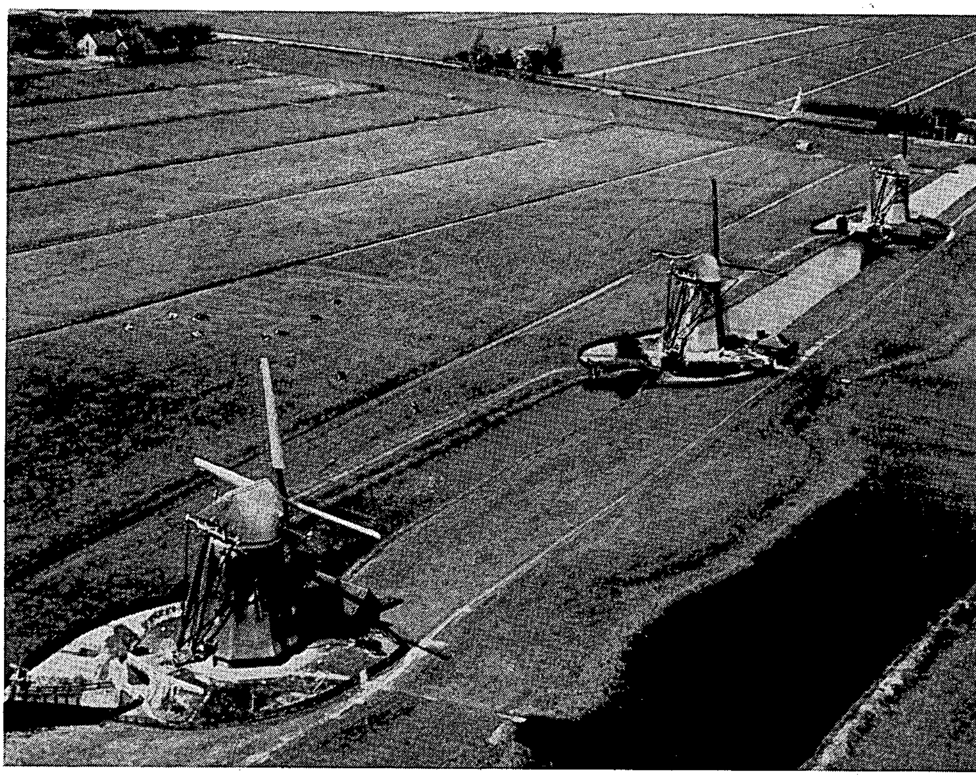
Figure 4 A man-made lake (1), named *plas*, with a fixed water level below boezem level, i.e. the level of the former polder. On the narrow strips of land (2) stacks of drying turves (the photograph was taken at the end of World War II), the very narrow strips of land (3) are the filled-in former ditches. The not yet cut-over land (4), the not-cut over land under the village and the road (5) and the deep polder on a former lake-bottom (6) complete the picture. Scale appr. 1 : 20 000. Photo APIS (Army Photographic Intelligence Service), F/O Wilson, 2nd Army, 400 Sqn R.A.F., 16 september 1944, F 20". height 27000 ft, files Soil Survey Institute 241 III 5.

shores could not withstand the impact of the waves. In the early 19th century it covered about 18 000 ha. Besides this large *meer*, several other *meer* lakes were present and many of them still exist. All form part of the boezem system and their water level, consequently, is only slightly below sea level.
When after 1202 the waters of the Oude Rijn were divided northwards, as much use as possible was made of such natural lakes.
The *meer* lakes acted as a large store during times of excess water in the boezem system. Due to this buffering, variations in water level were slight, even at times that discharge through the sluices was hampered by high sea levels, as is often the case during storms.

7.8 Reclamation of lakes

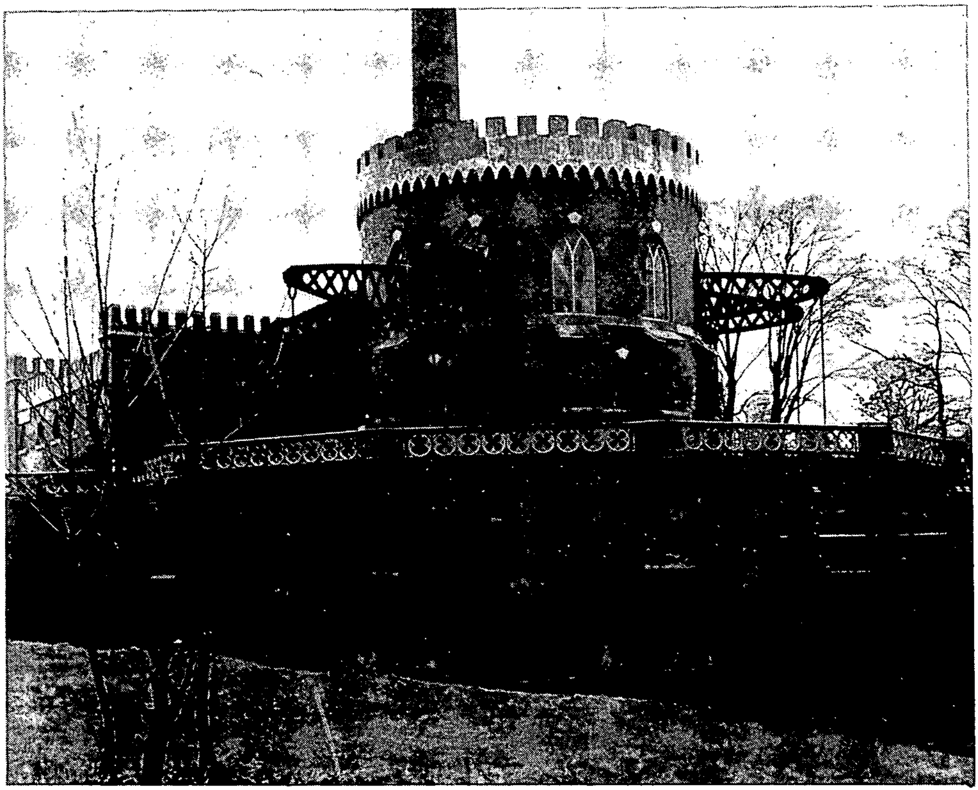
Both the natural *meer* lakes and the artificial *plas* lakes were about 4-5 meters deep and had a bottom consisting of Old Sea Clay covered with some peat remnants and organic mud. Most of these lake bottoms were potentially fertile soils.
As early as the 16th century the windmill had been developed far enough to drain small lakes, after which the lake-bottom soils could be reclaimed. Since the 17th century also large lakes - up to 5000 ha - were drained in this way. As the lake bottoms were about 4-5 m below sea level, and the water levels in the ditches had to be still lower, a single windmill with scoop-wheel was not sufficient to cope with the large difference with the boezem levels. Therefore, windmills operating in series *(molengang)* were used to overcome differences up to 5 or 6 meters (figure 5).
Reclaimed lakes (natural as well as artificial lakes) are known as *droogmakerij*. Before 1800 they were drained by gangs of windmills, since the 19th century steam engines were used. The windmill had the fundamental drawback that it only works when there is enough wind. Moreover its capacity is limited to about 40 kW in times of favourable wind.
For these reasons, drainage provided by windmills is not very satisfactory and soon other solutions were tried out. In 1774 the first steam engine was tried in the Netherlands, of course employed to pump water from a polder. This first trial was not successful, but 70 years later

Figure 5 Three windmills operating in series *(molengang)*, pumping from polder level (5 m below sea level) in three steps to boezem level (0.60 m below sea level). Photo KLM-Aerocarto, File number soil Survey Institute R47-35).



three large pumping stations, driven by steam (figure 6) were employed to drain the large Haarlemmermeer, uncovering in 1852 around 18 000 ha of loamy soils lying about 4 meters below sea level. Many other man-made and natural lakes were drained in the same way.
The old sea clay of these drained lakes proved to be well-suited for arable farming. Only less favourable soils in these drained areas are used as grassland. Therefore, they not only are lying several meters deeper than the neighbouring medieval polders, but they also contrast sharply in their land use.
The drainage of the man-made *plas* lakes, with water at polder levels, had little influence on the main boezem system. But the drainage of natural lakes, which formed part of this system, greatly diminished their

Figure 6 Steam-driven pumping station "Cruquius", built about 1850, nowadays housing a museum exhibiting models of mills, pumping stations, polders etc. Photo Soil Survey Institute R11-165.



water storage. The Rijnland Boezem Authority, therefore, strongly opposed the drainage of Haarlemmermeer, which was carried out by the central government.

Finally, they had to give in, but the central government had to provide extra pumping stations for the control of water levels within Rijnland's boezem. There was one favourable circumstance, which facilitated the enterprise: the mouth of the Oude Rijn near Katwijk, which had closed by natural processes around 1150, had been re-opened artificially shortly after 1800. This outlet was further deepened and widened as a compensation for the loss of storage capacity. Soon after drainage of Haarlemmermeer, Rijnland built a large pumping station at this point.

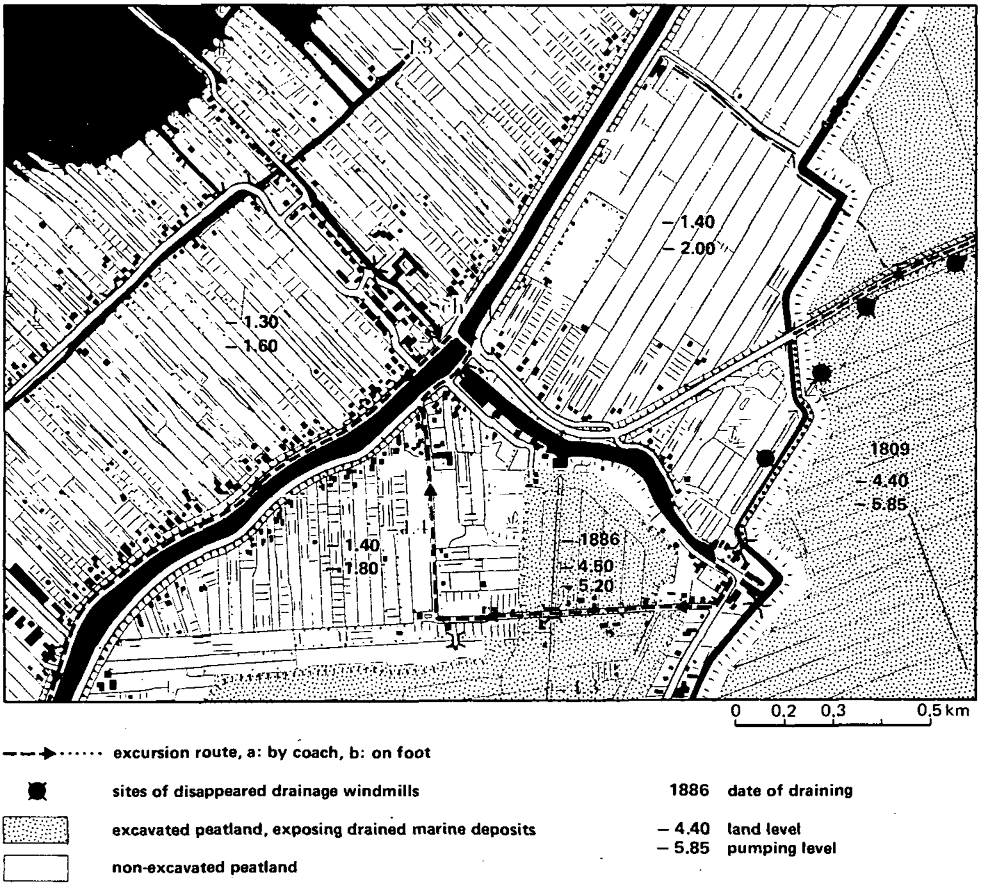


Figure 7. Different land and pumping levels (m below sea level) north of Ter Aar. The shaded areas are the deep polders (i) with mineral soils; the non-shaded areas are the grassland polders (ii), here also horticulture, with peat soils; the dark shaded canal is part of the *boezem system (iii)*. The deep polder in the east (3000 ha) was drained in 1809 by several series of mills *(molengangen)*, now all disappeared; remnants of such a *gang* are indicated.

Located between Band C on Figure 1, p. 86.

From: Excursion Guide "Transect Hilversum-Noordwijk", Soil Survey Institute

7.9 - Present water control

As a result of this long historical development, we have in the area three groups of water management systems (figure 7):

i) The deep polders, reclaimed from former lakes, both natural and man-made. Most of them date from the 18^{th} and 19^{th} centuries. Land use is mainly arable on old sea clay soils. The fields are large and production is high.

   The land is tile-drained and these tile-drains discharge into ditches, where the water level is at least 1 m below the soil surface. Pumping stations driven by diesel or electric power have replaced the 18^{th} century gangs of windmills and the 19^{th} century steam engines. They pump their water into the boezem system.

ii) Grassland polders, where the peat is still present; this is mainly wood peat which was unsuitable as fuel.

   Due to subsidence, land levels are now 1-2 m below sea level. These grasslands are not tile-drained and drainage is provided by the numerous parallel ditches which date back from the medieval reclamation period.

   Because the grasslands require less intensitive drainage than arable land, ditch levels are only 0.30-0.40 m below soil surface, that is around 2-2.5 m below sea level. This water is also pumped into the main boezem system, usually by diesel or electric pumping stations. In a few cases windmills are still in use.

   The grasslands are highly productive and carry more than two head of cattle per hectare, which is extremely intensive. These soft peat soils, however, have a low mechanical bearing capacity and their lack of firmness is often a problem under this form of management, especially during wet periods in spring and in autumn. As these peat soils become firmer by deeper drainage, there is a tendency to lower the polder levels from about 0.40 m to 0.80 m below surface. This, however, will increase the subsidence of the peat.

   A few *plas* lakes reamin at polder level. As they are of great value, both as nature reserves and for the recreation of the large urban population, they will certainly not be drained.

iii) The *boezem* system has the highest water levels, slightly below sea level (for Rijnland 0.60 m below MSL).
This system is a network of former rivers, canals and those natural lakes which have not been drained in the past.
Also these *meer* lakes will not be drained and reclaimed in future, for the same reasons as already mentioned for the *plas* lakes.
The boezem level is controlled by large pumping stations, although sluices are still occasionally used at Katwijk during low tide. Due to careful management, the fluctuations in level are kept within a few centimeters. As larger fluctuations would have serious consequences - for shipping, for the water control of polder areas, for nature reserves and for many other interests - the entire system is controlled with the help of data transmission, aided since 1970 by a special computer programme which monitors both water quantity and quality.
The expanding cities and in some areas the increase in the number of glasshouses cause a steady increase in the area of impermeable surfaces, from which water almost immediately reaches the open water courses. Especially during heavy showers this increases the peak loads on the system, thus necessitating an increased pumping capacity.
But the main problem at present is water quality. The dense population and the large concentration of industries are a formidable internal source of pollution. A large-scale water-purification programme was started, but even so it remained necessary to take in large quantities of water during summer to maintain a reasonable water quality and to maintain a constant water level in dry periods. This water has to be taken from the Rhine river, which itself is rather polluted. These qualitative aspects, however, would lead too far from our present subject: the water-management in a peat region, which not only allowed the development of an area, which must have been inhospitable and barren 900 years ago, but which also allowed continuous and uninterrupted land use ever since.

7.10 Literature

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8 REVIEW OF CHAPTER 7: WATER MANAGEMENT OF NORTWESTERN GERMAN PEATLANDS

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8.1 Introduction

In the Northwestern German peatlands are soils, which man has occupied for agricultural use. Every utilization of peatlands (peat cutting, agriculture, horticulture, forestry) requires an adequate water management.

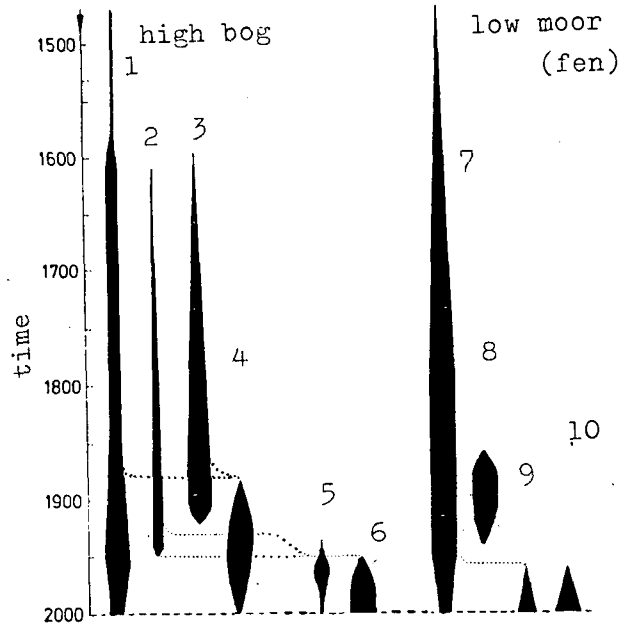
In Northwestern Germany most of the peatland reclamation began some centuries later than in The Netherlands. Figure 1 gives an oversight for the development of peatland reclamation.

8.2 Three typical peatlands

The three typical peat areas give an impression upon Northwestern German Peatlands, their development and water management. They lie in different districts and on various heights most above, only somewhere below mean sea-level (MSL).

8.2.1 Non-cutover raised bog

The raised bog Koenigsmoor lies between Hamburg and Bremen. The experimental farm of the Peat Research Station Bremen was situated here from 1911 till 1970. The height is about 40 m above MSL. The thickness of the peat layer varied between 0 and 4 m (1911).



1 = peat cutting
2 = Dutch fen cultivation
3 = bog burning for cultivation
4 = German raised bog cultivation
5 = sand cover cultivation
6 = deep ploughing sand mixed cultivation
7 = low moor cultivation
8 = sand cover cultivation
9 = deep ploughing sand cover cultivation
10 = deep ploughing cultivation

Figure 1. Historical development of peatland reclamation in Northwestern Germany after Kuntze (1971)

In the middle of 19th century peat burning for cultivation:

1875	first shallow drainage in connection with railway construction;
1905	drainage with open main ditches about 1,5 to 2,0 m depth;
1911/15	subdrainage with tile drain pipes in heather bed, depth 1,2 to 1,5 m, drain spacing 20 m, single drains of 150 m length, German high bog cultivation;

1912/70	partly only used for pasture, other fields only used for farming;
1936/38	after subsidence (by settling, shrinkage, oxidation) sand-mixed cultivation took place with Dutch fen cultivation or deep ploughing (depth 60 to 80 cm);
1959/60	2nd drainage period with small pumping station, new ditch level in sand subsoil, intermediate subdrainage on 10 m or 7 m distance for peat layer >1,5 m, shallow peat layers were deep ploughed (depth 80 to 150 cm), more than 50% of the experimental farm became sand-mixed cultivation;
1980	on raised bog grassland we measurend a complete subsidence of 0,9 to 1,5 m in comparison with the original peat level, more peat areas could be deep ploughed (Figure 2).

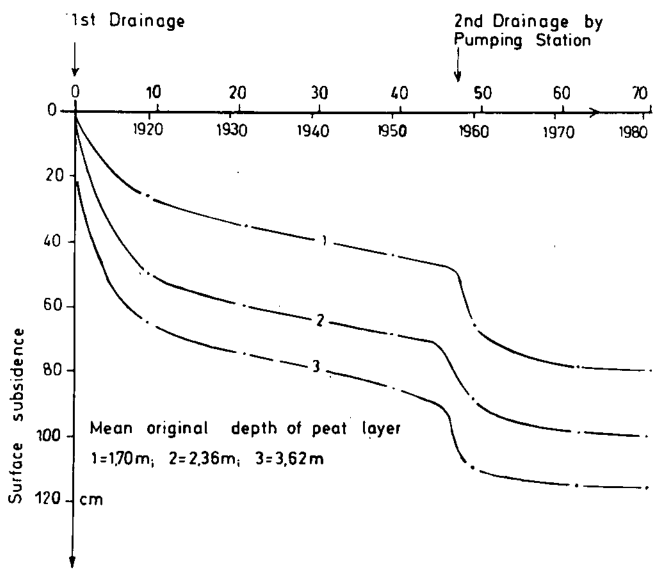


Figure 2. Raised bog surface subsidence at the Experimental Farm Koenigsmoor near Hamburg

8.2.2 Raised bog with peat cutting

In the south-eastern part of the Dutch-German peat district Bourtanger Moor lie the subareas Twist and Schoeninghsdorf. It is a typical raised bog, the height is about 10 m above MSL. The raised bog profile contains slightly decomposed Sphagnum peat layer (white peat) above strongly decomposed Sphagnum peat (black peat), subsoil is fine sand with fossile soil, type Podsol.
In 18th century and early 19th century there were several times peat burning for cultivation.

1875 construction of the South-North-Channel for drainage and shipping;

1890 Schoeninghsdorf: open ditches and German raised bog cultivation for farming;
Twist: industrial peat cutting, first for fuel peat and peat litter, later on for soil improvement;

1965 deep ploughing cultivation, with open ditch drainage in sand subsoil (Figure 3).

8.2.3 Peatland at MSL

The large peat area Moorriem lies near the county town Brake at the river Weser between the North-Sea and Bremen. The height varies between 2 m above and 1 m below MSL. Here we find low moor (fen) and raised bog profiles. The dikes along the river Weser have often been raised during last centuries.

1880 the river Weser was adjusted for shipping traffic to Bremen, this caused a higher tidal amplitude; therefore the drainage by sluices became better, begin of German raised bog cultivation for farming;

1950 after subsidence and oxidation, grassland for pasture has been preferred;

1955 construction of main pumping station for main drainage along the dikes, pumping substation for subdrainage;

1960 subdrainage with tile drains;

1970 subdrainage with PVC-drains.

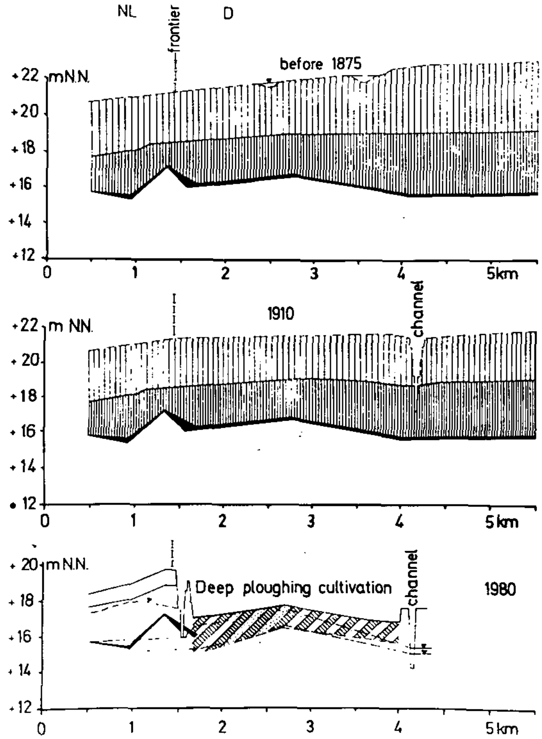


Figure 3. Raised bog profile development at Bourtanger Moor, on both sides of the Dutch-German frontier

8.3 General conclusions for water management

The peatlands of Northwestern Germany have an average water balance like Table 1.

Table 1. Water balance for Northwestern German Peatlands (in mm)

Period	Rainfall	Evaporation	Discharge	Storage
Winter	350	100	150	+ 100
Summer	400	400	100	- 100
Year	750	500	250	0

For peat grassland we need a drainage for pasture and hay or silage production by machine, therefore the watertable in spring should be between 60 and 80 cm below soil surface. Caused by evapotranspiration the watertable falls in summer 40 to 60 cm and rises in autumn/winter for the same rate or more.

For (deep ploughing) sand-mixed cultivation we demand mostly a ditch water-level of 20 cm below deep plough furrow in the sand subsoil. In this deep plough profile we find a similar ground water course between winter and summer with an amplitude of 50 to 80 cm (Figure 4).

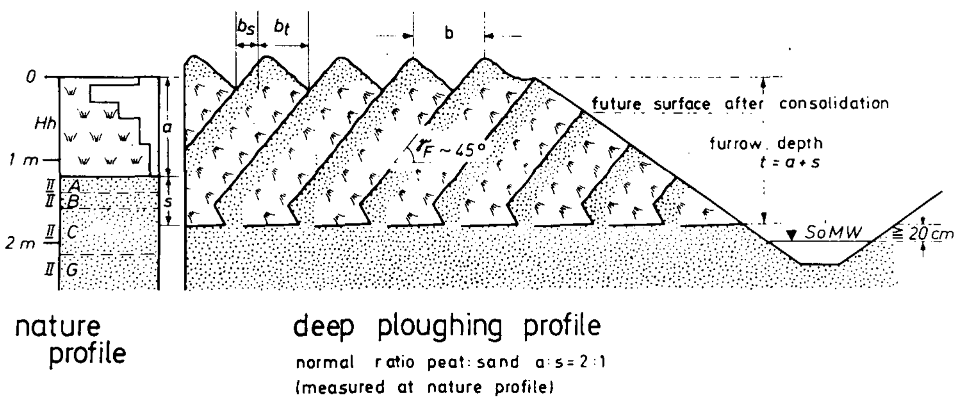


Figure 4. Scheme of deep ploughing profile for sand mixed cultivation

8.4 Peat profile character

In the last decades in peat grassland the peat density is compressed by subsidence, traffic with heavry tractors and machines, further by many cows on the grassland unit. High rates of fertilizing, special N in connection with liquid manure have caused a very thin top grassland layer with shallow rooting. This peat grassland got a character of a pseudo-gley, it is sensible to wet and dry phases. For intensive using a thin sandy cover may be desirable.

The (deep ploughing) sand-mixed cultivation profile is named "stable peat profile" (German: *Stabiles Moorprofil*), the other peat profiles with peat layer deeper as 2 m belong to the "unstable peat profile" (German: *Labiles Moorprofil*).

8.5 Peatland protection

In the last decades in Northwestern Germany the peatlands without agricultural use became under peat protection resp. nature conservation. Many protection areas got a hydrological protection zone. The width of this zone we calculate by the empirical formula

$$l = 200 \cdot k \cdot h$$

in this is

l = width in m

k = permeability factor in m/day

h = depth of ditch in m

Table 2 shows for different peat types the width of the hydrological protection zone.

Table 2. Width of hydrological protection zone

Peat type	Width m
Deep raised bog	30- 80
Shallow raised bog above fine sand	120-150
Shallow low moor above sand	200-350
Spring-water bog, wooded swamp	>350

Many high bog protection areas have been prepared to store the rainfall with the aim of peat regeneration and renaturation.

8.6 Literature

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9 DRAINAGE AND BEHAVIOUR OF PEAT SOILS

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9.1 Introduction

During centuries the low moor peat area in the western Netherlands has mainly been utilized as grassland. The old polders in this area are characterized by many ditches with high water levels at 0.2 to 0.4 m below the soil surface. The soil surface is situated at a very low elevation which varies from 1 to 2 m below sea level. Drainage is only possible by means of forced extraction of water by pumping stations. A more or less at constant level of the open water is maintained by a discharge in winter and water supply from the river Rhine in summer.
Mechanization and intensifying of the dairy farms in the last decennia increased the importance of a sufficient bearing capacity of the soils. At the traditional high water levels the bearing capacity of the soil generally is insufficient in winter and spring, as well as in wet periods in summer. This frequently impedes the required activities in farming. In wet periods it is not easily possible to spread slurry over the land, which means that a larger storage capacity for slurry is needed. In spring fertilizing and other activities have to wait till a dry period. Moreover, the growing season starts at a later date and this is also true with regard to the grazing period. In wet periods of the grazing season part of the grass production is lost by trampling and the sod is damaged which results in lower yields in following period. In autumn the grazing period is shorter and consequently the grazing period as a whole. In spite of such a shallow drainage these peat soils are very productive. On the average the gross production without nitrogen

Figure 1 Location of the experimental fields for deeper drainage of low moor peat soils under grass

fertilizing amounts to 10 metric tons dry matter per ha (Boxem en Leusink, 1978).

The bearing capacity can be influenced by deeper drainage. Then some disadvantages are to be expected as surface subsidence either or not combined with damage to the foundation of farmbuildings, bridges, etc. In spite of the centuries long shallow drainage the surface subsided from about 0.5 m above to 1 or 2 m below sea level, so 2 or more meters. For this reason it was feared that deeper drainage would reinforce the subsidence process. Moreover, moisture deficiencies in dry periods in summer and irreversible shrinkage of the top layer was imaginable.

To quantify the favourable and unfavourable aspects of deeper drainage three experimental fields were laid out in 1968 and 1969 in the western peat area (Figure 1). One of these, the experimental field Zegvelderbroek here will be discussed in particular.

9.2 Experimental field Zegvelderbroek

At the Regional Research Centre for Cattle Husbandry at Zegveld, 20 km West of Utrecht, an experimental field for deeper drainage was made in the spring of 1969 (Figure 2). Here the soil consists of 6 to 7 m wood sedge peat on a sandy subsoil and the surface elevation was 2.15 m below sea level.

An area of 20 ha of the experimental farm of the Regional Research Centre was destined for drainage experiments. This area was divided into 4 blocks: 2 blocks with a high ditch water level of 0.2 to 0.3 m and 2 blocks with a low ditch water level of 0.7 to 0.8 m below the surface. The blocks with the same water level were situated diagonally. The high water levels equalled the polder water level. The water level in low water level blocks were maintained by two small electric pumps. The ditch water levels were kept approximately constant during summer and winter at 2.35 m below sea level in the high water level blocks and 2.85 m below sea level in the low water level blocks. The ditch spacing varies from 25 to 50 m. To more closely control the groundwater level in the blocks with the low water level plastic drain pipes were installed with a spacing of 12 m, so depending on the width of the parcel 1 to 3 drains per parcel.

The ditches were dredged to the right depth and the dredged mud was spread over the land.

9.3 Items of investigation

The program of investigation included the following items:

- relation groundwater and ditch water level;
- relation bearing capacity, depth of groundwater level, moisture content and moisture tension;
- gross dry matter yield at different nitrogen applications for shallowly drained and well-drained soils;
- nitrogen uptake by the grass crop;
- moisture uptake of the crop;
- subsidence of the soil surface and of different soil tiers in connection with the depth of drainage;
- effect of drain depth on net yield.

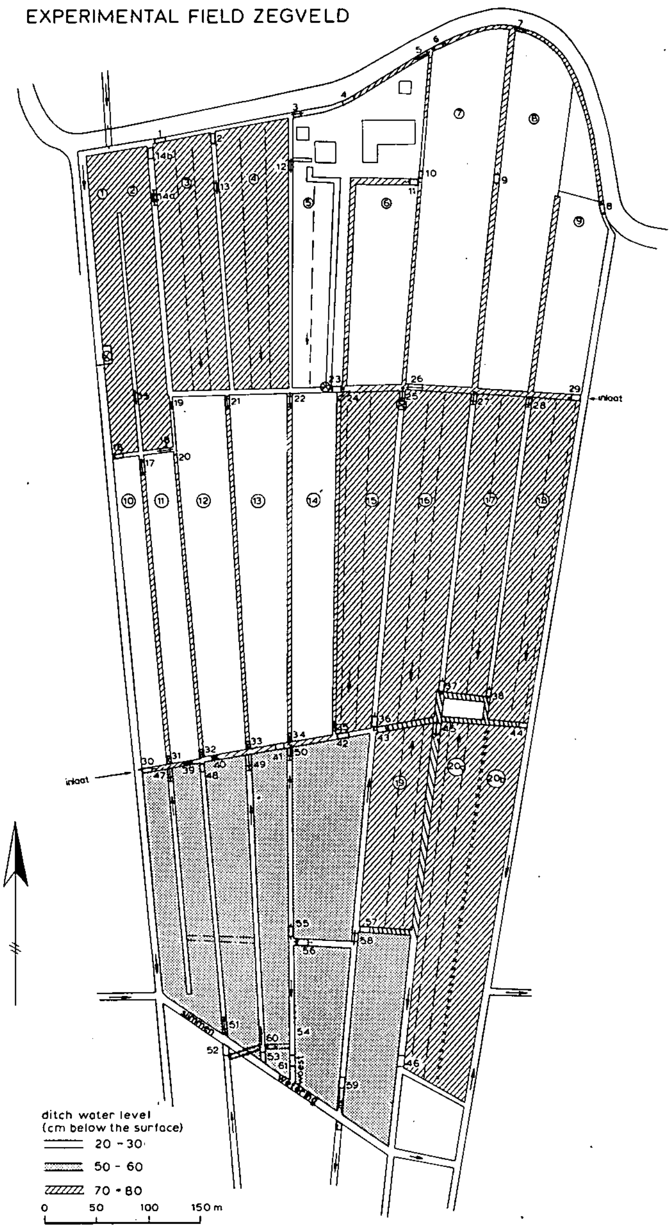

Figure 2 Layout of the experimental field Zegvelderbroek

9.4 Relationship groundwater and ditch-water level

In winter at a high ditch water level of 0.3 m below the surface the groundwater can rise to the surface under the condition of a precipitation surplus. After a dry period the groundwater can only subside to drain depth, that is to 0.3 m below the surface. Which means that the storage capacity is small. In summer the groundwater level draws down to a depth of 0.6 m below the surface or 0.3 m below the ditch water level under influence of an evaporation surplus (Figure 3). The infiltration from the ditch is very small (about 1 $mm.d^{-1}$) because of a low permeability in a narrow strip of about 5 m width along the ditch (Figure 4). The permeability of this strip is very small because shrinkage cracks are lacking on one hand and drinking cattle has compressed the ditch slope on the other. Beyond this little extended strip the permeability of the topsoil is very high, see Table 1.
By lowering the ditch water level with 0.5 m the groundwater table rises to about 0.4 below the surface in winter and drops to 0.9 m in summer. The lowering of the ditch water level results in a lower groundwater

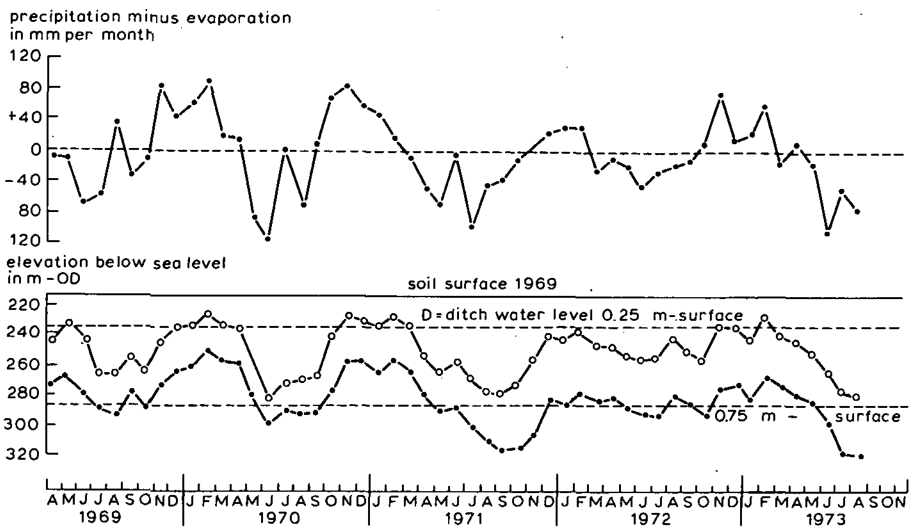

Figure 3 Precipitation surplus and groundwater levels at ditch water levels of 0.25 m and 0.75 m below the soil surface in the period 1969 through 1973 in the Zegvelderbroek field

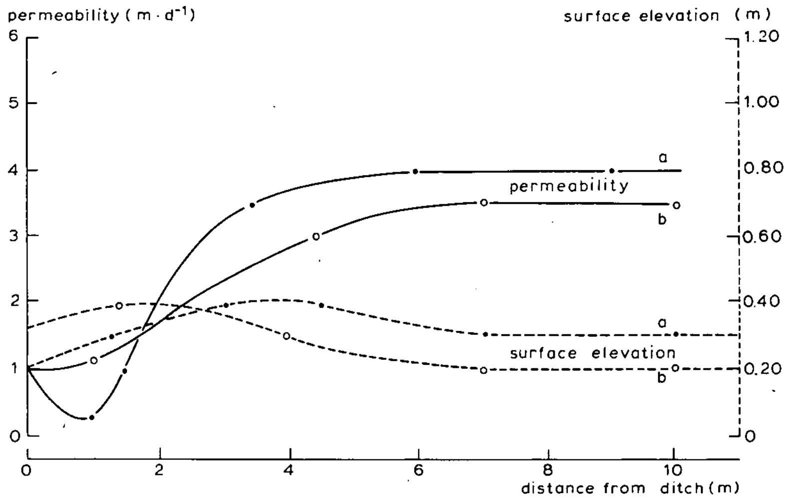

Figure 4 Two examples of the course of permeability (full line) of the soil and the surface elevation (broken line) in relation to the distance from the ditch (after Sonneveld, 1954)

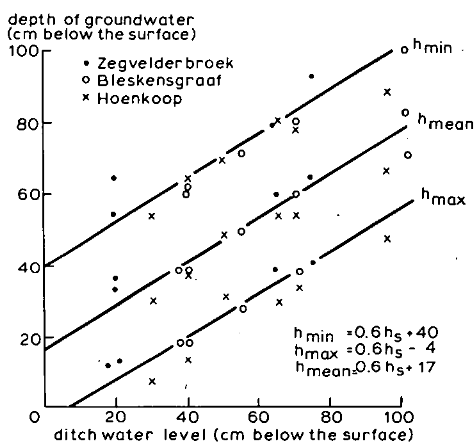

Figure 5 Relationship groundwater level and ditch water level at the three experimental fields. h_{min}, mean depth of groundwater in summer; h_{max}, mean depth in winter; h_m, mean depth over the year

Table 1. Permeability (k_s) of the soil at the experimental field Zegvelderbroek

Depth in m below the soil surface	k_s in $m.d^{-1}$
0.3 - 0.5	1.95
0.5 - 0.7	0.9
0.7 - 1.0	0.18

table as well in winter as in summer. This lowering of the groundwater table does not equal that of the ditch water level but amounts to some 60% of it (Figure 5).

9.5 Soil moisture conditions

Peat soils have a high organic matter content and therefore a low bulk density and a high pore volume. The bulk density of a peat soil profile decreases with the depth below the soil surface due to oxidation and shrinkage of the soil layers situated above the groundwater (Table 2). In this Table and the following ones, the symbols used are: V_w, bulk density in $g.cm^{-3}$; h, organic matter content in weight %; V_p, pore

Table 2. Main physical characteristics and the acidity of the Zegvelderbroek soil profile

Depth below the surface (cm)	V_w	h	V_p	V_n	pH-KCl
0 - 10	0.54	42	73	31	4.8
10 - 20	0.56	40	72	34	4.4
20 - 30	0.41	50	78	34	4.4
30 - 40	0.26	65	85	24	4.4
40 - 50	0.21	73	87	22	4.2
50 - 60	0.18	78	89	19	4.0
60 - 70	0.16	84	90	16	4.0
70 - 80	0.14	85	91	14	4.4

Table 3. Moisture (V_v respectively V_b) and air content (V_1) in volume % in spring (1972 and 1973) at a ditch water level (D) of 30 and 80 cm below the soil surface

Depth below the surface (cm)	D = 30 cm			D = 80 cm		
	V_v	V_1	V_b	V_v	V_1	V_b
0 - 10	65	8	34	56	17	25
10 - 20	65	7	31	58	14	24
20 - 30	76	2	42	70	8	36
30 - 40	83	2	59	80	5	56
40 - 50	86	1	64	82	5	60
50 - 60	88	1	69	87	2	68
60 - 70	88	2	72	88	2	72
70 - 80	89	2	75	89	2	75
Groundwater depth	30 cm			50 cm		

content in volume %; V_n, unavailable moisture content in vol. % at pF 4.2; V_v, total moisture content in vol. %; V_1, air content in vol. %; V_b, available moisture content in vol. %, $V_b = V_v - V_n$; V_u, moisture uptake in mm respectively %; V_s, solids in vol. %.

According to Table 2 the pore volume of the effective root zone (0 to 20 cm) amounts to 70 to 75% and it increases to 90% in the subsoil at a depth of 70 cm below the surface.

In spring at a shallow drain depth the root zone is nearly saturated and the groundwater table is situated at 0.2 m - surface. Then the air content is very low, about 5%. At a groundwater table of 0.4 m - surface by deeper drainage the air content increases to 15 vol. %, see Table 3.

According to Table 3 the moisture content of the effective root zone (0 to 20 cm below the surface) amounts to respectively 65 and 56 vol. %. The unavailable moisture ranges from 30 to 35% in the topsoil to 15% in the subsoil. It decreases with the depth below the surface in relation to the bulk density (see Table 2).

The available moisture in the effective root zone amounts to 65 mm in a shallowly drained and 49 mm in a well-drained soil. At a depth of 20 to

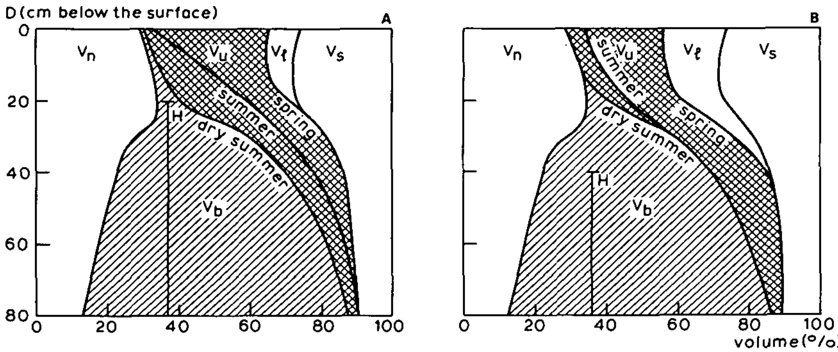

Figure 6 Moisture (see text) and air content (V_1) in volume % in relation with the depth below the surface in spring, in summer and in an extremely dry summer at a ditch water level of 30 cm (A) and of 80 cm below the surface (B)

40 cm below the surface the soil then holds 100 respectively 90 mm total moisture.

The peat soils contain a great quantity of available moisture. In spite of this in dry summer periods the grass growth decreases. Then, especially in well-drained soils, the root zone is nearly desiccated but at a depth of 30 to 40 cm below the surface the soil still holds 40 mm of available moisture at a pF 2.5 (see Figures 6A and 7A). Even in the extremely dry summer of 1976 this layer still contained 35 mm of avail-

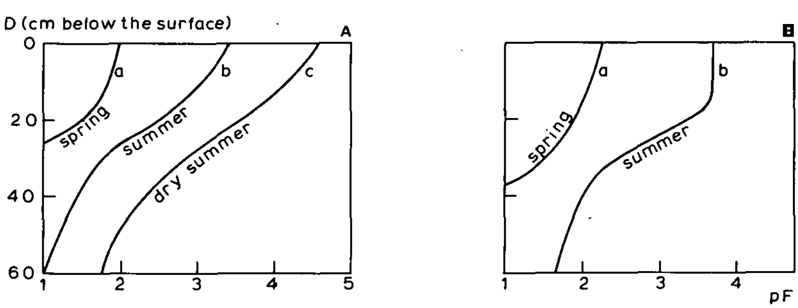

Figure 7 Relationship between pF and depth below the surface in spring (a), summer (b) and in the extremely dry summer of 1976 (c) at a ditch water level of 30 cm (A) and 80 cm below the surface (B).

Table 4. Moisture (V_v respectively V_b) and air content (V_l) in volume % during summer (1973 and 1974) and the pF at a ditch water level (D) of 30 respectively 80 cm below the surface

Depth below the surface (cm)	D = 30 cm						D = 80 cm					
	V_v	pF	V_l	V_b	V_u		V_v	pF	V_l	V_b	V_u	
					mm	%					mm	%
0 - 10	39	3.3	34	8	26	76	36	3.7	37	5	20	80
10 - 20	53	2.9	19	19	12	39	41	3.7	31	7	17	71
20 - 30	64	2.2	14	30	12	29	54	3.0	24	20	16	44
30 - 40	75	1.6	10	51	8	14	66	2.2	19	42	14	25
40 - 50	79	1.7	8	57	7	11	74	1.9	13	52	8	13
50 - 60	79	1.8	10	60	9	13	78	1.8	11	59	9	13
60 - 70	82	1.5	8	66	6	4	79	1.6	11	63	9	13
total					80						93	
Groundwater depth	75 cm						100 cm					

able moisture while the root zone was completely desiccated. In this situation the grass production also stopped completely (Tables 4 and 5). In the root zone (0 to 20 cm below the surface) about 100% of the available moisture was consumed but only about 50% of that in the layer of 20 to 40 cm and about 15% at a depth of 40 to 60 cm below the surface. In this situation the capillary rise to the root zone is entirely disturbed. even when the groundwater table was raised to 40 cm below the surface by subsoil irrigation, as was done in the field Z-17. The root zone remained dry, however.

The desiccation is not irreversible, but the process of rewetting goes very slowly under normal weather conditions (see sections 7.4 and 7.5). In the Figures 6A and 6B the moisture conditions in spring and summer are demonstrated, while Figures 7A and 7B show the course of moisture tension according to the pF-curve in relation with the depth below the surface.

Table 5. Moisture (V_v resp. V_b) and air content (V_l) in volume % in August 1976 and to the pF at a ditch water level of 30 cm below the soil surface

Depth below the surface (cm)	D = 30 cm					
	V_v	pF	V_l	V_b	V_u	
					mm	%
0 - 10	28	4.2	41	1	33	97
10 - 20	38	4.2	36	2	29	94
20 - 30	47	3.1	23	21	21	50
30 - 40	54	2.8	16	35	24	40
40 - 50	69	2.1	9	56	8	12
50 - 60	78	1.7	10	60	9	13
60 - 70	82	1.5	9	68	4	5
total					128	
Groundwater depth	100 cm					

9.6 Bearing capacity

Bearing capacity or soil strength is defined as the resistance of the turf of grassland against pressure caused by grazing cattle or machines. It can be measured with a penetrometer reading the soil strength in $kg.cm^{-2}$ or MPa and then is indicated as the penetration resistance. According to comparisons with penetrometer values and the existence of an insufficient bearing capacity, visible from poaching of the turf by cattle or from machines tracks, the bearing capacity is insufficient at a value of 5 $kg.cm^{-2}$ or lower and very good at a value of 7 $kg.cm^{-2}$ or higher. As a rule a value of 6 $kg.cm^{-2}$ is regarded as being sufficient.

9.6.1 Groundwater depth

An insufficient bearing capacity generally occurs on soils with a high moisture content of the sod (0 to 10 cm below the surface), for example

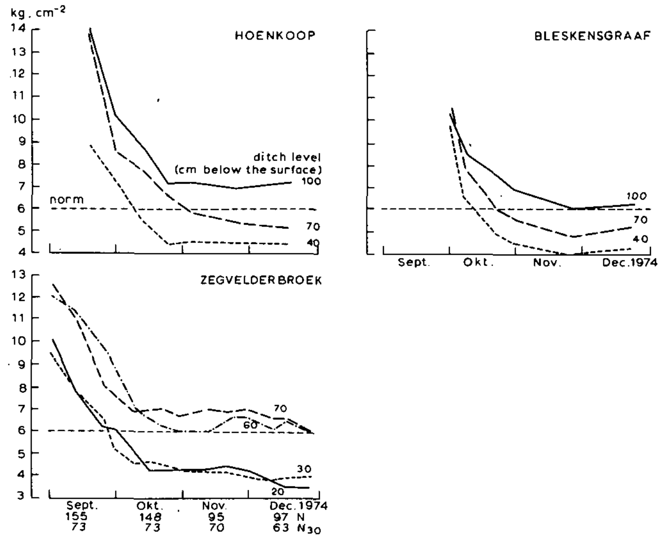

Figure 8 Penetration resistance of the turf in kg.cm^{-2} or MPa in the autumn of 1974 with 243 mm precipitation in the period October and November, for a drain depth of 20 to 30 and 70 to 80 cm below the surface at the experimental field Zegvelderbroek

on shallowly drained soils where the groundwater table can rise close to the surface. A change for the better will appear after a period with an evaporation surplus of about 20 mm. Therefore in spring it can take quite a long time before the soil has reached a sufficient bearing capacity.

The bearing capacity increases with a decreasing moisture content of the turf, for example by deeper drainage. Then the rise of the groundwater table in autumn or winter is kept below 30 to 40 cm below the surface. The turf then is not saturated and the bearing capacity remains sufficient.

So after a very wet autumn in 1974 with a precipitation of 240 mm in October through November (normal: 140 mm), the bearing capacity of the soil remained sufficient during the entire winter of 1974/'75 at a drain depth of 75 cm below the surface. This in contrast to the shallowly drained soils with a drain depth of 25 cm below the surface (see Figure 8). During this winter it was possible to spread about 400 tons of manure slurry over the well-drained land, i.e. 27 tons per ha. In the same period the spreading of slurry was limited to 50 tons, or 3 tons

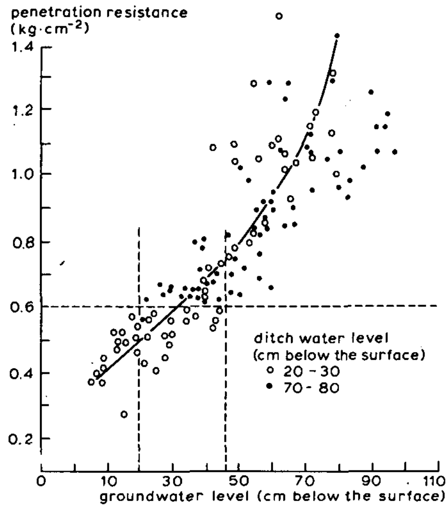

Figure 9 Penetration resistance of the turf in kg.cm^{-2} or MPa in relation to the groundwater depth in cm below the surface at a drain depth of 20 to 30 and 70 to 80 cm below the surface at the experimental field Zegvelderbroek in the period 1970 through 1975 (monthly means)

per ha, on the fields with the shallow drain depth. The mean value of the penetration resistance amounted to 6.3 respectively 4.3 kg.cm^{-2} over the entire period.

It has been found that to keep the bearing capacity sufficient, the groundwater level must not be allowed to exceed a depth of 30 cm below the surface as an average (see Figure 9), with a range between 20 and 50 cm below the surface depending on the duration of the high groundwater tables. This period is shorter at well-drained soils, respectively longer at shallowly drained soils. In the first case the period of reswelling is limited. Therefore in autumn at a groundwater depth of 20 cm the bearing capacity can be sufficient, while being insufficient at a groundwater depth of 40 cm in spring. In the latter period the turf is more loose or less compacted because of reswelling.

It could be concluded that the bearing capacity of a low moor peat soil is generally sufficient at a drain depth of 70 cm or deeper, depending on the permeability of the soil and the ditch spacing. At ditch spacings larger than 50 m a lower ditch water level is needed or a pipe drainage system.

9.6.2 Moisture content and moisture tension

In preceeding section the influence of the ditch water level and the groundwater level was dealt with. As mentioned, a low bearing capacity will improve by decreasing the moisture content of the turf. This is possible on the one hand by an evaporation surplus and on the other by deeper drainage.
According to Figure 10 a bearing capacity of 6 $kg.cm^{-2}$ will be reached at a moisture content of 65 volume %. At a pore volume of 75%, it means an air content of 10%. This is valid for a peat soil with an organic matter content of 40 to 50% in the turf (Zegvelderbroek).
In fact, it is not the moisture content but the moisture tension or the (negative) soil water pressure head that determines the soil strength.
At an equal moisture quantity the moisture tension can differ depending on the bulk density or the pore volume. For example a soil with a moisture volume of 65% has at a pore volume of 70% a lower moisture tension and therefore a lower bearing strength than a soil with a pore volume of 75% with the same moisture content.
The moisture tension is often deduced from the relation moisture content and moisture tension or pressure head (desorption-curve). This sometimes does not give good results because of hysteresis effects. A direct measuring of the pressure head by tensiometers is giving better results (see Figure 11). The relationships in Figure 11 concern the situation at the experimental field Zegvelderbroek in the spring of 1980. In spring

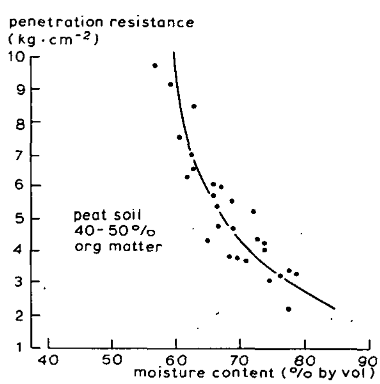

Figure 10 Relationship between bearing capacity and moisture content for peat soils with an organic matter content of 40 to 50%

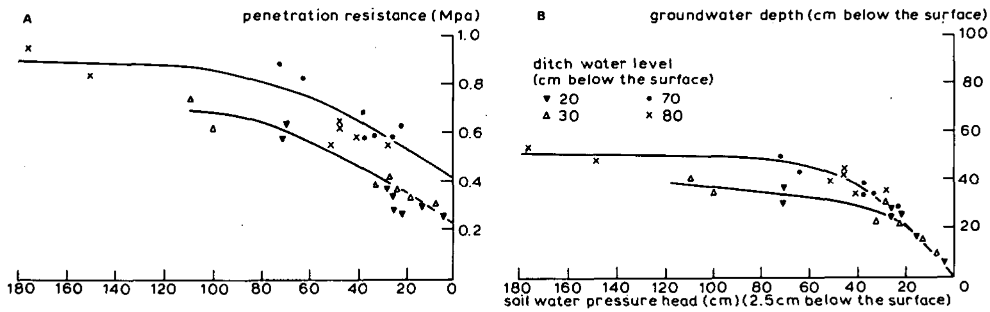

Figure 11 A, relationship between penetration resistance and soil water pressure head; B, relationship between groundwater depth (cm below the surface) and soil water pressure head (cm) at different ditch water levels

the groundwater table did not rise higher than 30 cm below the surface at a drain depth of 70 to 80 cm (Figure 11B). In this situation the penetration resistance did not get lower than 0.6 MPa or 6 $kg.cm^{-2}$ (Figure 11A). At a drain depth of 20 to 30 cm the groundwater table did rise to the surface and the penetration resistance decreased to 0.3 MPa. The penetration resistance at equal pressure heads (Figure 11A) differs depending on the drain depth. The difference is to be ascribed to a difference in bulk density. In the shallowly drained soil the top layer has reswelled by groundwater inundation, while its shrinkage remained at a groundwater table depth of 30 cm or more.

A reswollen top layer requires a pressure head of 70 cm to get a sufficient bearing capacity of 0.6 MPa, which can be reached after a period with an evaporation surplus.

The results of a direct measuring of the pressure head agree with the earlier found limit for the maximum allowed height of the groundwater of 30 cm below the surface.

9.6.3 Bulk density

As already mentioned, the bearing capacity (penetration resistance) depends, except on moisture content or soil water pressure head of the

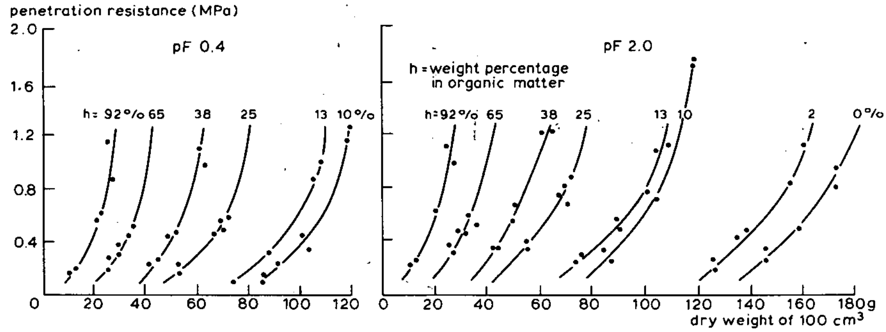

Figure 12 Relationship between penetration resistance and the bulk density at variable organic matter contents, for two values of the moisture pressure head (pF 0.4 = 2.5 cm and pF 2.0 = 100 cm)

turf on the bulk density. At an equal organic matter content the turf can differ in compactness and the more compact the higher the resistance of the soil and its bearing capacity (Wind and Schothorst, 1964).
Compaction results from grazing by cattle or from the wheel pressure of machines. This is evident on reseeded grassland when the top layer has been loosened by a soil fraise. A new turf is very sensitive to poaching in wet periods. On old peat grasslands the turf layer greatly can vary in density because of shrinkage in dry and reswelling in wet periods.
That the bulk density at an equal organic matter content is of great influence to the penetration resistance is demonstrated by Figure 12. It shows the results of a laboratory experiment. The penetration resistance increases with an increasing bulk density at every given organic matter content, as well in a saturated as an unsaturated condition (Schothorst, 1968).

So the soil strength is not only improved by a lowering of the moisture content or pressure head by deeper drainage, but also by increasing the bulk density by shrinkage or compaction. In practice it occurs mostly by both together.

An other possibility to increase the bulk density is dressing the soil with sand. In the past it has been done by farmers in some areas by means of a mixture of sand stable manure and mud dredged from the ditches.

A more modern method consists of covering the peat soil with 5 to 15 cm of sand. This system is applied to peat soils without a clay cover in the Northeast of The Netherlands where sand is present in the subsoil at an attainable depth for machines.

9.6.4 Grass species

Quite another factor which can influence the bearing capacity is the kind of grass vegetation. A turf containing grasses with creeping rhizomes as meadow grass *(Poa pratensis)* and couch grass *(Agropyron repens)* is very firm in contrast with a turf containing English ryegrass *(Lolium perenne)*, the most important and most productive grass of our pastures. When maintaining a low level of nitrogen application and a turf consisting of grasses with a low productivity, the bearing capacity can be kept sufficient at shallow drain depths.
The problem of an insufficient bearing capacity mainly occurs on intensively managed dairy farms.

9.7 Gross dry-matter yield

9.7.1 Effect of drainage

Peat soils are distinguished from mineral soils by a relative high nitrogen delivery. Therefore they are highly productive. Without additional nitrogen application a gross yield of 10 tons dry matter (D.M.) per ha has been reached at a shallow drainage of 20 to 40 cm below the surface. In comparison with sandy and clay soils, giving a gross yield of 6 to 8 tons D.M., such peat soils give a yield that is 2 to 4 tons D.M. per ha higher.
At a 50 cm deeper drainage (70 to 100 cm) the gross yield increased with 2 tons to 12 tons D.M. per ha without additional nitrogen application. This is an increase of about 20% on the average as a result of deeper drainage (see Table 6 and Figure 13).
According to Figure 13A a yield of 12 tons D.M. can be reached on the well-drained soil without nitrogen application, the same as on the shallowly drained soils with an application of about 150 kg of addition-

Table 6. Mean gross dry matter yield of grass at different levels of nitrogen fertilizer application and different depths of the ditch water level in the period 1970 through 1974

Experimental field	Ditch water level (cm below the surface)	Additional nitrogen ($kg.ha^{-1}$)		
		0	150	300
Hoenkoop	40	10.6	12.6	13.6
	70	11.2	13.0	13.7
	100	13.3	14.7	15.0
Bleskensgraaf	40	9.6	12.0	12.8
	70	11.1	12.2	13.1
	100	13.9	15.0	15.1
Zegvelderbroek	20	10.1	12.4	13.2
	30	11.3	13.4	14.2
	70	11.4	12.1	12.3
	80	12.7	13.6	13.8
Mean at a ditch	20- 40	10.3	12.5	13.4
water level of	70-100	12.3	13.4	13.8

al N. In this manner the yield depression caused by shallow drainage can be compensated for by nitrogen fertilizer. At a shallow drain depth the efficiency of an additional 150 kg N amounted to 15 kg D.M. per kg N and no more than 7 kg D.M. for well-drained soil. At an application of 300 kg additional N the efficiency decreased to respectively 6 and 3 kg D.M. per kg N. The effect of 300 kg additional N per ha on the well-drained soil compared to the effect reached with 150 kg N amounts to no more than to 0.4 tons D.M. or 3%.

It may be concluded the discussed peat soils are very productive, yields of 13 to 14 tons D.M. per ha can be reached on the average.

The higher yield of dry matter when applying deeper drainage is to be ascribed to a better aeration of the topsoil. The circumstances then are more favourable for taking up nitrogen from the soil and the efficiency of an additional N-application will be lower.

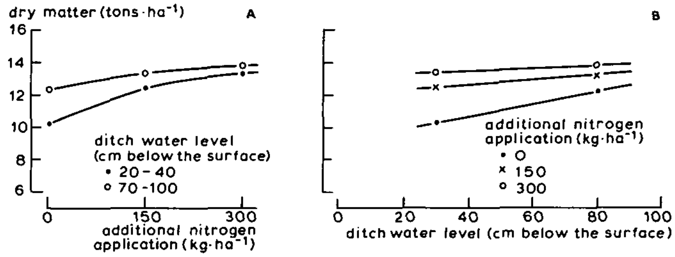

Figure 13 A, relationship between mean gross dry matter yield in tons.ha^{-1} and additional nitrogen application at different drain depths of the experimental fields Hoenkoop, Bleskensgraaf and Zegvelderbroek during the period 1970 through 1974; B, relationship between mean gross dry matter yield and drain depths of the three experimental fields for different additional nitrogen applications during the period 1970 through 1974

9.7.2 N-uptake from the soil

That the nitrogen take up from the discussed low moor peat soils is important is demonstrated by Table 7 and Figure 14.

The N-uptake from the soil has been calculated from the N-content of the gross dry matter yield. The N-content has been determined in the years 1973 and 1974 for the experimental fields Hoenkoop and Bleskensgraaf and in 1970 through 1974 for Zegvelderbroek.

In mineral soils with a yield of 6 to 8 tons D.M. per ha and an N-content of 3%, the N-uptake amounts to 240 kg per ha as a maximum. On shallowly drained peat soils with a D.M. yield of 10 tons and an N-content of 3.2% the uptake is 320 kg N per ha, so an additional uptake of 80 kg per ha.

On well-drained (100 cm below the surface) peat soils with a D.M. yield of 13.5 tons and an N-content of 3.55%, the uptake increases to 480 kg N per ha. This is an additional N-supply of 240 kg per ha.

Deeper drainage of peat soils highly increased the uptake of nitrogen from the soil resulting from a more favourable aeration of the topsoil.

Table 7. Uptake of soil nitrogen without additional N-application in kg per ha at different drain depths

Experimental field	Ditch water level (cm below the surface)	N-uptake ($kg.ha^{-1}$)
Hoenkoop	40	336
	70	400
	100	496
Bleskensgraaf	40	256
	40	320
	70	368
	100	544
Zegvelderbroek	20	320
	30	352
	70	400
	80	464

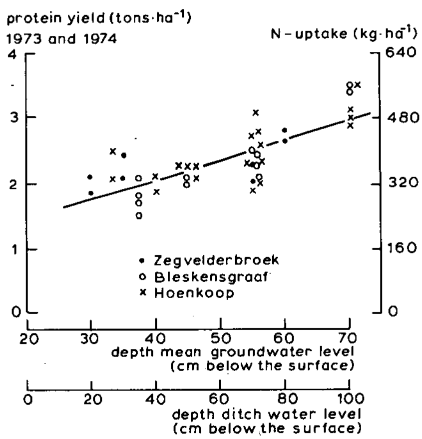

Figure 14 Protein yield of grass without additional nitrogen application and nitrogen uptake from the soil as a function of the depth of the ditch water respectively groundwater level

This means a higher production with a lower additional N-application. On the other hand, the increased N-supply by the soil is caused by decomposition of unrenewable organic matter. The loss of organic matter causes a decrease of the total volume of peat and consequently a subsidence of the surface. This aspect will be dealt with in a following chapter.

9.7.3 Grass growth in spring

Important for the management of intensive dairy farms is the course of the grass production during the growing season. A regular production without great fluctuations is required and in spring the date of reaching of a certain production available for grazing or mowing is important. A production of 1.5 tons D.M. can be regarded as a sufficient production to start the grazing season.
In other experiments on well-drained peat and clay-over-peat soils it has been found that with an additional N-application of 70 $kg.ha^{-1}$ a yield of 1.5 tons D.M. was reached on the average 4 days earlier in spring than on shallowly drained soils (see Figure 15).
On well-drained soils grass growth starts earlier in spring, which means that additional nitrogen can be applied at an earlier date. In the Netherlands the optimal period for the first N-application generally is the first part of March for well-drained soils, and the second part of

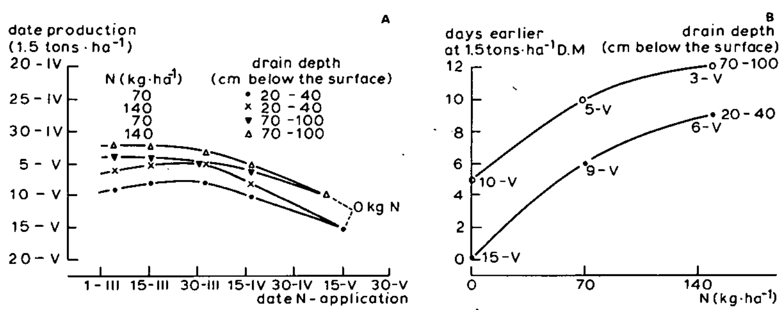

Figure 15 Number of days of an earlier grazing yield as a function of additional nitrogen application for different drain depths of peat and clay-covered peat soils in the period 1969 through 1971

March for shallowly drained soils. However, the last mentioned soils do not often possess a sufficient soil strength in this period, so nitrogen application sometimes is to be delayed till mid-April, resulting in an additional two days delay of reaching 1.5 tons D.M. Then the total difference amounts to six days in favour of the well-drained soils.
A production of 1.5 tons D.M. generally is reached in the last week of April. The growing season starts relatively early in the peat area discussed.
On well-drained soils a higher yield not only is reached in spring at the time of the first cut but also in the following cuts. Past June, however, the grass production on the average has an equal course on shallowly and deeply drained soils.

9.7.4 Influence of weather conditions

The favourable effect of deeper drainage is related to the precipitation during the growing season. In a wet summer as 1972 with about 400 mm rainfall in the period of April through August, the gross yield of well-drained soils without additional N-application amounted to 14.5 tons D.M. per ha and to 10 tons at a shallow drainage, so a difference of 4.5 tons D.M. per ha. These figures concern the experimental field Zegvelderbroek. After application of 300 kg N the yield increased to 15.5 respectively 14.4 tons per ha. The difference then decreased to about 1 ton D.M. The yield depression caused by shallow drainage for the greater part was compensated for by additional N-application.
In the extremely dry summer of 1976 with about 100 mm rainfall in the period April through August, the gross yield of the deeper drained soil without N-fertilizing amounted to 9 tons D.M. per ha and 11 tons D.M. on the shallowly drained soil. Under these weather circumstances the total yield of the shallowly drained soil was 10% higher, and the total yield of the deeper drained soil was 38% less than the yield in 1972. During the period June through September the production on the last mentioned soils was very low: 2.6 tons D.M. per ha. The yield on the shallowly drained soils amounted to 3.8 tons D.M. which also is a low production, but 1.2 tons higher than on the well-drained soils. The additional N-application had a little positive influence.

The extremely dry summer was also very unfavourable for the production on the deeper drained peat soils without clay cover, as in Zegvelderbroek.

9.7.5 Irrigation

In 1976 an experiment with irrigation was carried out on the well-drained soils. It appeared that the efficiency of sprinkler irrigation after desiccation of the top layer (0 - 20 cm) was very low due to cracks and macropores. Most of the water supplied did flow to the subsoil and was evacuated to the ditch without sufficiently rewetting the topsoil. Afterwards in July the water level in the ditches was raised to 20 cm below the surface by a continuous water inlet from the polder to prevent the subsurface outflow. Then the groundwater level within a week had risen to 40 cm below the surface. This was in contrast with the high water level blocks where the groundwater subsided to 100 cm below the surface, so 80 cm below the ditch water level. Here the low permeability of the strip along the ditch played a role. In the other case the soil of the strip along the ditch desiccated and cracked, which resulted in a high permeability.
However, a groundwater table of 40 cm below the surface on its own did not restore grass growth because the root zone (0 - 20 cm) remained dry. Grass growth only started after rewetting the root zone by sprinkler irrigation in combination with raising the groundwater level to 40 cm below the surface. A reswelling of the soil took place and it regained its required moisture content. Sprinkler irrigation combined with a high ditch water level gave a yield of 14.8 tons D.M. without nitrogen and 16.5 tons D.M. after applying 300 kg additional N per ha. Comparing this with the yield of the block without irrigation (9 tons D.M. at 0 kg additional N and 9.9 tons D.M. at 300 kg additional N) an increase of 64% respectively 67% was reached.
In practice the farmers applied flood irrigation and in this way quickly restored the moisture content of the topsoil too. Flood irrigation, however, requires a great quantity of water, namely 1000 m^3 per ha. Moreover, flood irrigation is risky with regard to the possibility of a following rainy period. Then the soil strength will be insufficient

with as unfavourable results poaching by cattle or tracks of machines and lower net yields. Furthermore the surface has to be flat to prevent runoff. Therefore sprinkler irrigation is to be preferred and it has to be started befor desiccation of the root zone has occurred.
The extremely dry summer of 1976 showed that one can get into trouble with deeper drainage of peat soils not having a clay of sand cover after desiccation of the top layer. At a constant low water level restoring of the moisture capacity passes very slowly (Van Wallenburg, 1977). A rapid restoring could be achieved by saturation of the topsoil by flood or sprinkler irrigation combined with a temporarily high ditch water level.

9.8 Subsidence

9.8.1 Surface subsidence

Deeper drainage of peat soils generally results in surface subsidence. From its reclamation in the Middle Ages, the surface of the western peat

Table 8. Surface subsidence, subsidence of the subsoil (settlement) and of the topsoil (shrinkage oxidation inclusive) in mm at different ditch water levels in the period 1969 through 1979, according to measurements

Field	Ditch water level (cm below the surface)	Surface subsidence (mm)	Settlement (mm)	Settlement (%)	Shrinkage incl. oxidation (mm)
Z-13	20	77	28	36	49
Z- 8	30	48	11	23	37
Z-20b	50	74	21	28	53
Z- 3	70	155	32	21	123
Z-16	80	110	23	21	87
Z-20a	80	110	31	28	79
H-E	40	39	6	15	33
H-D	70	33	8	24	25
H-B	100	111	27	24	84
Bl-V	40	53	7	13	46
Bl-III	70	69	5	7	64
Bl-I	100	154	40	26	114

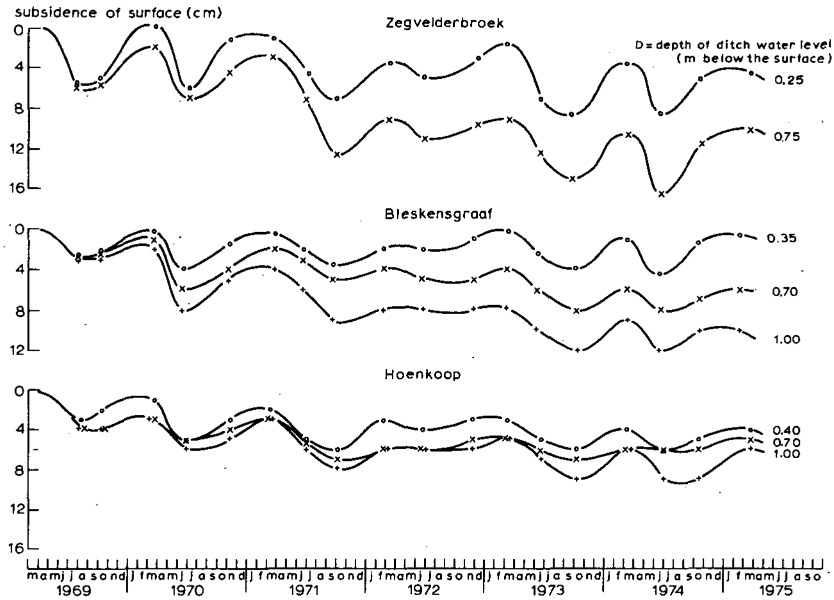

Figure 16 Subsidence of the soil surface in the period 1969 through 1975 in the experimental fields Zegvelderbroek, Bleskensgraaf and Hoenkoop at different drain depths

area in the Netherlands gradually subsided. Initially the surface elevation was about 0.5 m above sea level. In a period of 8 to 10 centuries the surface subsided to 1 to 2 m below sea level, so about 2 m in spite of a continuously shallow drainage (see Table 8 and Figure 16) (Schothorst, 1977).

In the period 1969 through 1979 at the traditional ditch water levels of 20 to 40 cm below the surface, the surface subsided 5 cm on the average. The extremely dry period from 1975 through 1976 mainly is responsable for this large subsidence. The surface is not subsiding at a constant rate as the rate depends on the weather conditions. The surface subsides in summer, more in a dry than in a wet summer (see 1971 respectively 1975 and 1972), and rises in winter. In a dry winter the reswelling is limited (1971-1972). The surface can fluctuate with 4 cm on clay-covered peat soils to 8 cm on peat soils without a clay cover as in Zegvelderbroek.

After deeper drainage the subsidence increases, especially during the

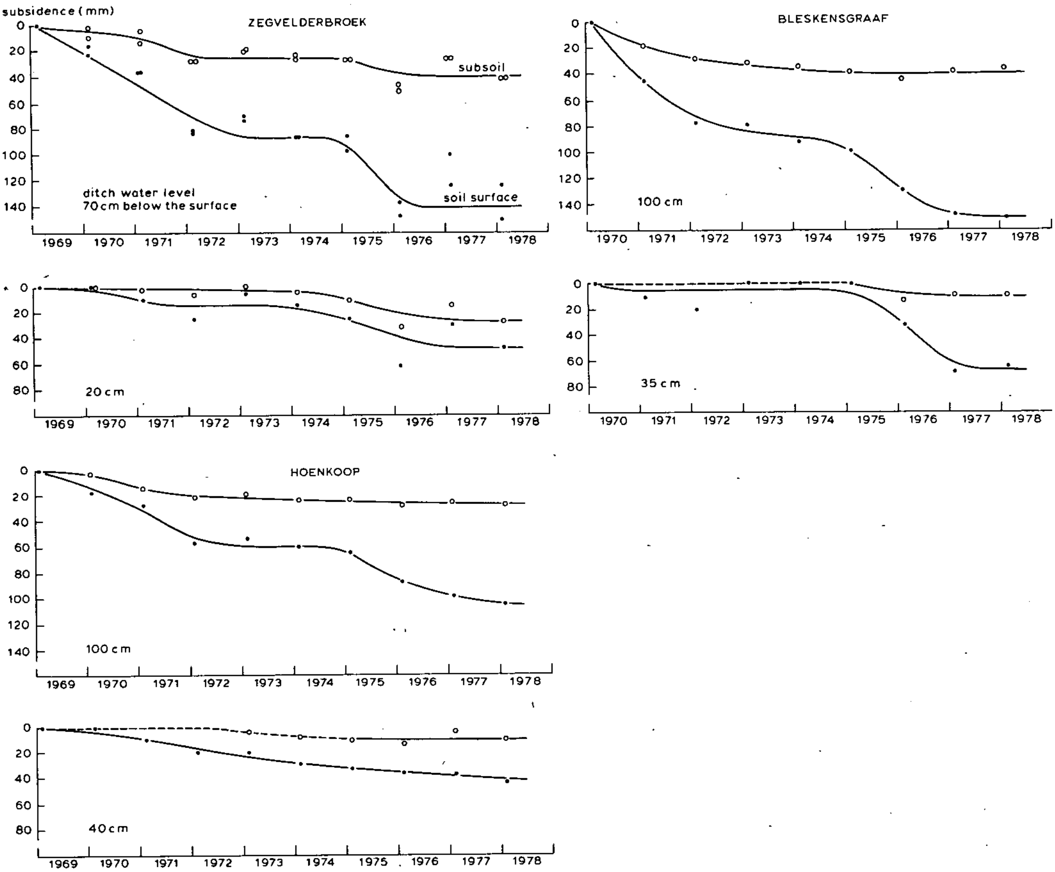

Figure 17 Subsidence of the soil surface and the subsoil (deeper than 1 m below the surface) at different drain depths on the experimental fields Zegvelderbroek, Hoenkoop and Bleskensgraaf during the period 1969 through 1977

first years after deeper drainage (see Figure 17). After 11 years the surface subsidence amounted to a maximum of 15 cm at a 50 cm deeper drainage (see Table 8).

Surface subsidence results from a decrease in soil volume. With regard to the cause of subsidence due to drainage of peat soils three components can be distinguished, i.c.:

a Settlement of the subsoil below the phreatic surface. It is a mechanical process as a result of a drawdown of that surface. Because of the decreased buoyancy the load of the topsoil increases with 1 g.cm^{-2} for each cm the groundwater is lowered and the subsoil below the phreatic surface will become more compressed.

b Shrinkage of the topsoil above the phreatic surface. This is a physical process due to highly negative water pressure heads under influence of an evaporation surplus.

c Oxidation of organic matter resulting from biochemical processes above the groundwater level. Under favourable aeration conditions micro-organisms decompose organic matter.

9.8.2 Settlement of the subsoil

On the experimental fields the surface subsidence was regularly measured 2 or 3 times a year. The settlement of the subsoil below the maximum depth of the phreatic surface of 100 cm below the surface was measured by means of disks. In a row and at vertical intervals of 20 cm, metal disks were placed at different depths from 20 to 140 cm below the surface in the undisturbed soil profile. The elevation of the disks was measured with a leveling instrument with respect to a fixed point on an iron pole driven into the sandy subsoil to a depth of 10 m below the soil surface. In this way the subsidence of the different layers could be measured with an accuracy of 1 mm.
As can be seen in Table 8 the settlement of the subsoil in a period of 11 years amounted to 40 mm as a maximum. Settlement mainly appears in the first years of deeper drainage. After 3 years of deeper drainage 70% of the total settlement has been realized. Afterwards the settlement has hardly been influenced by the extremely dry period from 1975 through 1976, while the surface subsided considerably. After 11 years the settlement amounted to 20 to 25% of total subsidence.
It may therefore be concluded that a groundwater table permanently lowered with 25 to 30 cm results in a maximum settlement of 40 cm (see Figure 17). Since its reclamation in the Middle Ages the land never was drained as deep as it is now in the experimental fields. Therefore it is plausible to assume that the surface subsidence in the past mainly is to be ascribed to a decrease in volume of the topsoil due to shrinkage and oxidation of organic matter.

9.8.3 Shrinkage

Shrinkage occurs in the topsoil above the phreatic level due to highly negative soil water pressure heads caused by an evaporation surplus. It can be calculated by comparing the bulk density of the soil layers above and below the phreatic water level. Because shrinkage is mainly determined by the organic matter content and not by the minerals in the soil, the bulk density calculations of organic matter can be used. This has been applied to 8 plots of the peat soil in Zegvelderbroek (see Table 9). In this Table the following symbols have been used:

W_s = bulk density of solids, $W_h + W_m = W_s$;

h = weight percentage of organic matter;

S_{sh} = shrinkage in cm, $S_{sh} = \dfrac{d_2 \cdot W_{h2}}{W_{h1}} - d_2$;

W_{h1} = bulk density of organic matter below the maximum groundwater depth (80 cm below the surface) = 0.12 $g.cm^{-3}$, $W_h = W_s.h$;

W_{h2} = the same, but above the maximum depth of the groundwater table;

Table 9. Mean bulk density of organic matter (W_h) and of minerals (W_m), calculated shrinkage (S_{sh}), shrinkage including oxidation ($S_{sh} + S_o$) and oxidation (S_o) of 8 peat soil plots of the experimental field Zegvelderbroek

Depth (cm below the surface)	W_s ($g.cm^{-3}$)	h (%)	W_{h2} ($g.cm^{-3}$)	W_{m2} ($g.cm^{-3}$)	S_{sh} (cm)	$S_{sh} + S_o$ (cm)	S_o (cm)
0 - 10	0.49	49	0.24	0.25	10	90	80
10 - 20	0.41	54	0.22	0.19	8	66	58
20 - 30	0.26	69	0.18	0.08	5	22	17
30 - 40	0.20	75	0.15	0.05	3	10	7
40 - 50	0.17	76	0.13	0.04	1	6	5
50 - 60	0.17	76	0.13	0.04	1	6	5
60 - 70	0.15	80	0.12	0.03	0	2	2
70 - 80	0.15	80	0.12	0.03	0	2	2
total					28	204	176

W_{m1} = bulk density of minerals below the maximum groundwater depth, $W_m = W_s(1 - h) = 0.025\ g.cm^{-3}$;

W_{m2} = bulk density of minerals above the maximum groundwater depth;

d_2 = actual thickness of the layer considered = 10 cm;

d_1 = initial thickness to be calculated, $d_1 = \frac{d_2.W_{h2}}{W_{h1}}$ and $S_{sh} = d_1 - d_2$.

This system of calculating shrinkage and oxidation is only possible for homogeneous peat soils without fluvial or marine influences, as in Zegvelderbroek.

According to Table 9 28 cm shrinkage could be calculated and it can be said that generally speaking shrinkage amounted to about 30 cm. So the total subsidence of 2 m in the past can only be explained for a small part (15%) by shrinkage of the topsoil.

9.8.4 Oxidation of organic matter

When the subsidence in the past cannot be explained by settlement of the subsoil and by shrinkage of the topsoil, the only possibility that remains is the oxidation of organic matter.

The higher amount of mineral elements in the top layers possibly is to be ascribed to oxidation. When organic matter oxidizes the total quantity of mineral elements will remain the same, but their weight percentage will increase.

Applying the same method of calculation as used to calculate shrinkage, the oxidation can be calculated by means of the bulk density of the mineral soil according to:

$$S = \frac{d_2.W_{m2}}{W_{m1}} - d_2.$$

This concerns the decrease of soil volume by oxidation including shrinkage, so $S = S_{sh} + S_o$ and therefore $S_o = S - S_{sh}$. The results of this calculation are also given in Table 9.

A total shrinkage of 204 cm was found from which 176 cm is to be ascribed to oxidation of organic matter, so 86% of the total subsidence. For a period of 9 centuries this means a mean oxidation rate giving a

2 mm subsidence per year.
The method of calculation described can explain that an initial peat formation with a thickness of 1.5 m, a bulk density of 0.15 $g.cm^{-3}$ and an organic matter content of 80% has been reduced to 20 cm muck soil with a bulk density of 0.45 $g.cm^{-3}$ and an organic matter content of 50%.
The conclusion that oxidation of organic matter of the peat soils plays a very important role in the process of subsidence is supported by the nitrogen supply from soil as dealt with in section 7.2.
In Table 7 the soil nitrogen uptake is given at different drain depths.
To calculate the nitrogen uptake from peat soils the maximum nitrogen uptake from mineral soils has been used as reference level, being 240 kg N per ha. The uptake from nitrogen fertilizers can be supposed to be about 50% of the additional applied nitrogen. The same applies to soil nitrogen. The N-content of the organic matter in the topsoil accounts to 4% according to analyses.
At a nitrogen take up of 320 kg the loss of organic matter is

$$\frac{320 - 240}{0.5 \times 0.04} \doteq 4000 \text{ kg.ha}^{-1} \text{ (dry weight)}.$$

At a mean bulk density of organic matter in the topsoil of 0.2 $g.cm^{-3}$ (see Table 9) the loss of organic matter, expressed in cm subsidence, is

$$\frac{0.04 \text{ g.cm}^{-2}}{0.2 \text{ g.cm}^{-3}} = 0.2 \text{ cm}.$$

In this manner the loss of organic matter has been calculated as given at different drain depths (see Table 10). According to Table 10 the loss of organic matter at the traditional drain depths of 20 - 40 cm below the surface agrees with a subsidence of 2 m in 9 centuries (2 $mm.year^{-1}$).
At a deeper drainage of 70 cm the average loss increases to 4.2 mm per year and at a drain depth of 1 m it increases to 7 $mm.year^{-1}$.
When these values are compared with the measured values for shrinkage including oxidation (S_{sh} + S_o in Table 8), the results given in Table 11 are obtained for the period 1969 through 1979.
The oxidation rates for the period 1969 through 1979, with the exception of one (H - D), all are lower than the measured values for shrinkage including oxidation. This means that the values calculated for oxidation are not too high and that the difference between S_o and S_{sh} + S_o

Table 10. Loss of organic matter in metric tons (dry weight) per ha and in cm subsidence for different drain depths

Experimental field	Drain depth (cm below the surface)	Loss of organic matter ($tons.ha^{-1}$)	The same ($mm.year^{-1}$)
Hoenkoop	40	4.8	2.4
	70	8.0	4.0
	100	12.8	6.4
Bleskensgraaf	40	0.8	0.4
	40	4.0	2.0
	70	6.2	3.1
	100	15.2	7.6
Zegvelderbroek	20	4.0	2.0
	30	5.6	2.8
	70	8.0	4.0
	80	11.2	5.6

Table 11. Oxidation and shrinkage (in mm subsidence) over the period 1969 through 1979 (Z = Zegvelderbroek; H = Hoenkoop; Bl = Bleskensgraaf)

Field	$S_{sh} + S_o$	S_o	S_{sh}
Z-13	49	22	27
Z- 8	37	31	6
Z- 3	123	44	79
Z-16	87	62	25
H-E	33	26	7
H-D	25	44	-19
H-B	84	70	14
Bl-V	46	22	24
Bl-III	64	34	30
Bl-I	114	84	30

can be considered as being irreversible shrinkage. The negative value for shrinkage of field H - D can be explained by swelling because in this field the ditch water level has been raised to 40 cm below the surface in 1977.
It may therefore be concluded that at a shallow drain depth the subsidence by oxidation amounts to about 2 mm per year and that it increases to about 6 mm per year at a drainage 50 cm deeper.
The process of oxidation courses is slow but continuous. In contrast the settlement of the subsoil and the shrinkage of the topsoil mainly occur during the first years of deeper drainage.
After a period of 30 years a surface subsidence of about 25 cm may be expected from which respectively 4 cm is to be ascribed to settlement, 4 cm to shrinkage and 18 cm to oxidation. So at a fixed ditch water level during this period, the efficiency of the deeper drainage amounts to about 50%.
At a traditionally high water level of 20 to 40 cm below the surface a subsidence of 8 to 10 cm can be expected to occur. This implies that the additional subsidence due to deeper drainage amounts to 15 to 20 cm after 30 years.
This applies to peat soils without a clay cover at an initial drain depth of 25 cm which is lowered to 75 cm below the surface and for peat soils with a clay cover of 30 to 40 cm thickness at an initial drain depth of 40 cm which is lowered to 100 cm below the surface. At the same drain depth, a peat soil without a clay cover is more susceptible to subsidence than one having a clay cover.

9.9 Summary

The main problem of the western peat area in The Netherlands is the bearing capacity of the topsoil in wet periods because of the increased mechanization and the intensifying of the management of dairy farms during the last decades. At the traditional drain depths of 20 to 40 cm below the surface, the bearing capacity now often is insufficient. It could be improved with good results by lowering the ditch water levels to 70 to 100 cm below the surface. The deeper drainage is coupled with a better aeration of the topsoil.

In spite of their traditionally shallow drainage these low moor peat soils are very productive with a mean yield of ten metric tons of dry matter per ha without additional nitrogen application. Deeper drainage favours the natural nitrogen uptake from soil to a great extent, resulting in still higher yields of dry matter and protein and in an earlier grazing yield in spring.

This profit is coupled with a disadvantage. Because of the better aeration of the topsoil at deeper drainage, the more organic matter is faster decomposed. This not only gives more nitrogen free, but it also gives a loss of organic matter respectively a reduction in soil volume which results in a subsidence of the surface.

Oxidation of organic matter is the factor most responsible for surface subsidence in the present as well as in the past. The surface subsidence of 2 m in the past may be ascribed for 85% to oxidation of organic matter. This agrees with the calculated subsidence of about 2 mm per year. The same rate has also been measured on the experimental fields at traditional drain depths. At a 50 cm deeper drainage the oxidation rate increases to 6 mm per year.

Another disadvantage can appear in very dry summers, especially on peat soils without a clay cover, after desiccation of the root zone. When normal weather conditions are regained, rewetting of the topsoil is a difficult and slow process because a quick discharge of precipitation to the subsoil respectively to the ditch through cracks and macropores occurs, without rewetting the topsoil. A quick restoring of the required moisture content of the root zone can be achieved by means of sprinkler or flood irrigation combined with a temporarily high ditch water level.

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10 REVIEW OF CHAPTER 9

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The paper presents the comprehensive analysis of possibilities and effects for improvement of grass-land on peat land and readjust it for the needs of intensive farming. There is tendency to improve the bearing capacity with a simultaneous crop increase and earlier start of the pasture season. Necessary lowering of groundwater level from 20-30 cm to 70-80 cm reinforce the oxidation of the organic matter and subsidence of the peat land surface, and in dry periods effects in soil overdrying. It is also connected with difficulties in wetting of an overdried topsoil.
In 1968-1979 on three objects observations were made on the influence of different depths of water levels in soil and ditches, moisture content and tension, bulk density, kind of grass vegetation on the bearing capacity, crop, nitrogen uptake, starting of the pasture season, effects of gravitation and sprinkling irrigation and the course of low moor peat land subsidence.
The key problem is the dependence between the level of groundwater and moisture content and tension of upper layers of the soil profile. In the experimental field Zegvelderbroek there were deep wood-sedge peat on a sandy subsoil, having been used as meadows for hundreds years. The traditional high level of groundwater (0.2-0.3 m) must have inhibit the muck process.
The porosity of root zone (0-20 cm) is about 70-75% and the subsoil extends to 90%. In spring by lower drainage in this zone the air content is 5 vol.%, by deeper drainage 15 vol.%. The ash content of the top layer is ca. 60% and the bulk density 0.55 g/cm^3. The available moisture

(pF 1.8-4.2) in the effective root zone (0-20 cm) amounts to 65 mm in a shallowly drained, and 49 mm in a deeply drained soil, the moisture content 65 vol.% and 57% respectively. However, such comparison is not fully correct because in the conditions of deep drainage the thickness of root zone increases to 30 cm (air volume more than 8%) what increases the available moisture content from 49 to 85 mm.

If the mentioned soil would be classified into the muck-peat soils (see Okruszko's paper) it would be marked MtIIIb. It means that a highly mucked stratum of 30 cm thickness is deposited on moderately decomposed peat. The muck of that kind of soil in Poland has got mostly a lower bulk density (0.30 g/cm^3) and higher porosity (82%). In spring with low groundwater level (30 cm) the moisture content of top layer is 72 vol.% and with deeper (70 cm) level 65 vol.%, respectively the air content 10 and 17.2 vol.%. The optimal groundwater level is taken in spring 30 cm and in summer 60 cm. The available water content in top stratum of 30 cm is 94 mm. When the subsoil is a highly decomposed peat, the optimal levels of groundwater would be in spring 35 cm and in summer 45 cm. These data would point to too high lowering of groundwater in Zegvelderbroek, what in long-lasting periods of droughts would effect later on in overdrying of top strata of soil and difficulties with its moistening. The overdrying of such soils for their productivity is presumably more dangerous than a greater oxidation of organic matter. The wetting of overdried organic soils goes very slowly and not smoothly. In spring 1980 on low moor peat land in Ankelohe near Bremerhaven after few weeks of spring drought and later rains there was noticed the fluctuation of moisture content of the topsoil from 30 to 60 vol.%. The full wetting is obtained only after soil saturation through irrigation or in the next winter. During laboratory investigation it was checked that lowering of muck moisture content from pF 0 to pF 2 last about 20 days, while repeated saturation 35-44 days.

Presented results clearly show that proper bearing capacity is obtained on low moor peat land with groundwater level to 70 cm, when the moisture content of top stratum is 65 vol.% and moisture tension 20-70 cm H_2O. The Figure 11 shows separate curves representing the relationships that exist between penetration resistance and moisture tension for different depths of groundwater level. However, what is surprising, it is the fact that with the same moisture tension of topsoil the bearing capacity

is higher by deeper drainage. It can be explained by hysteresis, if it is assumed that by lower drainage the process of soil dewatering is observed (drying curve for the relationship between moisture content and moisture tension) and with deeper drainage the process of soil wetting is noticed (wetting curve). In such a situation by the same moisture tention of the topsoil the moisture content for lower drainage would be noticeably higher than for deeper drainage. A higher moisture content univocally lowers the bearing capacity (Figure 10). I do not think that the difference could be explained with bulk density that is differentiated by swelling of more wet soils. Figure 12 shows that more significant influence for bearing capacity would be the increase of bulk density from 0.50 to 1.00 g/cm^3, and such changes do not result from swelling of soil and fluctuation of moisture content from 40 to 70 vol.%.
The higher mineralization of organic matter by deeper drainage enables the lowering of additional nitrogen application, but simultaneously it contributes to permanent lowering of peat land surface through the flameless peat burning and in perspective to peat land decay. It causes as well the necessity of permanent deeper drainage and readjustment of pump stations and ditches to the changing surface levels.
The course of surface subsidence of two peat lands with different depths of groundwater level points to nearly twice higher loss of thickness with deeper drainage (0.7 m). Very noticeable is the influence of dry years (1975 and 1976) on the subsidence. I also observed similar phenomenon on peat land Ritschermoor in the valley of the Elbe.
The surface subsidence of peat lands is in the paper divided into three elements: settlement, shrinkage and oxidation of organic matter. There are big difficulties with the division of the effects of discussed causes. Always the whole effect is measured. Schothorst tried to determine the point of peat shrinkage in subsidence through comparison of bulk density of organic matter and the part of oxidation through comparison of ash content and nitrogen uptake. The shrinkage can only be explained for a small part (15%) of the subsidence. In labour investigations of peat shrinkage I found that this part is about 18%.
Bulk density in Zegvelderborek is 0.45 g/cm^3 in 0-20 cm layer, but in 20-60 cm layer it is in average 0.20 g/cm^3. During investigation led in high peat land Ritschermoor it was checked that bulk density of 0-20 cm layer rose to 200%, and in the stratum 20-60 cm 50% in comparison to the

data before reclamation. For Zegvelderbroek polder the adequate values were 300% and 33%, respectively, If we compare the data from Table 9 as to subsidence values coming from shrinkage and oxidation (S_{sh} + S_o) we see that in the 0-20 cm layer (156 cm) the results 3.5 times higher than in 20-60 cm layer, while in Ritschermoor the results are 4 times higher. In my investigation the comparison of ash contents in such strata showed 4-time difference. The discussed investigations clearly show that the subsidence takes place mainly in 0-60 cm layer and especially in 0-20 cm layer. The description of shrinking influence through comparison of bulk density of organic matter content is not correct, because peat compactability can also be an effect of pressure and the changes from a fibrous structure of peat to a granular structure of muck. Part of irreversible shrinkage in whole shrinkage is accord to authors investigations about 5-15%.

The description of size of organic matter oxidation through comparison of top stratum and deeper strata ash content is correct. It shows that in described conditions oxidation causes 86% of subsidence which means that during 9 ages of agricultural utilization the yearly loss of peat was 2 mm.

However in 1967-1979 the size of subsidence was 5 mm/year by low drainage or 15 mm/year by deeper one. With deeper drainage (70-90 cm) on high moor peat land Ritschermoor in 1968-1979 the average subsidence was noticeably higher and rose on grassland to 19-32 mm/year.

The described complex investigation points that intensive mechanized farming on low moor peat land with grass-land must cause a quicker peat loss and rise of reclamation costs. Therefore there exists a conflict between the agricultural needs and the requirements of environment protection. The presented effects of the above described activities should enable to make a decision what kind of reclamation to choose and how to use the land.

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11 URBAN USE OF PEAT SOILS

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11.1 Introduction

By the urban use of soil we mean making the soil suitable as living, working and recreational area, including the infrastructure.
In this article successively will be dealt with the following aspects of the urban use of peat soils in The Netherlands:

- historical development of the settlement and reclamation of peat soils;
- characteristics of peat concerning the urban use;
- requirements that soil will have to meet for various urban forms of use;
- the means to make the peat soils that are unsuited for urban use suitable;
- future developments in peat areas.

11.2 Historical development of the settlement and reclamation of peat soils

11.2.1 Reclamation

The peat in The Netherlands, now lying below sea-level, has been able to grow during phases of regression in the rising of the sea-level after the last ice-age. In those days raised bogs developed with a natural drainage on the big rivers. The surface of the area was then situated above sea-level.

The peat is situated on the sediments of Calais (old marine clay in the west) or right on the pleistocene subsoil. Large parts of peat have been covered with clay from the Dunkirk transgression (cf. Chapter 1).
In the period 900-1300 A.D. the population in Europe grew constantly. Caused by this growth of the population all over Europe waste soils were being put into use. In The Netherlands these were for an important part peat soils.
The reclamation took place starting from the banks of rivers. The first settlement happened on the levees, consisting of clay.
The levees were overgrown with woods. The names of old towns and villages still end in 'woude' (wood) i.e. Zoeterwoude, Rijnsaterwoude, Spaarnwoude, Hazerswoude. Old names of towns and villages ending in 'berg' (mount) have a pleistocene background.
From the 11th century onwards parcels of land were handed out by the landowner for cultivation. The transfer of the land and also the land itself was called 'coop' or 'cope' (cf. Chapter 3).
The pattern of parcelling of this 'cope' cultivation is very regular. The colonists settled along the river or canal on the parcel allotted to them.
Thus a long-drawn village came into being, with behind the houses parcels running parallel, divided by ditches. Towns emerging from such a cultivation often have names ending in 'coop' or 'koop' (Boskoop, Oldeberkoop).

11.2.2 Land use

On the newly cultivated land cereals were grown for the increasing population. From this can be deduced, that the drainage must have been reasonably well.
The fertilization consisted of mud from the ditches, manure mixed with dunesand and perhaps waste from the towns. The soil was probably also improved with calcareous clay and sandy clay that was taken from underneath the peat.
Besides the oxidation of peat has always attributed to the fertilization of the crop. This may be one of the reasons for the almost completely being absent of lost villages, or *Wüstungen,* that do occur in the rest

of Europe.
Caused by the agricultural use subsidence occurred, whereas the surface of the sea kept rising. Around the year 1200 the situation became troublesome. Count Floris III of Holland had Zeeland dammed in. His son, Count Willem I of Holland, had dykes built in the Southwestern area of Friesland, and he also provided a closed dam around Zuid-Holland. These dykes made further cultivation on a larger scale possible.
The ongoing subsidence caused a rising in the watertable and an increasing unfitness for arable land use.
Around 1500 cattle-breeding must have been the most important source of living. In the 15th and 16th century people passed into poldering and draining by means of windmills.
In the course of time much of the peat has been dug away for heating purposes and for the gaining of kitchen salt as well.
The last has taken a great shape in Zeeland and also in Friesland. Peat digging for household fuel however has been much more extensive. For this the centres of peat areas with moss peat were most suitable, whereas the clayey wood peat alongside the rivers was not dug away.
The result of this was that extensive lakes came into being.
Later on a part of these lakes was reclaimed. Most of the time the sediments of Calais (the old marine clay) are exposed (cf. Chapter 5).
In the polder Giethoorn in Northwestern Overijssel and a number of polders in Friesland this is the pleistocene sand.

11.2.3 Urban development

Towns developed alongside canals, rivers and dug waterways and on the edges of the peat area on the sandy subsoil of the coastal barriers.
At some of these places the Romans already had settlements, i.e. Utrecht, Zwammerdam and Katwijk, all situated alongside the river Rhine.
In the Middle Ages it was the custom that for building the site was raised and the walls of the houses were founded on double rows of piles, that formed the division of the plot of land at the same time.
In Amsterdam for instance sites were raised with waste from the city moats. In the course of time soil in the towns was further raised with

clay, refuse from the town and sometimes with manure. The thickness of the raisings can eventually amount to several metres.

In the 17th century the towns reached a limit that would not extend much farther for two more centuries.

Initially there was still much open space within the city-walls.

In the 19th century the towns extended in an important way, moving farther away from the rivers and coastal barriers. These extensions of the towns are situated in areas where building was accompanied by greater problems and thus was more expensive as in the original hearts of the cities.

Important parts of Amsterdam, Rotterdam, Gouda and Gorkum have been built on peat soils.

One may wonder why exactly in such an area towns have developed.

The development of the towns is a combination of natural and economical factors.

In the early Middle Ages the soil (clay and mineralizing peat soils) could maintain, together with fishery, a growing population. Most of the interior transportation had to take place by boat. The population was therefore fixed on the water to a large extent and a merchant fleet could easily come into being. A merchant fleet needs harbour facilities, therefore towns.

Besides, the situation of the west of The Netherlands with regard to other countries is thus, that cities had to develop. Initially on the less unsuited soils and as a town grew, the extensions of the town came to be situated, from a civil-technical point of view, in more and more unsuitable areas.

The small settlements in the peat-area, originally fully agricultural, also extended. Caterers, non-residents and the tourist-industry required extension of these places as well.

11.3 Characteristics of peat soils in relation to urban use

11.3.1 Introduction

Naturally the groundwater-level of peat soils is high and they have little bearing capacity. With urban use the draining of the works to be

constructed is important.
the necessary requirements are also made for the accessibility of the site.
The peat has come into being under wet circumstances. If a peat soil is being drained, air enters and the peat-mass irreversibly starts to loose water and the water-binding power decreases. The entering air also causes oxidation of the organic matter (cf. also Chapter 9). In cultivated peat soil a further draining takes place by the roots of the plants, through which the density increases with the maturation. To avoid strong settlement, agricultural soils situated on peat therefore were not drained too deeply.
The fact, that peat soils are liable to settlement, plays an important part if measures are taken for the sake of drainage and accessibility. Most of the time these consist of a raising of the ground level or a decreasing of the level of the groundwater or both.
To be able to judge the effect of certain measures to make the soil fit for building, here follows a brief soil mechanical explanation.

11.3.2 Soil mechanical aspects

Peat has a fibroid structure with little strength and it consists for a great deal of water.
The specific gravity of peat comes close to that of water.
In Figure 1 a profile has been drawn of a layer of peat on sand.
With line σw the water pressure has been indicated on a certain level, and with σw the weight of the whole column of ground above a certain level. The difference between ground stress and water stress is grain stress.
In Figure 2 an upper-loading has been applied because of which the ground pressure increases.
In a sandy soil the grain frame takes up the extra loading. The water pressure remains hydrostatic and the increase of the grain stress is equal to the extra loading.
In peat soils the increase of loading can be taken up by peat fibres if the structure has grown compact. Therefore water must flow off first. Since peat is badly permeable, this takes place in a slow way so in the

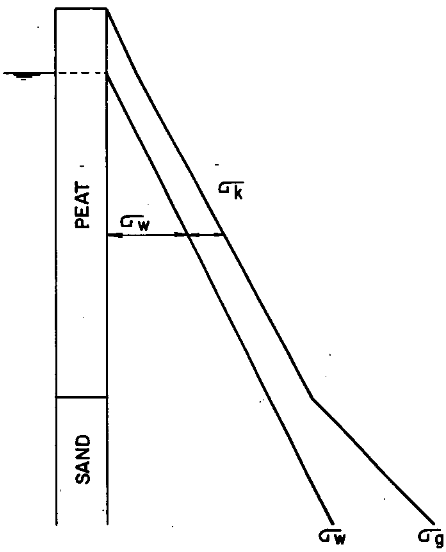


Figure 1

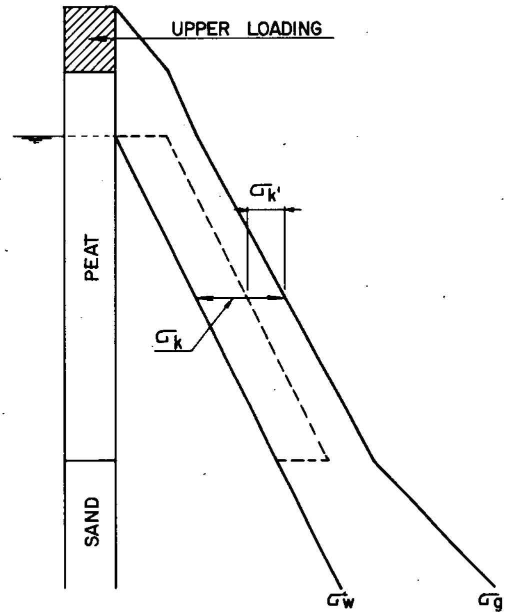


Figure 2

first instance the water takes up the applied loading and the term confined water is used.

If the distribution of the pressure of the water is hydrostatic again, because water has flowed off, the loading has been carried over to the peat. The grain stress then has increased and the volume of the peat has decreased.

In Figure 3 is indicated that a decrease of the level of the groundwater also causes an increase of the grain stress. This can only be caused when water has flowed off and the volume of the ground has decreased. The relation between settlement and increase of grain stress is indicated in the formula of Koppejan, a combination of the formulas of Terzaghi and Keverling Buisman.

The relation has been indicated in Figure 4. The size of settlement depends, among others, on the thickness of the compressible layer and the increase of the grain stress with regard to the present grain stress. The values Cs and Cp depend on the type of soil and are being calculated directly from compression tests.

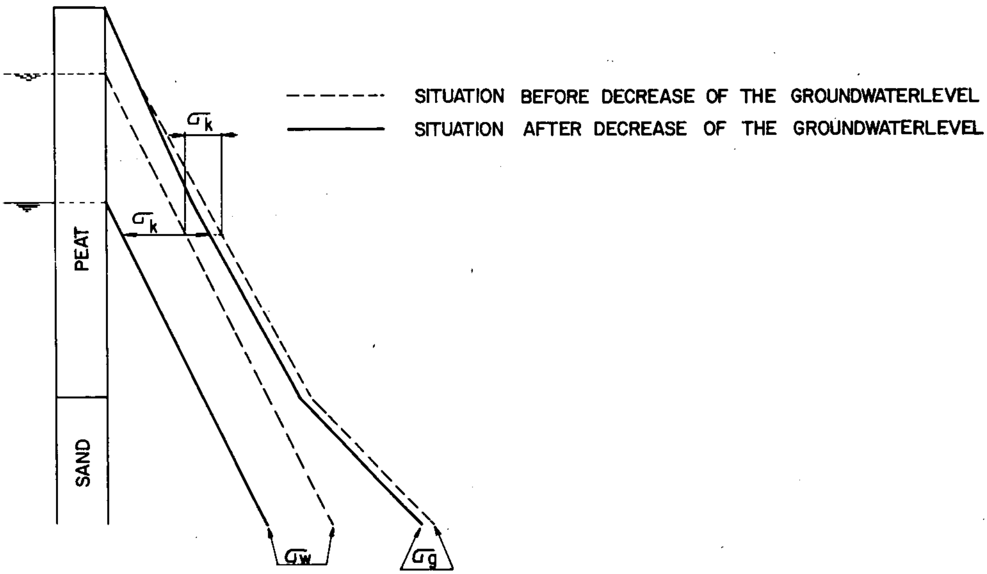
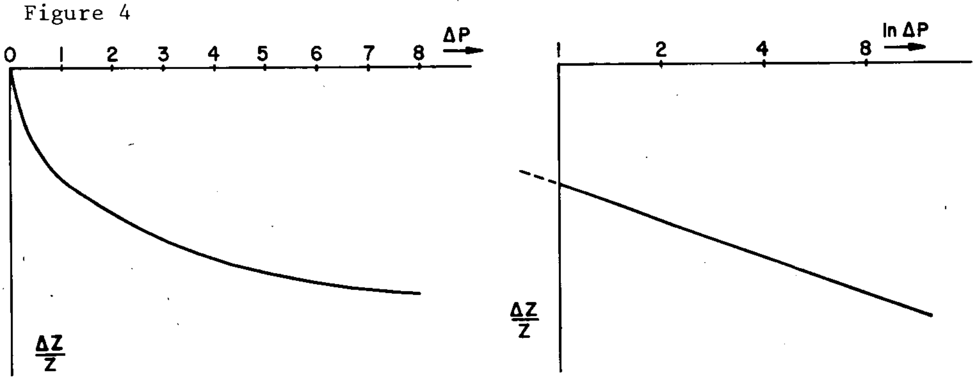


Figure 3

Figure 4



$$\text{KOPPEJAN:} \quad \Delta Z = Z \left(\frac{1}{Cp} + \frac{\log t/to}{Cs} \right) \ln \frac{P+\Delta P}{P}$$

ΔZ = settlement

Z = thickness of the compressible layer

P = present grain stress

ΔP = increase of the grain stress

to = 1 day

t = time counted in days

Cp = primary constant of settlement

Cs = secular constant of settlement

Figure 4

The effect of time on the course of settlement is twofold (Figure 5)

- consolidation
- secular effect

The consolidation theory of Terzaghi is connected with the delay that the compression experiences, caused by the pore water in the soil. First the water must flow off from the compressible layer before settlement occurs. The consolidation therefore will have ended when the water pressure is equal to the hydrostatic pressure.

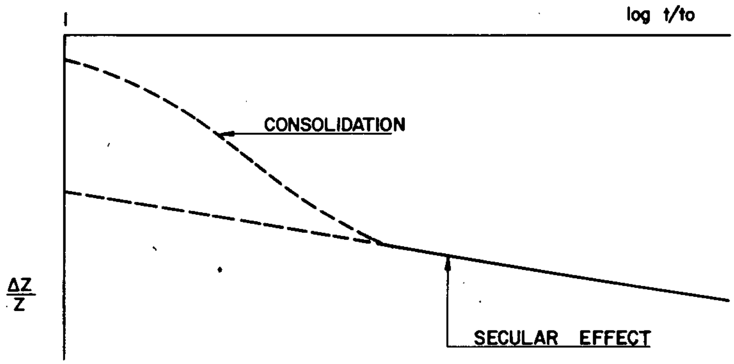


Figure 5

The duration of this period is related with the permeability of the soil, the size of the increase of loading and is proportional with the square of the distance that the extracted water has to cover.
The secular effect of Keverling Buisman has no theoretical end value. It is ascribed to the water fixed to the parts of the soil themselves, and/or connection between the parts of soil.
In peat soils sometimes very low grain stresses can be found. In the calculation $\frac{P + \Delta P}{P}$ then becomes very large, so that non-real settlements are calculated.
By a combination of the 'Elastic law' of Terzaghi from soil mechanics and the 'Law of soil ripening' from soil science Fokkens has been able to meet this. Compression is described by him as a function of:

- the water content of the peat
- the organic matter content of the peat
- the increase of the grain stress

The approach then agrees with reality better.

Till now border effects have not been considered. These effects may consist of:

- the pressing away sideways of sagging layers, caused by which the settlement is bigger than was expected;
- the sticking to elements that do not settle, caused by which settlements are reduced.

Raise and decrease of the groundwater-level cause a process of settlement in a peat area that may be considerable and may stretch out over a long period of time.

Measures, to decrease the damage caused by settlements, are:

- the pressing away or excavating of layers of peat;
- timely applying increases of loading so that settlements have occurred for the greater part before the execution of the actual work gets started;
- the speeding-up of the process of settlement by:
  a) the applying of an extra loading and removal of this when the calculated settlements have occurred (Figure 6).
     This may take place by the application of an extra height as well as by a temporary decrease of the level of the groundwater.
     The effect on the surroundings should, however, be considered.
  b) The speeding-up of the drainage of confined water. This can be done by using vertical drainage (Figure 7).
     The shortening of the distance that the confined water has to cover has a square effect on the decrease of the length of the consolidation time.
     With the application of vertical drainage with peat, use is also being made of the better permeability of this soil in a horizontal direction, with regard to that in a vertical direction.

Another negative quality of peat is the small shear resistance.

The shear resistance of soil is characterized by the angle of internal friction, that is the relation between the vertical grain stress and the available shearing stress (Figure 8).

The shear resistance is used for the stability of soil retaining construction.

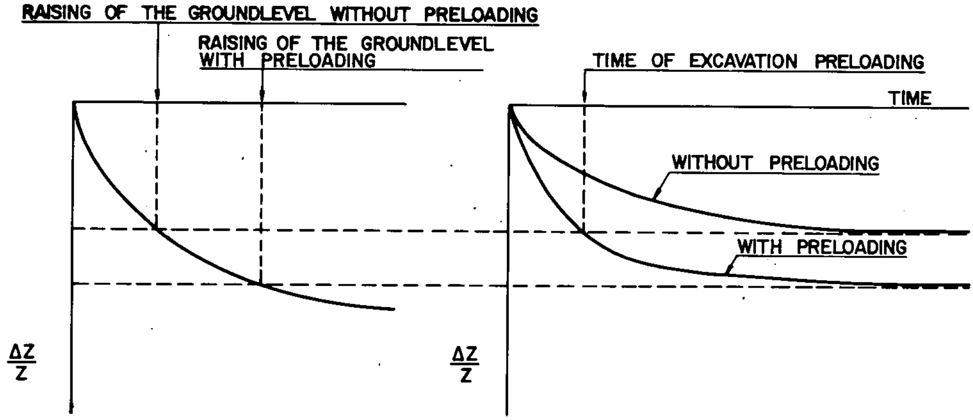


Figure 6

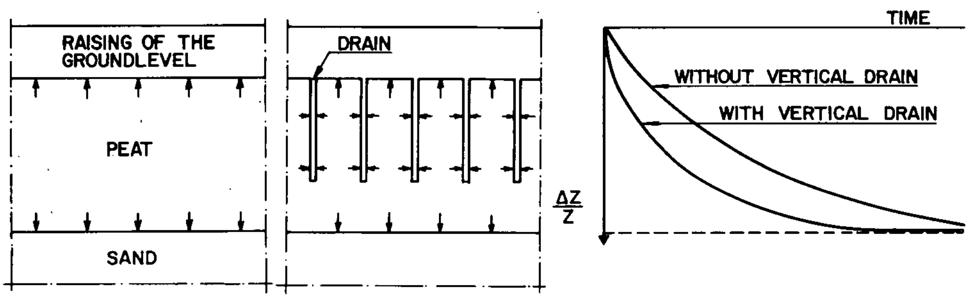


Figure 7

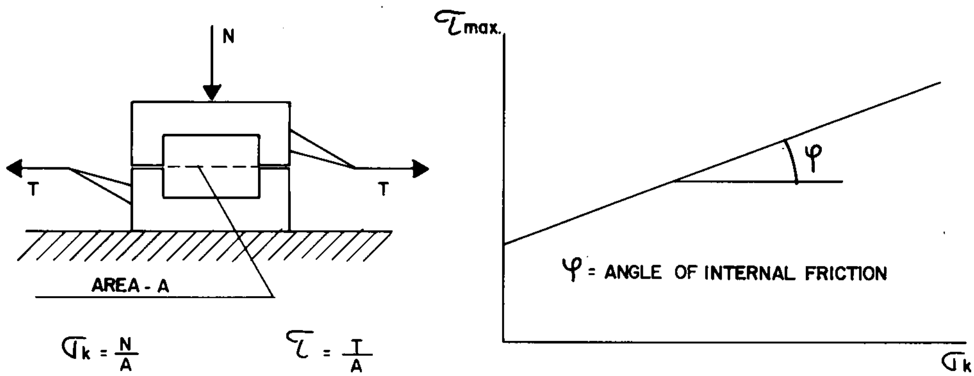


Figure 8

11.3.3 Aggressive groundwater in peat areas

Building materials as concrete and steel may be very strongly attacked by aggressive groundwater in peat soils.

The aggressiveness of groundwater is influenced by a number of factors that are partly interdependent:

- the salt content; a higher ionic strength quickens the attack of building materials;
- acidity;
- the appearance of sulphates and sulphides combined with certain bacteria;
- the presence of complexing organic substances;
- microbiological activity.

I would like to say something more about the microbiological aspect. This is namely the most spectacular aspect.

Micriobiological activity can cause a rapid infection of building materials under aerobic as well as under anaerobic circumstances. Under humid circumstances iron reacts, as most metals do, with (acid) water. With this hydrogen gas is released.

$$Fe + 2H_3O^+ \rightarrow Fe^{2+} + 2H_2O + H_2$$

The hydrogen gas protects the iron from a rapid further infection unless the hydrogen is oxidized by bacteria.

With oxidation of the hydrogen the reaction is strongly accelerated.

A large number of bacteria, in the past belonging to the *Hydrogenomonas genus*, is able to oxidize hydrogen. This is an aerobic process. Under anaerobic circumstances a similar reaction can occur as well. The hydrogen is then removed by bacteria from the *Desulfovibrio* and *Desulfotomaculum genera*. These bacteria are able to reduce sulphate to sulphides, with the aid of hydrogen.

These bacteria are responsible for the so-called anaerobic corrosion.

The created sulphide can react, with the Fe^{2+}-ions, to FeS.

Under aerobic circumstances the presence of sulphides has a devastating effect.

The sulphides are oxidized to sulphates by bacteria of the *Thiobacillus genus;* with this reaction considerable numbers of H_3O^+-ions are released

(acid). *Thiobacillus thio-oxydans*, in the past also known as *Thiobacillus concretivorans*, is resistant to, and still biologically active with an acidity pH = 2.
A production of acid like that is strongly destructive to iron and steel.
Alternating aerobic and anaerobic conditions and the presence of sulphates and sulphides thus may cause a continuous breakdown of iron and concrete. Under aerobic circumstances oxidation of sulphides to sulphates and the production of acid takes place.
Under anaerobic circumstances the sulphates are reduced to sulphides again.

11.4 Means to make peat soils suitable for use

11.4.1 Building sites

People will realize development of a town by preference on soils that have sufficient bearing capacity and possibilities for drainage. Thus on a building site it must be possible to transport and store materials. Cables and pipes must preferably be placed above the level of the groundwater. For the destination of 'building' of a site the following criteria may be used:

- the average highest level of the groundwater should be situated below 0.8 m minus the level of the surface;
- the soil should be rather well permeable till 1.20 m below the surface of the soil;
- to 2.00 m below the surface of the soil the soil profile should be rather homogeneous and contain no layers that are liable to settlement.

In peat areas measures will be taken to improve the natural bad qualities for building. These measures can be:

1) *Decrease of groundwater level*
   With this the level of the groundwater is decreased by a decrease of the polder water-level, possibly combined with drainage.
2) *Raising of the ground level*
   With this sand or soil is applied.

Both measures can also be taken in a combined way. As has already been stated, the measures will cause a subsidence that may last for years. Decreases of groundwater level may cause unfavourable side effects, like the increase of (saline) seepage and the bringing to the watertable of wooden foundations of surrounding buildings. Also the vegetation will certainly be impoverished. A site that is filled up with sand, will loose all natural characteristics.

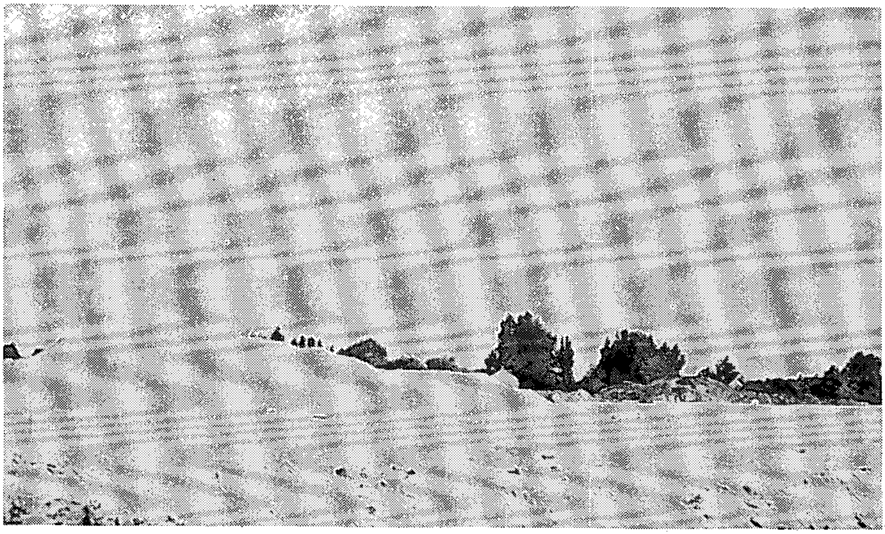


Photo 1. Nederhorst den Berg. The large hillocks of sand that are to be seen, are meant as extra raisings to speed up the settlements on those spots where the total settlements will be largest

The costs of making the soil suitable for building will - not taking into consideration the larger costs of maintenance - be higher in a peat area than those in a sandy area. Thus making a site suitable for building in an area will consist of limited levelling, digging of shallow road trenches, placing of sewer systems and pavements, while keeping the excation pits dry.
The costs will amount to between Dfl 15.- and Dfl 20.- per m^2. In a peat area, where 1.5 m of sand is provided, an intensive drainage is applied (including discharge) sewer systems are placed, pavements are applied (including partial overlays) these costs may rise from Dfl 50.- to Dfl 70.- per m^2.
Yet it is possible to adjust more to the given basis.

This does mean however, that the water-levels as well as the level of the surface should remain unchanged as much as possible.
Since the floor level should be 1 m higher than the water-level, stairs are being used. The level of the surface connected with the houses will be made thus, that settlements will be no problem.

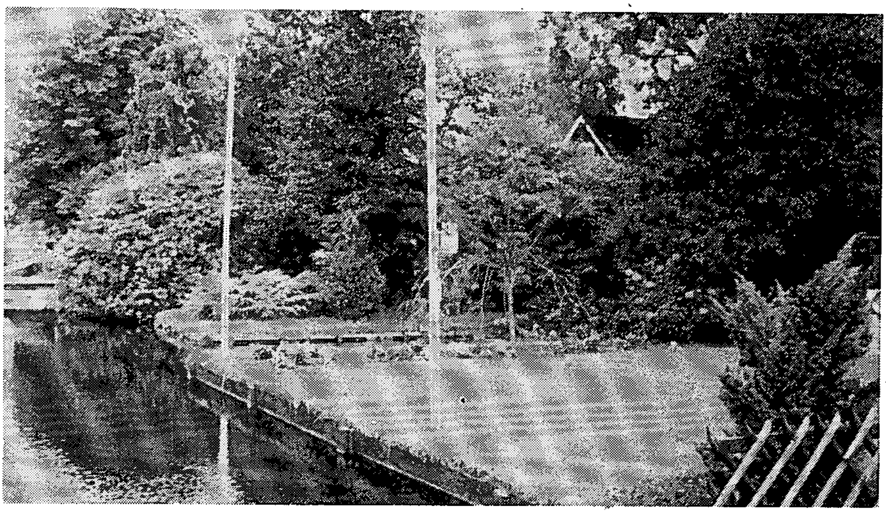


Photo 2. Houses in the extension Boskoop. A house should not be situated against the ditch or road. Space has to be provided, so that plantation can supply a changeover

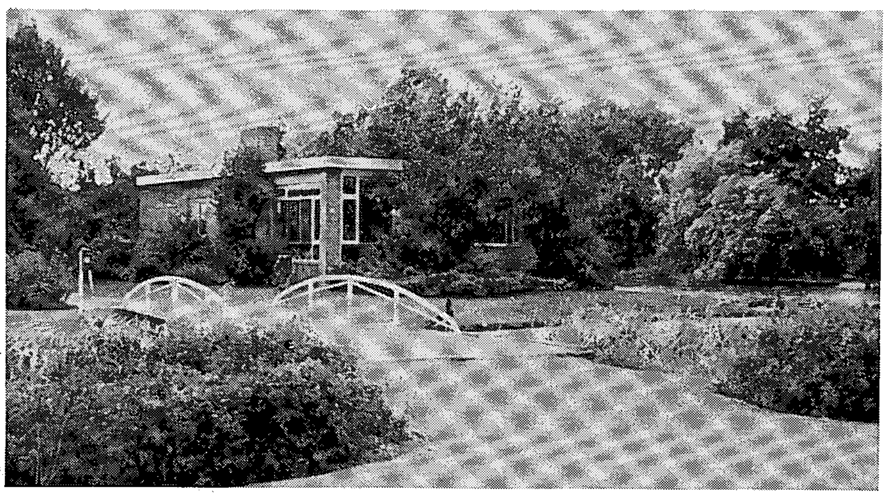


Photo 3. House at Zuidwijk (Boskoop). If it is impossible to maintain existing ditches, the water-levels will have to be maintained in a different way

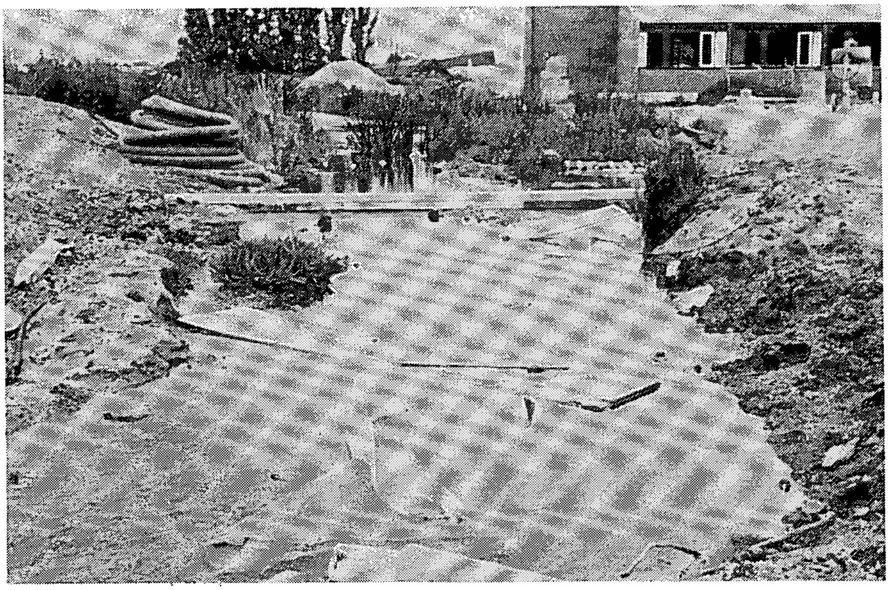


Photo 4. Maria-Oord. By an infiltration system and a group of ponds within the buildings it may be achieved, that despite the filling up of ditches, the original level of the groundwater is maintained as much as possible

11.4.2 Roads

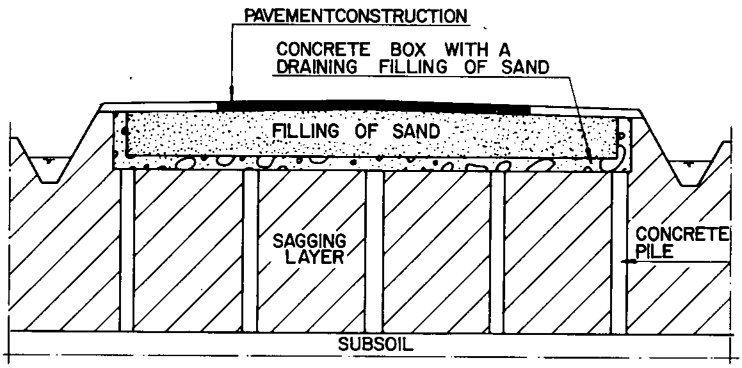
For the building of roads the subsoil is a definite datum. In a peat area measures are necessary from the point of view of stability.
A number of possibilities present themselves.

1) *Fixed system*

   With this the road is founded on piles. It is a concrete box with a draining filling of sand.
   It is a very expensive solution, with which connections and widening of the lanes are very hard to construct (Figure 9).

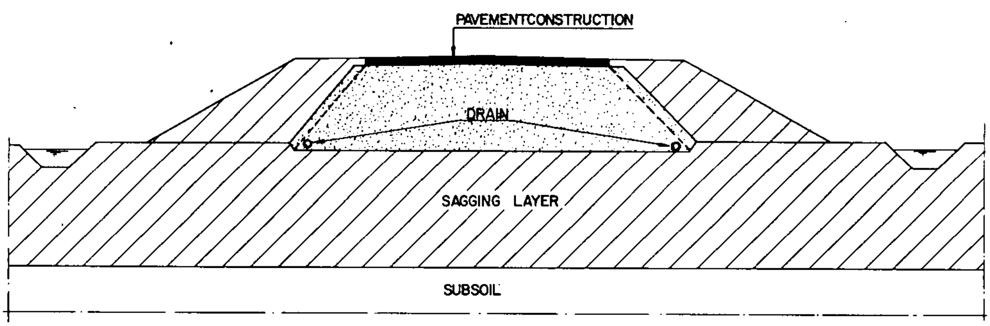
2) *Floating system*

   This system will always be combined with sediments.
   The hydrodynamical period will last for 3 to 5 years and may possibly be shortened. The secular effect however will continue (Figure 10).



FIXED SYSTEM

Figure 9



FLOATING SYSTEM

Figure 10

To decrease settlements it is possible to:

1) limit the height of the road-bed;
2) apply light materials;
3) remove saggy layers completely or partially by pressing away, excavating or dredging.

To accelerate settlements it is possible to:

1) temporarily apply an overloading;
2) apply vertical drainage.

Especially concerning the application of light materials a lot of experiments have taken place. Materials to be considered in this respect are:

- expanded clay
- bales of peat dust
- flugsand
- scum slags

Flugsand and scum slags are applied often. The dry volume weight of these materials is about 1.2 g/cm^3 and the wet volume weight about 1.4 g/cm^3. Scum slags have a little hydraulic action, which means that by water a compound is being brought about, with the characteristics of a plate. Flugsand is not hydraulic and excavating activities in this in connection with cables and pipes can be carried out well.

Expanded clay has a dry volume weight of about 0.4 g/cm^3 and a wet volume weight of about 1.1 g/cm^3. The application is still in an experimental stage.

Especially the resistance to heavy traffic will yet have to be displayed.

To give an impression of the various costs of the building of roads in peat areas with regard to those in sand, the following:

In a sandy area a road with an asphalt pavement, 4.5 m wide, will amount to a little over Dfl 300/m'. With this we start from an unfounded sewer Ø 300 mm, the digging of an excavation and the application of 0.6 m of sand.

The costs of building of this road in a peat area are estimated to be about Dfl 570/m'. With this we start from a founded sewer, a separation cloth and 0.6 m of scum slags.

11.4.3 Sewerages

To limit the size of the sewers the divided system is suitable in a peat area. With this rainwater is carried off paved surfaces, directly to the surface water.

Because of the low weight P.V.C. sewerage is suitable. These pipes are placed without foundation. The sewerage can go along with the subsidence of the whole site. Special provisions will have to be made with the connection of the founded sewage pumping station and the buildings (Figure 11). These provisions consist of the application of loops in the connecting pipes. The connections are carried out in a flexible way.

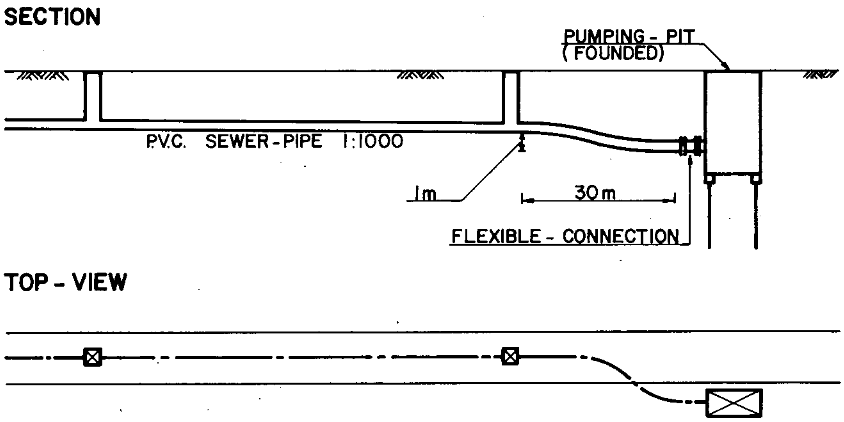


Figure 11

Pipes of asbestos-cement are indeed light, but will breaf off, because of the rigidity of the material.
In certain cases concrete sewerage can be applied on an improvement of the soil with scum slags. Founded sewers will be very heavily loaded as the surroundings settle. If strong settlements can be expected it is desirable to apply unfounded sewers.

11.4.4 Pipes

For the transportation of gas and drinking water in peat areas also many pipes have been placed.
Problems occurring with this concern the following aspects:

1) *The transportation of the pipes*
   The slight bearing capacity of the top soil requires the following provisions:
   - construction of a flugsand track
   - construction of a narrow track
   - transportation by helicopter
   - transportation by hovercraft
   - vehicles with a low wheel pressure
2) *Loss of soil*
   The peat from the excavation, that is stored, oxidizes to the air.

At the same time an irreversible decrease of volume is caused by drying out. The lacking material will have to be supplemented by another, often heavier material. Besides, by increase of the loading on the storage of the soil, water can flow out of the existing profile in the trench and cause settlement.

3) *Stability of the trench*

In order to maintain the counter-pressure on the wall of the trench in a very saggy subsoil a canal is dug, in which water is admitted. The pipe is floated into this and sunk down.

4) *The lifting of pipes*

The weight of a gas pipe is in general smaller than that of the excavated soil. With a high groundwater-level an empty or gas-filled pipe is inclined to lifting, when light supplementary materials are used. The pipe can then be anchored by drilling anchors in cohesive layers. If this is not possible the pipe can be weighted with concrete blocks, thus that the weight of the pipe with blocks is equal to the upward water pressure. The pipe is therefore placed in a suspended way.

5) *The filling up of the trench*

Because of loss of soil and settlement of the transportation road and the level of the groundwater, extra filling materials will always be required in peat areas.
The weight of these should be thus, that no extra loadings are applied, because of which settlement occurs by groundwater flowing off and compression of the ground mass is caused.
Tests with bales of straw and hay have passed off unsatisfactory. After the event unequal settlements occur.
Flugsand is used very often. This material can be compressed very well, by which little settlement of the supplement itself takes place. By the low volume weight the loading of the underlying peat is hardly increased and therefore the settlement is limited.

11.4.5 Recreation grounds

Sport fields, playgrounds and park areas have a practical function as well as a function with regard to physical planning. This means that the grounds will have to stand intensive trodding and playing on, while favourable conditions for the vegetation are preserved. The programme of requirements concerning recreative factors of use of peat areas is concerned with the following factors:

- firmness of the top layer
- bearing capacity of the total profile
- drainage
- smooth situation of the level of the surface
- suitability of the soil for plantation.

In order to be well played on, the top layer of grass sport fields, play- and sungrounds must be able to meet the effects that are exercised on it with use and maintenance, while no damage to the vegetation occurs. This means that this top layer should have a resistance to penetration of at least 1.4 MN/m^2 (= 1.4 MPa).

This requirement of firmness concerning the top layer of grassfields for various recreative practical functions implies measures for the improvement of peat soils.

The elevation of peat soils influences the firmness of the top layer. The bearing capacity research on peat grassland also supplies information about the desired elevation above the groundwater-level, of 0.30 m minus ground level, permitted for the firmness, must not take place.

A sufficiently smooth situation of the ground level is a condition for sport fields to be well playable.

The requirements that have to be made for the composition of the top layer are:

- a top layer with an organic-matter content < 5%
- a clay content < 5%
- a silt content of < 10%

The suitability of peat soils, with regard to plantations to be provided on recreational objects, is also limited. Only a limited choice, with regard to wood species to be applied, is possible. This limitation is also caused by the lack of a sufficiently firm topsoil for the plantations.

Laying-out of recreation grounds on peat soils

Of most Dutch peat soils the ground level is situated too low with regard to the level of the open water in order to reach the desired draining for the new purposes.
Because of the high groundwater-level they are insufficiently firm for intensive treading and playing on. To be able to create grass sport fields, play- and sungrounds there, suitable sand should be applied after levelling. If the underlying peat layer is poor in clay, as much of that layer can be cultivated, that a mixture with about 5% of organic matter comes into being on the parts of the ground that will be trodden and played on intensively.
For the parts that will be trodden on less intensively a sandy top layer with about 3% of humus will be sufficient.
On peaty soils it is of great importance that the sand covering is poor in clay and silt and that only organic matter is used in combination with the sand in order to provide the soil with the necessary cohesion, firmness, ability for the development of roots and water retention capacity.
For a good, firm top layer on peaty soils a moderate sand covering of about 15 cm, which is poor in humus, is needed.
For peat soils with a slight bearing capacity this will however be a loading that is too heavy on account of which settlement of the soil occurs. By the deeper drainage also a decrease of the ground level is brought about, caused by oxidation of organic matter.
If filled up waterways or clayey or sandy strips are found in the ground then the ground level will settle unevenly. By an uneven settlement the drainage system will function in an insufficient way.
In grass sport fields hollows have to be filled up periodically which is very expensive. In peat soils with a slight bearing capacity and a high level of the groundwater sometimes one or more coatings of polystyrene plates are applied 30 or 50 cm below the ground level. Another measure that is often applied is the use of flugsand in ditches to be filled up. By using these materials, with a specific weight near that of peat, uneven settlement is partly avoided and a higher ground level can be obtained. Thus the bearing capacity increases and root development is improved.

Because of these measures the costs of establishing sport fields on peat soils are approximately 60% higher than when established on sandy soils. The difference is mainly caused by the extra costs of drainage, filling up of ditches with flugsand, working of the top layer and pavements.

11.4.6 Foundation in peat areas

In Section 3 attention has already been drawn to the slight bearing capacity of peat soils. For the foundation of buildings it is therefore almost impossible to have the loads taken up by peat soil.
In the past light buildings were situated on a shallow foundation in peat areas. As far as these buildings still exist they are liable to subsidence, caused by increased loading and decrease of the groundwater level. Often the consequences of slight changes of the groundwater-level can be observed in the jamming of windows and doors or continuous cracking of the walls. For heavier buildings pile foundations had to be employed. In the past wooden piles with slatted floors were used, on which the walls were built.
Caused by the increasing urbanization loads increased and besides people were inclined to increase drainage of the soil. One and another often has as a consequence that in urban areas the groundwater level will be decreased, because of which danger arises that the wooden foundation will decay. Nowadays more and more concrete piles are used, or wooden piles provided with concrete tops.
In Figure 12 some principle cross sections are given of past and modern ways of foundation on piles.
With a pile foundation in most cases the total loading is passed on through the point of the pile to the underlying bearing layer.
Besides this point bearing capacity in general, forces of friction between pile and soil will arise along the shaft of the pile.
The extent of frictional resistance depends on the composition of the soil. In clay and peat layers the resistance is mostly slight but in sandy layers the resistance can be considerable (Figure 13).
To be able to realize building sites in areas with peat layers of a thickness of several metres, nowadays it will be necessary to raise the ground with sand, till the required definite situation of the level of

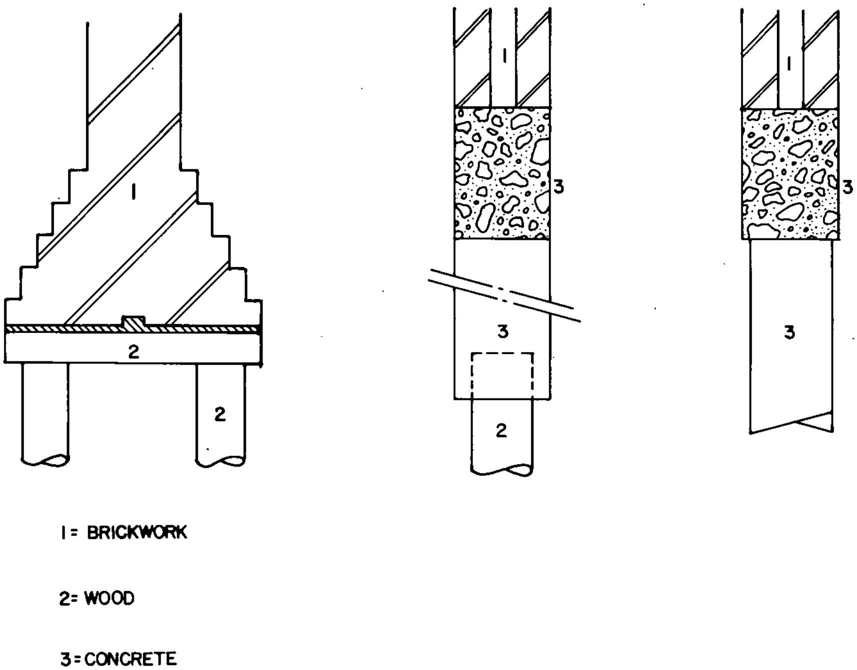


Figure 12

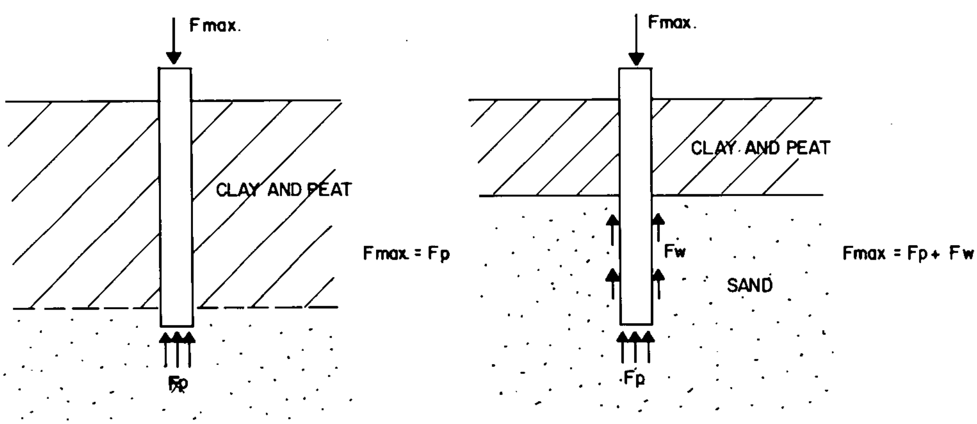


Figure 13

the surface has been reached. The thickness of this layer of sand often amounts to several metres, mainly by the settling of the peat. It has already been mentioned that after a few years the larger part of the

settling will already have taken place, but settlements up to some centimetres can still be expected afterwards. For the grounds and roads this mostly presents no problems. For pile foundations however this is important. With subsidence of the layer of sand with regard to the pile the frictional forces between the supplied sand and the pile are directed downwards.
This is called negative skin friction (Figure 14).

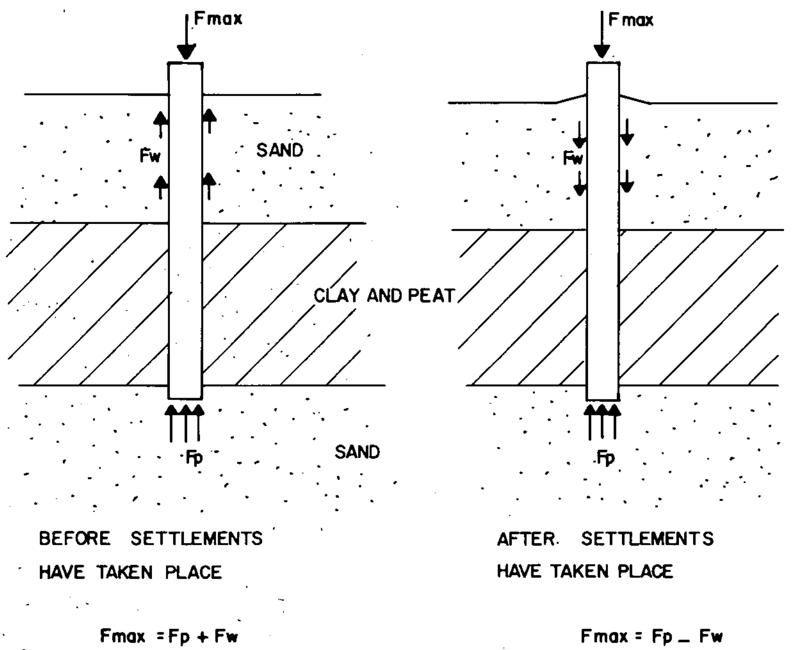


Figure 14

This negative skin friction can diminish the useful bearing capacity considerably. The number of piles for a similar building will therefore be larger than when no negative skin friction is to be expected.
When the settlements are small, nowadays piles are sometimes coated with bitumen of such a composition, that the resistance to shearing forces is slight. In this case friction between the soil and the coating will arise, but this friction is not passed on to the pile (Figure 15).
In the preceding part it has been pointed out that for foundations quite a number of measures are necessary to eliminate the negative influences of peat soil.

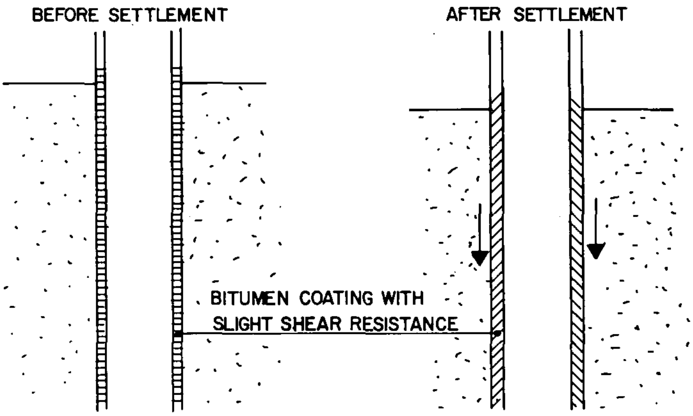


Figure 15

These measures will in general cause an increase of costs. Thus an average house in an area with the bearing layer situated on the level minus 10 m will be about Dfl 5000.- to Dfl 8000.- more expensive than a similar house with the bearing layers on less than 1 m below the ground level.
This increase of costs is caused by the pile foundation. The layers with less bearing capacity however do not exclusively have to consist of peat. Also layers of clay and layers of sand with a bad bearing capacity will generally need a similar pile foundation as is needed for a house in areas with peat in the topsoil.
Also other, above mentioned, negative qualities of peat, as the slight shear resistance and the causing of negative skin friction are no specific qualities of peat soils.
In saggy layers of clay the same phenomena are found as well and here too the construction will have to be adapted to these circumstances.

11.4.7 The stability of soil retaining constructions

With soil with a good shear resistance soil retaining constructions may be anchored to the soil by means of anchor plates (Figure 16).
If the values for T are very small no stability is possible.
In general the shear resistance of peat soils is very slight. Besides,

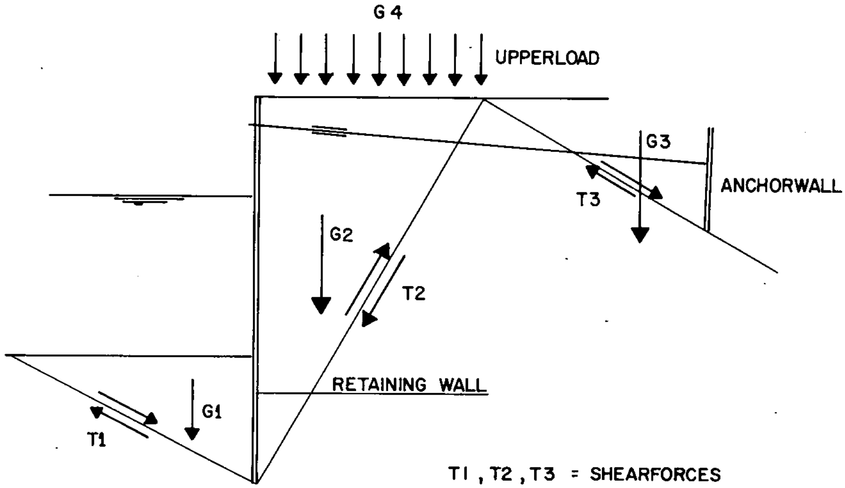


Figure 16

the permitted shearing stress depends upon the vertical granular stress and this too is usually very small with peat.
It is therefore mostly impossible to anchor soil retaining constructions of some importance in this way.
In that case more complex foundation systems will have to be chosen, or draught anchors will have to be applied in the layers of sand that are usually situated deeper (Figure 17).

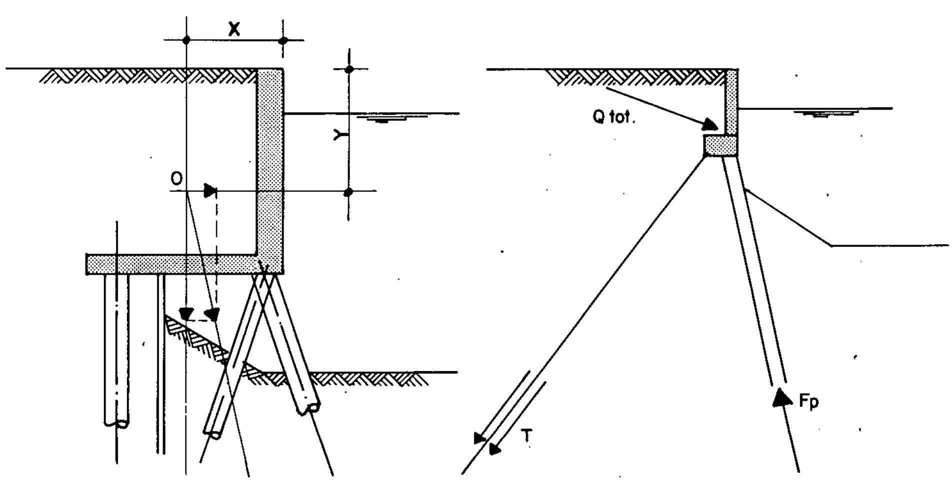


Figure 17

In special cases other methods to take up the horizontal forces are being used. An example of this is the connection between the land abutments of a number of movable bridges in Boskoop (Figure 18, Photo 5). The displacement of the abutments of some millimetres might already cause that the movable part will no longer move. To this end the abutments have been braced with U-shaped concrete blocks. These blocks are prefabricated and applied before the pouring of the concrete abutments, and anchored to these.

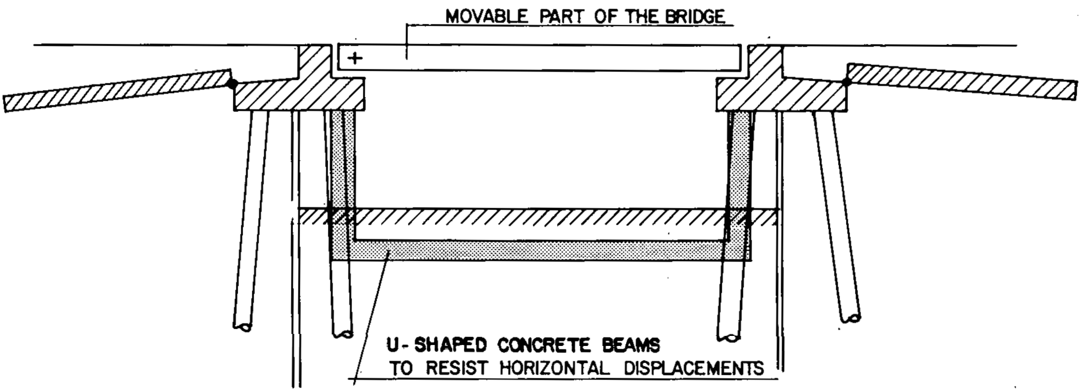


Figure 18

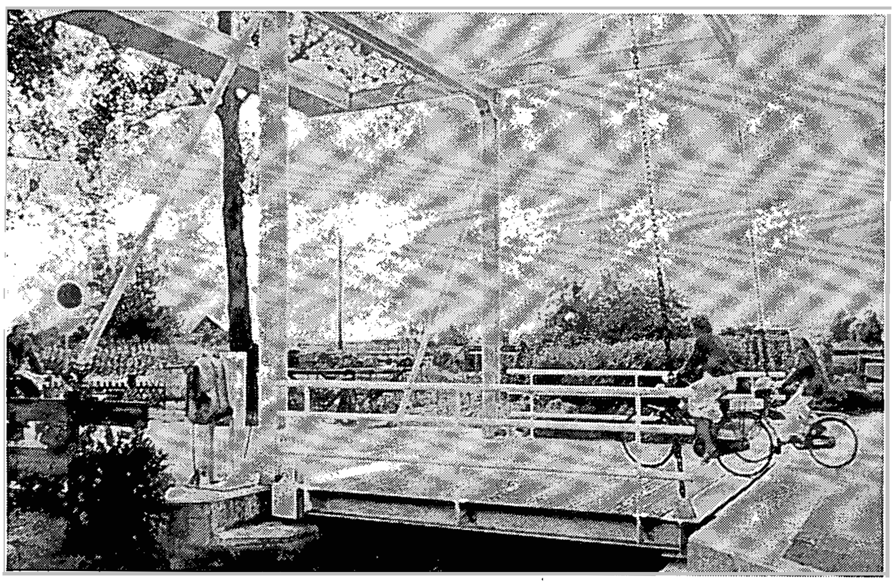


Photo 5. Movable bridge in Boskoop

Such a possibility also arises with two soil retaining walls on a short distance, with which a braced floor can be applied on the bottom of the canal or harbour (Figure 19).

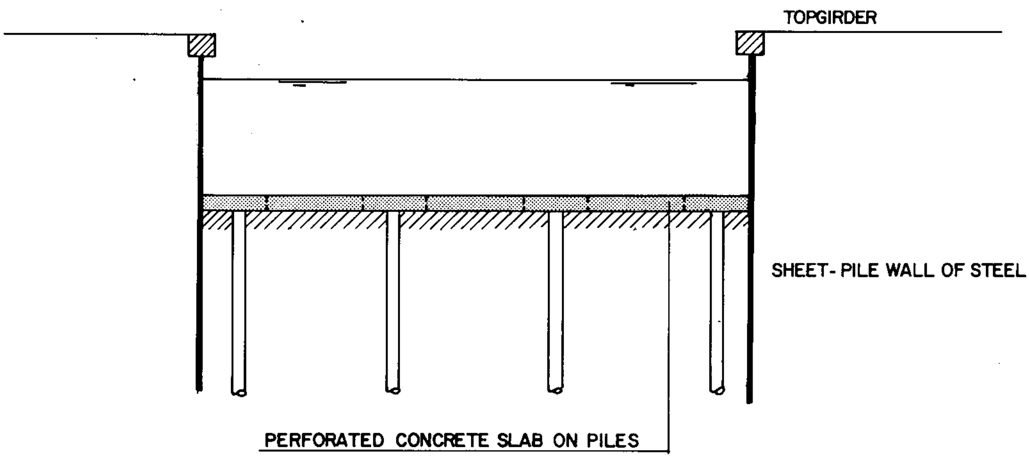
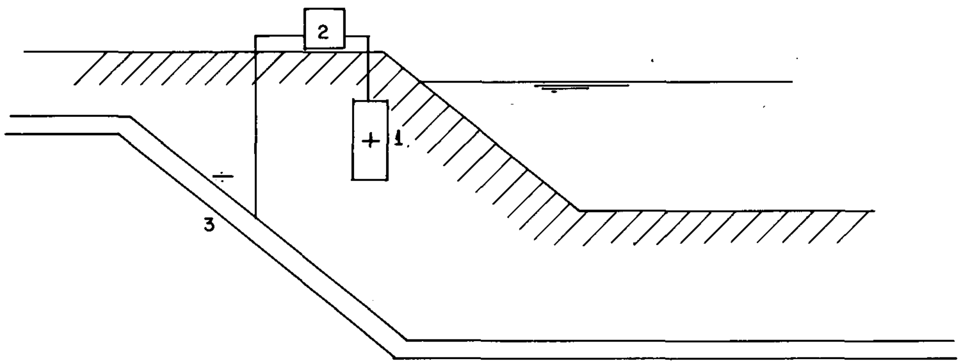


Figure 19

11.4.8 Aggressive groundwater

As a consequence of the aggressiveness of groundwater in peat areas the attack of buildings materials such as concrete and steel is a multiple with regard to the attack in sand- and clay areas.
Concrete for sewage pipes and foundation works must have a great tightness in order to resist peat acids.
This tightness can be obtained by a well gradation of the materials sand and gravel, special additional materials and a good mechanical compaction of the concrete morter.
Also with such a composition of the concrete it is usually necessary to provide the surface with a coating to prevent that the concrete gets so heavily attacked within a few years, that the reinforcement will rust.
Steel can also be protected with a coating, adapted to the aggressive environment.
Besides, steel may be provided with a cathodic protection. With this a metal object is applied at some distance of the object that is to be

protected. By taking care that the electric potential of this object is constantly higher than the potential of the object to be protected, the last then forms the cathode in the electric system and corrosion is prevented (Figure 20).



1 ANODE
2 MEASURING -APPARATUS
3 PIPELINE TO BE PROTECTED

Figure 20

11.5 Future developments in peat areas below sea-level

11.5.1 Introduction

The old peat areas are less densely built up than areas with a different subsoil. Towns have developed along waterways and on the edges of the peat area on the sandy subsoil.
The result has been that the Holland-Utrecht peat area is practically enclosed by towns. Within the peat area itself, some larger centres as Gouda, Alphen and Woerden are found, that have all arisen along waterways that cross the peat area.

11.5.2 Urban development

In the third memorandum on Physical Planning Section 3d, governmental decision on rural areas, the Holland-Utrecht peat area and the river forelands are mainly considered as:

- areas with alternately agricultural, natural and other functions in larger physical units and
- open spaces with a restrictive policy with regard to growth and spreading of the population.

A restrictive policy with regard to growth and spreading of the populations means that the population cannot be spread out over all centres and that efforts will be made to reduce the in-migration surplus to zero or to strive to obtain an out-migration surplus. For large parts of the peat areas north of Amsterdam also a restrictive policy with regard to growth and spreading of the population holds. For an important urban development on peat soils only Capelle on IJssel is mentioned.
Other locations do have a saggy subsoil or probably peat at some depth. The houses that have yet to be built in the open Holland-Utrecht peat area should mainly be established in the centres Gouda, Alphen, Woerden and Gorinchem.
Around Amsterdam and Rotterdam some motorways have been planned, of which building could be started before 1990. The motorway Utrecht-Leiden is not as yet a complete dual carriage way.
Building of the last part of the motorway here could also be started before 1990.

11.5.3 Landscape, nature and recreation

The landscape of peat soils has great cultural-historical and natural values. Lake districts with various stages of peat lands have a rich flora and fauna.
Four areas, with amongst others peat soils below sea-level, have to this end been selected as potential national parks, namely Northwestern Overijssel, that has been an experimental area as a national park, the Vechtplassen and Southwestern Friesland.
The motives for realization of the national parks are also to be found

in the field of recreation.
In protected landscapes agriculture is often limited in its development by its environment, by its grouping in plots, accessibility (sometimes by boat) and bearing capacity.
Preservation of landscape and land use automatically imply the creation of reservations and management agreements, for instance fixing of mowing dates and subsidized reed culture. With regard to tourism, management is thus, that vulnerable parts are closed for the public, whereas in other parts access will only be partly permitted, especially to boats.
The stimulation of tourism is directed to areas where tourism is admissible because of biological values and physical possibilities. Quiet forms of recreation, as angling, will be stimulated. Footpaths are being made connected to stops of public transportation.
For the rest it is a fact, that touristic pressure, especially caused by day-trippers, is considerable in these areas. Also pressure of sojourn recreation is considerable in Southwestern Friesland and the Vechtplassen area.
On supreme days 10,000 recreative vessels are found in these regions.
Finally it may be stated, that areas with predominantly peat soils still possess a relatively open character, owing to the unfavourable qualities of the soil. Their most important destination will be agricultural and recreational. A different sort of use will not take place other than for very pressing reasons.

Note

[1] Involved in the composition of this article were:
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R.T.J. de Ruijter
H.W. Sinke
A. Talsma
H.E. Zonderland
all working with Ingenieursbureau 'Oranjewoud' B.V.

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APPENDIX 1
ROUGH SURVEY CONCERNING THE COSTS OF LAYING OUT 'AVERAGE' SPORTS-GROUNDS ON VARIOUS FOUNDATIONS

Sportsgrounds 'Cellesbroek-Middenwetering' in Kampen
total area about 6,000 ha

3 football grounds + 1 training ground	3.10 ha
other grassfields and verges	1.00 ha
plantations: forest trees and trees	1.20 ha
pavements: access road	
carpark (for about 60 cars)	0.30 ha
footpark (about 600 m')	0.10 ha
ditches, buildings and so on	0.30 ha
	6.00 ha

These sportsgrounds have been laid out (completed in September 1980) on a foundation, consisting of a topsoil of heavy sticky clay, thickness about 0.20 m, lying on a peaty subsoil, mainly wood peat.
This peat layer varied strongly in thickness from 1.50 m to over 6.00 m.
In the following survey the parts of work and the costs of laying out belonging to them have been further specified.
Besides, estimates have been made of the costs of laying out, in case these sportsgrounds would have been laid out on a clayey soil or on a sandy soil.

Nr.	Part of work	Costs* of laying-out/construction			Causes of differences in costs
		peat soil	clayey soil	sandy soil	
1	Preparation of work-measuring works	10.000,--	10.000,--	10.000,--	
2	Clearing works	15.000,--	15.000,--	15.000,--	
3	Tree moving and treatment	20.000,--	20.000,--	15.000,--	transportation, anchoring
4	Drainage				in peat areas high level of ditchwater
	- pumping-infiltration	25.000,--			
	- drainage	85.000,--	60.000,--*	35.000,--**	* sand in trenches instead of flugsand **intensity; no assembled drainage system; do not fill up trenches with sand
	- sewerage - rainwater	30.000,--	30.000,--	30.000,--	
5	Earthworks				
	- filling up of ditches	40.000,--	15.000,--	10.000,--	on peat filling up with flugsand; on clay-sand filling up with soil from ground, on sand less and smaller ditches
	Transport	225.000,--	150.000,--	115.000,--	

*In Dutch Guilders

Nr.	Part of work	Costs*of laying-out/construction			Causes of differences in costs
		peat soil	clayey soil	sandy soil	
	Transport	225.000,--	150.000,--	115.000,--	
	- earth moving - digging	50.000,--	50.000,--	30.000,--	workability
6	Laying out of grassfields				
	- other grass and verges	25.000,--	25.000,--	20.000,--	workability
	- sportsfields	145.000,--	100.000,--	70.000,--	workability; measure of sand covering, passability of ground
7	Plantations	25.000,--	25.000,--	25.000,--	workability
8	Pavements	240.000,--	160.000,--	140.000,--	construction: on peat: cloth and slags; on clay and sand: excavation
9	Fencing				
	- fencing ground	25.000,--	25.000,--	25.000,--	
	- fencing sportsfields	45.000,--	45.000,--	45.000,--	
10	Campsheddings etc.	10.000,--	5.000,--		
11	Sprinkler irrigationsystem	35.000,--	35.000,--	45.000,--	filtration well instead of open drainage
	lighting	P.M.	P.M.	P.M.	
12	Maintenance for 1 year	20.000,--	20.000,--	15.000,--	workability
	Costs of laying-out/ construction	845.000,--	640.000,--	530.000,--	

*In Dutch Guilders

	peat soil	clayey soil	sandy soil
Amount carried forward	845.000,--	640.000,--	530.000,--
Costs of management about 15 %	125.000,--	95.000,--	80.000,--
	970.000,--	735.000,--	610.000,--
V.A.T. 18 %	174.600,--	132.300,--	109.800,--
	1.144.600,--	867.300,--	719.800,--
For rounding off	5.400,--	7.700,--	5.200,--
	1.150.000,--	875.000,--	725.000,--

Relation of costs	peat soil	clayey soil	sandy soil
items - 1 + 2 + 3	1,15	1,15	1
- 4 + 5 + 6 + 7	1,95	1,40	1
- 8	1,70	1,15	1
- 9 + 10	1,15	1,05	1
- 11	0,80	0,80	1
- 12	1,35	1,35	1
TOTAL	1,60	1,20	1

APPENDIX 2

FILLING MATERIALS

Scum slags

(Blast furnace) slags come into being as a residuum with the melting of iron ore and consist of liberate non-metals, ashes of coke and additives as chalk, necessary with the melting process, all in a condition of heating.

The slag, that rises to the surface because of a lower specific gravity than that of metal, is caught in pans. The chemical composition of iron blast furnace slag is mainly:

28-50% CaO

28-40% SiO_2

5-20% Al_2O_3

0-10% MnO

2-15% MgO

½- 2% S

0- 2% FeO

0- ½% P_2O_5

0- 2% $Na_2O + K_2O$

With a process of slow cooling after pouring off of the pan, a slag with a tight structure is obtained.

By means of a special process a scum slag may be obtained. With this, the heated slag is passed through a stirring machine, while steam under high pressure is syringed.

Scum slags are a hydraulic, voluminous, highly porous and easily breakable material, with an uncompacted volume weight of 0.7-1 g/cm^3.

Flugsand

This is a natural product, that has come into being with the vulcanic eruptions in the Eifel mountains, in the quaternary age (1-3 million years ago). The many creater-lakes, the so-called *Maare,* occurring in the Eifel mountains, testify to these vulcanic eruptions.
In this respect the Laacher See, with the abbey Maria Laach situated on it, is well known.
With the eruptions various types of stones were brought up, with large contrasts in appearance and qualities. To this end the hard and solid basalt should be compared to *'bims',* that is provided with gas channels by the production of steam with the eruptions and has obtained a foamy structure because of that.
According as the grain size of the pieces was finer, they were blown further away up to many kilometres, by the force of the eruption.
For this reason the fine *'bims'* obtained the name 'flugsand'. Its grain size is 0-8 mm and from a laboratory investigation the following was learnt:

dry volume weight with Florida compaction with 10% moisture	0.92 g/cm^3
apparent specific gravity	1.76 g/cm^3
hollow space with Florida compaction (pores between the grain)	48 full %

Expanded clay grain

The expanded clay grain is produced in a rotary furnace, at a temperature of approximately 1100° Centigrade.
The round grain has a hard brown crust and a cellular nucleus.
The cells with stagnant air render a - for a stony material even exceptional - low weight of 0.35 g/cm^3, poured, for grain size 10-16 mm.
Other qualities are:
- frost resistant
- strong and no deformation, not even with prolonged loading
- resistant to any form of attack as decay, fungi, chemicals, etc.
- draining

12 REVIEW OF CHAPTER 11

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During the last few years I have developed a keen interest in Dutch soil mechanics problems, partly through literature studies, partly through discussions with my colleague Prof. I.M. Beattie, who visited The Netherlands a few years ago, and partly through contact with Dutch-born persons in Fredericton. The foundation problems in The Netherlands are without question quite unique and obviously require much ingenuity for their proper solution, as evidenced, for example, by Van den Kerkhoff's paper.

It is evident that the author has been aiming at a general rather than a specific or detailed account of foundation problems with Dutch soils, and he has indeed succeeded in arousing interest in this topic. On account of the time span of construction involved (some 1100 years) and the very extensive field of construction covered, his paper invites a number of comments and questions, particularly from a reviewer who is not very familiar with Dutch soil mechanics conditions.

During my work with organic soils in Canada, it has become increasingly evident that the term *peat* can represent just about any organic, diatomaceous or calcareous soil that has a mineral content of up to 80%. The corresponding range of geotechnical properties[1] for this very large group of soils is extremely wide. Since the present paper does not include any boring logs or geotechnical properties, it is unfortunately not possible to draw any comparisons with peat in other countries or within The Netherlands.

The soil mechanics aspects of peat described in Section 11.3.2 suggest to the reviewer that some of the peats referred to may be sedentary and others may be sedimentary[2]. Thus a fibrous structure, a very high water content, a natural density comparable to that of water, and a very high compressibility are typical of sedentary peats. Slow consolidation (several years required for dissipation of pore pressures), varying degrees of organic content (Fokkens), shear deformation (lateral displacement), and low shear strength are typical of sedimentary peats.

In the case of sedentary (fibrous) peats, the reviewer has found that they typically have an angle of internal friction of about 30^{o}. When subjected to vertical compression, the fibres act as horizontal reinforcement, inducing a lateral internal resistance that effectively counteracts lateral expansion (shear deformation) under a normal range of vertical loads (up to about 40 kPa). In general, vertical (sand) drains[3] do not seem to accelerate consolidation, partly because $k_h > k_v$ and partly because of smearing, clogging and horizontal consolidation. The latter is caused by the high horizontal hydraulic gradient near the drains.

In the case of sedimentary peats, shear deformations are generally quite pronounced, on account of high pore pressures, low undrained strength, low permeability, and a general lack of fibre reinforcement. These soils are in fact quite susceptible to local (and hence general) undrained failure as a result of the generation of pore pressures. This generation of pore pressures is again a result of a very high porosity and thus a potentially unstable structure. The secular effect would therefore be very pronounced, but it would not occur after dissipation of pore pressures. On the contrary, the secular effect would *create* pore pressures.

In regard to secular effects, the equation attributed to Koppejan (Chapter 11, Figure 4) is not the same as either of those suggested by Koppejan in his Rotterdam conference paper (ISSMFE, 1948, Vol. III, pp. 32-37), viz. equations I and II. Has Koppejan revised his 1948 equations?[4]

The secular effect is stated by the author to be attributed to the water that is bonded to the soil particles or to the connections between the soil particles or to both. The reviewer must take exception to this statement, having found no evidence of such bonds in sedentary peats (other than a slight capillary action). In sedimentary peats, such bonds may certainly exist, but they do not in any way seem to control the secular effects. Rather, the controlling factor appears to be the long-term (secular) behaviour of the organic material itself. For example, secular consolidation was found by the reviewer to occur in dry wood waste (sawdust, bark), fibre glass, and steel wool. If the rate of secondary (secular) consolidation exceeds the rate of possible drainage (low permeability), pore pressures will be generated, whether the water is bonded or free.

Returning to the question of vertical (sand) drains,[3] the reviewer would be interested to know if and under what circumstances they have actually been successful in The Netherlands. Experiences in Scotland and Canada have been largely negative.

The use of 'flugsand'[5] has caused the reviewer some puzzlement. Its very low dry (and wet) density suggests that it has an extremely low specific gravity and an extremely high porosity as placed. What are the geotechnical properties of this material?

In regard to the use of light-weight material, one technique used in Norway and Canada is to estimate the settlement to be expected under a certain thickness of mineral fill. Light-weight fill (e.g. sawdust, compressed peat) is then placed to a thickness equal to or greater than the expected settlement, followed by the mineral fill. Under ideal conditions, the top of the light-weight fill settles to the ground water level. Is this technique used in The Netherlands, and if so, has it been successful?[6]

The reviewer would also like to obtain some information on the current approach to the erection of buildings on peat.[7] The author states that buildings are very sensitive to settlement and that they must therefore be founded on piles to firm ground. The alternative approach would be to accept the settlement (or to reduce it through surcharging) and to design the buildings so that they can settle without significant damage. Is this approach being pursued or practised in The Netherlands? If so, considering your rather unique soil conditions, what are your experiences with such an approach? It is noted (Section 11.4.6) that after a few years, the remaining settlement is generally limited to 'several centimeters' only. Ideally therefore, the fill should be placed a few years before the start of building construction.

The author's contentions with respect to friction piles[8] are not fully understood. The frictional resistance is claimed to be small in both peat and clay. This is certainly the case in peats, whether sedentary or sedimentary. In clay, however, friction piles are used extensively, and they derive practically all their bearing capacity from skin friction. Perhaps the clays referred to by the author are organic compressible clays? In the case of negative skin friction, the reviewer would be interested in some details concerning bitumen coating. The illustration (Figure 4?) is missing in the reviewer's copy. Does this illustration corroborate the statement that no friction is transferred to the pile? Finally, on the subject of bridge *(beweegbare bruggen)*[9], the statement that a displacement of only a few millimetres can cause jamming seems to imply an unusually strict geotechnical requirement. Is it not possible to allow for a displacement of several centimetres rather than millimetres?

Notes

(J. van den Kerkhoff and co-workers)

1 *Some geotechnical properties*

- volume weight (wet): 0.9-1.1 g/cm^3
- volume weight (dry): 0.1-0.3 g/cm^3
- water content: 300-800%
- cohesion: 0-5 kN/m^2 (kPa)
- angle of internal friction: 15^o-20^o
- cone resistance: ca. 0.2 MN/m^2 (MPa)

The peat in the excursion area has a thickness of 4 to 10 metres, often in combination with saggy layers of clay, because of which the total compressible mass is often approximately 10 m.

2 *Kinds of peat*

Descriptions can be found in the Sections 1.4.2.2; Chapter 5, the Figures 1, 2, 3 and 4, Table 2 and Section 5.3.1; and Chapter 9.

3 *Vertical drainage*

From 1952 onwards, vertical sand drainage has been applied in The Netherlands, especially in the area around Rotterdam. The diametre of the drain usually amounts to 0.25-0.3 m, the drain distance is 2 to 4 m and the length may rise to 30 m.

In The Netherlands the reputation of sand drainage is generally good. This is partly caused by the structure in layers of the subsoil, because of which the horizontal permeability is often larger than the vertical permeability.

Sand drainage is applied by means of syringing with water and ramming. With ramming a good drainage path will come into being, whereas with syringing the hole could be more irregular, by leaching of layers of sand.

With syringing the smearing effect is absent and an increase of the confinement of water as a result of displacement of soil as with ramming will not either take place.

Synthetic drains are brought to depth with the aid of a steel pipe duct by pressing, ramming, vibrating or syringing.

The volume of these drains is small, because of which little displacement of soil will occur. The site of work will remain clean and will not be polluted by argillaceous and peaty rinse water as would be the case with the application of sand drainages.

The price of the synthetic drains per m^2 is higher than that of sand drains, starting from a same measure of acceleration of consolidation.

4 *Equation of Koppejan and secular effect*

The equation of Koppejan, presented in Rotterdam (ISMMFE, 1948, Vol. III page 36) runs as follows:

$$S = h_o \left(\frac{1}{cp} + \frac{1}{cs} \log t\right) \ln \frac{p_o + p}{p_o}$$

The same equation has been used in the marginal note belonging to Figure 4, Chapter 11.

For a period of 30 years log t ≈ 4.

For peat the factor $\frac{1}{1/Cs + 4/Cp}$ usually lies between 2 and 10.

The values for Cs and Cp are, as a rule, not fixed.

After reaching a certain grain tension (marginal tension) often a smaller value for Cs and Cp is found.

With experiments on clay and peat even after the end of the consolidation period settlement will go on and no end value is reached, not even with experiments that have been continued for years.

The cause of this is not quite obvious, and is partially attributed to water, present in very narrow pores, and therefore more bonded.

The secular effect, found by professor Landva in dry wood waste, may perhaps be compared with creep effects, as they occur with wood and concrete.

5 *Flugsand*

As an addition to the further description in Chapter 11, Appendix 2, we may state, that the stability of flugsand may at least be compared with that of sand.

After compaction counted may be with an angle of internal friction of approximately 40^{o}.

Furthermore clay percentage is less than 10% and the median of the size of the particles approximately 600 μm.

The permeability is approximately 4 mm/sec.

6 *Lightweight fill*

(From the editors) Turves (blocks of dried peat), formerly used for fuel, were used as light-weight fill in the peat district discussed during the symposium.

Today peat harvesting for fuel is (practically) finished in The Netherlands, this material is not available anymore, or has to be transported too far.

Sawdust was never used to our knowledge.

7 *Foundations*

In The Netherlands buildings are designed thus, that they will not be susceptible to settling. A number of reasons for this can be mentioned:

- floors that will have to remain level
- building in more storeys and large units with a rigid centre (lift-shaft)
- eccentricity, caused by irregular settlements, will introduce increasing loads
- jamming of doors and windows
- disturbance in pipes for gas and water

In farm building experiments with slags have taken place. Instead of pile foundations a concrete floor was applied on a layer of slags. On this the stables of wood were built. Generally speaking this has not been very successful because of irregular settlements afterwards.

8 *Jacket friction*

Positive jacket friction on foundation piles in layers of clay and peat will only occur with strongly cohesive soils.

These layers of clay and loam only occur in a few areas in The

Netherlands. In general the layers of clay are saggy and also in the layers of peat practically no frictional forces between pile and soil will come into being.
This holds for positive as well as for negative friction.
The negative skin friction therefore will occur in those layers with a large frictional resistance between pile and soil, that are exposed to settlement because of the more sagging layers in the subsoil.
To prevent this negative skin friction piles are sometimes provided with a bitumen coating, which will undergo extensive deformations even with slight shearing forces. The bitumen coating then functions as a sort of lubricant between soil and pile.
The surrounding soil will settle, but will exercise little or no shearing forces on the shaft of the pile.

9 *Land abutments of bridge* (cf. Photo 5 in Chapter 11)
In order to prevent pushing effects the space between land abutment and bridge deck is limited.
A part of the available space is necessary for the thermic changes in length, so that there are few possibilities for displacement in a horizontal direction.
Besides, horizontal displacements will mostly be uneven, because of which a distortion of the movable part in the horizontal surface may be caused as well.
This may lead to jamming of the bridge length- or crosswise and possible failures in the regulating equipment for the operation of the bridge.

13 THE USE OF PEAT SOILS FOR GRASSLAND

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13.1 Introduction

Already some thousand of years ago men penetrated by boat and in some higher places on foot the peat-district in the Rhine delta.
Besides hunting and gathering products of the vegetation in the field, they started grazing cattle in open places between the wooded peat land. By burning, cutting down and digging small drainage ditches a more regular grassland husbandry system was developed. However, this caused lowering of the sod surface, so a marsh forming process.
Therefore a more organized system of reclamation was developed. In this way a system of polders came into being in which the water was removed by a system of ditches and canals with the farm-houses situated in the higher parts on the river sides. The grassland lies in long narrow fields behind the farm-houses towards the centre of the polder.
The water was pumped up by wind mills from the ditches in the then low lying centre part of the peat regions into canals with a higher water level and from those canals into the rivers. Because in rainy periods like in autumn and winter the pumping capacity of the wind mills often was too small, the low lying centre parts of the polders became extremely wet. Often the watertable rose above the soil level. Also in some polderdistricts the ditches were made very wide, so that the watersurface was one third of the total surface. This opened a possibility to store more water after heavy rains. But in the low lying centre parts, this usually was not a guarantee for the grassland to obtain a somewhat lower ground-watertable.

The grassland in the centre parts was in the top layer of the soil free from saturation with water only in summertime. This caused a slow start of the growth of the plantcover in springtime. Mostly actual growth started at the beginning of June.
Together with the great distance from the farm-houses, this grassland was only cut and the hay with the minerals absorbed from the soil by the herbage was transported to the farm. Near the farm the grassland was always grazed by cattle and also the farmyard manure from wintertime was brought on to the grassland nearby.
Throughout the centuries this has caused great differences in mineral availability to the herbage. Together with the effect of use differences this brought about a high diversity in plant communities from *Molinietum; Nardetum; Lolio-Cynosuretum* to *Poa-Lolietum.* About 25 years ago this zonation could still be seen on vegetation maps.

13.2 Grassland vegetation and production in former days

The grassland near the farm, which was always grazed and was regularly fertilized with stable manure, consisted of a plant community with *Lolium perenne* as a dominant species (*Poa-Lolietum*). Together with this species we found *Phleum pratense, Poa trivialis, Poa pratensis, Agrostis stolonifera, Trifolium repens.* We always find a low percentage of *Alopecurus geniculatus* and *Ranunculus repens* indicating the high humidity state of the organic rich clay on peat soil underneath the pastures. If these pastures received less dung which was possible if they were situated at a further distance, species like *Cynosurus cristatus* partly replaced *Lolium perenne*, and there would be less *Poa trivialis*, but more *Agrostis stolonifera (Lolio-Cynosuretum).*
Because of the migration of minerals during centuries from the hayfields via the cows and their dung to the pastures a rather high phosphate and potash level in the soil was achieved and therefore a good production was possible. By changes in the humidity of the organic matter during the year, nitrate mineralization was possible and also influenced a relatively good production level. The yield from year to year fluctuated by differences in the weather. With a cold and wet spring and autumn the yield was decreased. A dry summer in those districts fa-

voured the production on these humid soils with a good capillarity from the ground water.
In cutting experiments on those pastures, which are still there, during many years, without adding fertilizer nitrogen and optimal phosphate and potash, we found an average gross production of $\pm$ 6 tons per hectare. This means that the pastures could feed about 2 cows per hectare during the pasture season.
But because the import of minerals to the farm area as a whole was very limited (possibly some with straw), and even on these low lying peat-soil some drainage of minerals occurred, the average herbage production was low. So a taxation is that only about 1 cow per hectare could be foddered the whole year round.
The hayfields comprising about two thirds of the total area of a farm were the source for fodder during wintertime, when the cattle was housed in the stable.
The composition of vegetation on those hayfields was quite different from those on the pastures. The fields situated at the greatest distance from the farm-house, with the lowest mineral status had a very rich flora, sometimes with about a hundred or more different plant species. It was called "blue" grassland (*Cirsio-Molinietum*), as the colour of the herbage was blue green and gray green during the growing season. This in contrast with the pasture land, which had a more dark green colour. On the hayfields *Molinia coerulea* was the dominant grass species. Another important species was the *Carex panicea*, called the "blue sedge" with its blue green leaves. Other frequently occurring species were a thistle *Cirsium dissectum*, various sedge species, *Gentiana pneumonanthe* with nice blue violet flowers and various orchid species.
The richness of this vegetation was possible as the low mineral supply caused a low growth rate. Because of this always enough light was left near the bottom, even at the time of cutting (about half August), so that different species had live possibilities. The mineral situation was not so extremely low that only specialists under the plant species could live there. The mineralization from the peat was regular, when after the extremely wet situation in wintertime, the peat became drier in the growing season. As no other factors were extreme either, various species find there life conditions in this environment.

The hay production was very low compared with the manured fields. From former cutting experiments was found that the yield would be about two tons per hectare of dry matter. Compared with the average production of about 12 tons dry matter as an average per ha nowadays, it is only a fraction.
The quality of the hay in respect to the mineral composition and proportions was good. Only the phosphate percentage was too low and the digestibility of carbohydrates and protein was low.
On the grassland farms the zonation of the green pastures behind the farm-houses and the yellow brown zone in wintertime, altering in the blue green-grey green zone during the growing period, remained until the fertilizers appeared. This rather stable period, only sometimes disturbed by troubles with the water regulation gave a contribution to the prosperity of the towns in the sixteenth and seventeenth century.
Also in later centuries the by-products of the beer and other alcoholic production and cheap fodder grains, were used for pig feeding, and so some import of minerals to the grassland farms was possible.

13.3 Change in vegetation and production of the grassland after better drainage control of the polders and the application of fertilizers

With the introduction of motor pumps, the control of the groundwater-level became better. This created a better possibility to get with farm wagons to the fields at a greater distance from the farm-house. So together with the introduction of fertilizers, it meant a possibility to introduce minerals to those distant hayfields.
At the beginning phosphate and potash was used. Together with the nitrogen mineralized from the peat by the lowered groundwater table, an evolution of the "blue" grassland started. Species like *Molinia coerulea* and *Carex panicea* dominating the "blue" grassland quickly disappeared, and species like *Holcus lanatus*, *Anthoxanthum odoratum* already present in low percentages increased and *Poa trivialis* present in the "pasture" behind the farm-houses migrated to the hayfields. Many species like orchids and more rare sedge species disappeared. The number of species decreased from 80-100 to 40-50.

The new hayfield plant-community replaced in the years 1920-1930 almost all of the old "blue" grassland. The production increased to about 6-7 ton dry matter per ha. This meant that after a hay-cut in July, the aftermath could still be grazed.

This grassland type called haypasture was colourful during the hay cut as standing crop. The *Holcus lanatus*, a grass species with reddish glumes and the reddish brown colour of the sorrel (*Rumex acetosa*) and the yellow of the group of *Caltha palustris*, *Ranunculus acris* and *-repens*, *Rhinanthus glaber*. On the more humid places the reddish colour of the *Lychnis flos-cuculi* was striking.

Depending on the type of use and the groundwater supply we found various types of this *Calthion* vegetation.

At the end of 1930 and from 1945 again also the amount of fertilizer nitrogen increased to an average of about 70 kg pure N per hectare per year.

From 1960 until nowadays the amount of nitrogen increased highly.

On the moment the average is about 250 kg N/ha/year.

Together with the increase in N the grass silage replaced more and more the role of hay as a fodder.

Also the mixed use-system per field increased, with the purpose of obtaining a better and more homogeneous floristic composition of all the grassland on the farm.

Therefore the differences in the vegetation of the grassland in the peat-district grow smaller and smaller.

Still we find the difference between the predominantly grazed fields near the farm-house, because the same species from former days are still there, but more dominant now with less accompanying species.

The dominant pasture species like *Lolium perenne* and *Poa trivialis* have migrated to the grassland further away from the farm-house although they occur here in lower percentages.

A species like *Holcus lanatus* coming from the former "blue" grassland, became dominant in the successor, the colourful haypasture of 1920-1950 and migrated in low percentages to the above-mentioned pastures. This species is benefitted by fertilizing as found in experiments, but not tolerant to regular grazing. Therefore its optimum is situated in the fertilized hay pastures.

Also a "mow" species *Alopecurus pratensis* is important in the haypas-

tures, sometimes with rather high percentages.
Some other plant species like *Rumex acetosa, Anthoxanthum odoratum* and *Cardamine pratensis* remained as relicts in the grassland fields to the centre of the polders.
The production of the grassland has increased again and is now on an average 12 tons of dry matter per ha per year. This means a doubling of the production of the period 1930-1950.
If the drainage situation of the peat is good, and with the additional feeding of concentrates at present usual, a cattle density of 2-2.5 units per ha is an average. The average fertilizer nitrogen dressing is 250 kg pure N per ha per year. In some places the intensity of the grassland exploitation is so high, that we can speak of over-exploitation. This is indicated by plant species like *Poa annua, Stellaria media, Rumex obtusifolius* and *-crispus* and *Agropyron repens.*
In cutting experiments with grassland types on peat with optimal phosphate and potash situation, as an average of 10 years research, without N-fertilizer we found an average uptake of 300 kg pure N in the total annual herbage yield per hectare on the well drained peat soil. This uptake is 215 kg N on the more poorly drained peat, in the plots which were not fertilized with N in those 10 years.
So this means fertilizer application on peat soil had to be adapted to this knowledge to prevent over-dosing and over-exploitation.

13.4 An additional function of the peat district

Nowadays with landreconstruction development the results of vegetation surveys are used to get information about possibilities for nature and landscape management.
In the peat-district plans are developed to restore the former abovementioned haypasture vegetation. So on the vegetation maps special attention is given to the vegetation types with as many as possible relict plant species of former vegetation types. To this purpose the vegetations along the ditch sides are also surveyed. Often those linear-elements have more relicts as the grassland fields. It could be possible that these linear-elements serve as dissimination centres to the hayfield. On the latter fields an adapted management had to be devel-

oped, to decrease the level of minerals in the soil and adjusting the time of cutting, to give some plant species the possibility of seed production.

Because in the peat-district still many grassland birds are nesting and finding feed, this function is of interest as well.

By more intensive grassland exploitation possible by higher fertilizer input and drainage improvement, the cattle number and grazing frequency increased. This cattle is moved already early in the growing season together with the traffic of agricultural machinery and wagons to the more distant fields in the polders. So the quietness of those parts of the polder of earlier days disappears. It also means that more and more nests of the grassland birds are disturbed.

To preserve and develop the possibilities for brooding of the grassland bird, in some regions restrictions to grassland use and drainage are planned.

With the knowledge about decreased grassland production with those restrictions, the cost price to maintain grassland bird brood regions are calculated.

So the knowledge about the relation between the floristic composition and the growth factors, giving the indication of the production level are used for some aspects of nature management in the peat-district.

In this respect experiments are also done about recovering the former vegetation types, not only of the grassland, but also of the banks of the ditches and in the water of the ditches.

This means that the peat-district will be given a new function, not only for a number of biologists, but also for the recreation of many people in this densely populated coastal district.

	I	II	III		I	II	III
Lolium perenne	63	9		*Holcus lanatus*	1	29	1
Poa trivialis	13	31		*Plantago lanceolata*		+	1
Poa pratensis	+	2		*Rumex acetosa*		1	+
Poa annua	3	+		*Luzula campestris*		+	+
Agrostis stolenifera	7	24		*Anthoxanthum odoratum*		+	5
Phleum pratense	2	1		*Juncus effusis*		+	5
Cynosuris cristatus	1	−		*Carex nigra*		+	+
Trifolium repens	2	+		*Lychnis flos-cuculi*		+	−
Cirsium arvense	+	−		*Trifolium pratense*		+	
Ranunculus acris	+	+		*Molinia caerulea*			62
Ranunculus repens	3	+		*Carex panicea*			7
Taraxacum officinalis	1	+		*Eriophorum angustifolium*			1
Cardamine pratensis	1	+		*Potentilla erecta*			2
Plantago major	+	−		*Valeriana dioica*			+
Carex hirta	+	−		*Viola canina*			+
Potentilla anserina	+	−		*Hypochaeris radicata*			10
Agrostis tennis	3	4		*Cirsium palustre*			1
Stellaria media	+	+		*Centaurea pratensis*			+
Polygonum hydropiper	+	+		*Sieglingia decumbens*			3
Bellis perennis	+	+		*Agrostis canina*			1
Festuca pratensis	−	7		*Cirsium dissectum*			1
Glechoma hederacea	−	+		*Galium palustre*			+
Bromis mollis	−	3		*Festuca ovina*			+
Dactylis glomerata	−	1		*Succisa pratensis*			2
Cerastrium fontanum	−	+		*Achillea ptarmica*			+
Alopecuris geniculatus	+	+		*Gentiana pneumonanthe*			1
Festuca rubra	−	+	1	*Orchis maculata*			+

Records made 25 years and more ago of 3 grassland plots in the peat district of the province South-Holland. Record I is an example of the *Poa-Lolietum* and III of the *Cirsio-Molinietum*, both grassland communities mentioned on p. 215 and 216. Record II is an example of the community mentioned on p. 218 as the new hay field type.

14 REVIEW OF CHAPTER 13

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This paper has given us a good insight into the historical use of peat soils for grassland in The Netherlands. We particularly noted certain similarities and sometimes marked differences with our own agricultural developments.

When European settlers reached our shores they too penetrated by boat deeply into our country but choose to farm on mineral rather than on peat soil. The failure to develop Irish peat for agriculture is in our opinion not related so much to the absence of land scarcity as to the fact that Irish peats were less productive than what the initial settlers in The Netherlands and elsewhere found. The peatlands we had 1000 years ago were mostly of the blanket and raised types with relatively little fen available. It would be interesting to know the extent of fen peat in The Netherlands before burning and peat cutting started or was the fen only exposed in the burning and cutting operations?[1]

Windmills were not a feature of even the most organized attempts to reclaim our peat areas for agriculture. Presently the need for pumping is being largely avoided by cutting through moraine gravel ridges and arterial drainage. Burning is no longer carried out as a mineral enriching technique. Open drainage ditches and shelter plantings are kept to an absolute minimum. Trees should be used more as a landscape feature rather than as a form of shelter until their positive contribution to grass or animal production is established. We find that no mention is made of surface claying or marling[2] or the use of farm yard manure (FYM) in the earlier reclamation periods. The establishment of grassland on Irish peats in times past necessitated such treatment. The use of a

cutting as distinct from a grazing regime on the Dutch peats must have quickly exhausted soil reserves of nutrients. Did these nutrients mainly come from coastal alluvial materials rather than the peat itself?[3]
Our peats contain very poor reserves of P and K. However, the efficiency of utilization of fertilizer derived P and K at the optimum rate of application is approximately 80 per cent for each nutrient. The high diversity in plant communities attributed to differences in mineral supply and use have not been exactly pinpointed in the paper. We are especially interested in species establishment and survival under varying moisture, nutrient and management levels. It would be useful to know if the effects of FYM as a supplier of major and trace mineral nutrients and as a seed carrying agent on the botanical composition have been separated. Would slurry produced under intensive systems of grassland management have similar effects?[4] We associate the use of slurry with weed spread. The dominance of *Lolium perenne* in grazed swards treated with FYM was probably mainly associated with higher levels of P and K. The disappearance of *Lolium* from Irish peat pastures is usually associated with acidity. In Ireland under cutting conditions a sward of rosette weeds and poorer grasses receiving yearly increments of N and P grown on peatland can be quickly converted to almost a pure culture of *Festuca rubra*) in the absence of K whereas in the absence of P rosette weeds predominate (Murphy 1966). The yield response to nitrogen and phosphorus on such pasture varied from 7.9 kg DM per kg N to 93 kg DM per kg P applied. *Phleum pratense* is not very competitive under Irish conditions and is more susceptable to iron chlorosis when grown on peatland. We find *Agrostis spp* plentiful where fertility is low but rarely does one find *Cynosurus cristatus* dominant. *Lolium perenne* is usually the most favoured spp. from a production point of view. However, equally good production of mutton has been obtained from *Poa trivialis/Trifolium repens* swards or swards of *Cynosurus cristatus* and *Agrostis tenuis* plus nitrogen when grown on mineral soil (Murphy 1965). The effect of prostrate type grasses on the utilization efficiency of the sward especially under moist conditions should receive more attention. In our opinion the use of *Stenotaphrum secundatum* (Roselawn St. Augustinegrass) in Florida helps, by means of its very thick stolons, to prevent poaching or damage caused by treading. We have no temperate climate equivalent to this grass. It might get over some of the disadvantages we associate with

reducing oxidation losses by keeping the watertable high. In present circumstances we recommend late varieties of *Lolium perenne* as well as *Poa trivialis* and *Trifolium repens* on poorly drained sites because of utilization problems. Generally the survival rate of the sown species will depend on acidity, nutrient and moisture levels and on whether the sward is used for cutting or grazing.

The mowing experiments described in the paper on old cow pastures showed an average response of 6 tonne of DM or a stocking rate of 2 cows per hectare during the grazing season without added nitrogen. Is it known what proportion of this nitrogen comes from peat mineralisation as distinct from clover or elsewhere?[5] In our experience very little nitrogen is released for plant growth on our newer peats because of an unfavourable C/N ratio. Under cutting conditions the dry matter production from a *Lolium perenne* sward per kg of applied nitrogen is 35 kg using up to 336 kg N/ha annum. The apparent recovery of fertilizer nitrogen from a sward so treated is 80%. The dry matter response to nitrogen on an established *Lolium perenne/Trifolium repens* sward similarly treated is only 12 kg. This raises under our conditions the importance of clover and the botanical and management conditions necessary for its survival. In this respect the compatibility of clover as a source of nitrogen and prostrate type grasses to improve bearing capacity needs to be further elucidated. The bearing capacity of the sward may also be improved by the addition of sub peat mineral materials to peat but is unfortunately in some circumstances associated with poor conversion of grass to animal product because of molybdenum induced copper deficiency. We need to know more about the ideal proportion of peat to mineral soil and the effect it has on grass utilization.

The paper states that better drainage and the use of fertilizer increased the *Holcus lanatus* and *Rumex acetosa* content of the sward. Under Irish conditions these species also become dominant where the soil is acid or where ground limestone is insufficiently incorporated irrespective of drainage conditions.

Today's stocking rate of 2.5 livestock units per hectare in Holland compares very favourably with our results where equivalent fertilizer N inputs are made. Grazing trials over a 184 day period on shallow cutover raised bog have shown that the optimum stocking rate is 4.3 bullocks per hectare having a starting liveweight of 280 kg where clover supplied most of the nitrogen requiremtns of the sward. This can be increased to 5.6 bullocks per hectare of similar liveweight where artificial nitrogen is applied. One third increase in the carcass gain of heifers having a staring liveweight of 275 kg has been recorded from nitrogen applications to pasture stocked at approximately 8 heifers per hectare until mid-season and reduced to 4 per hectare thereafter. In our calf to beef systems work 2.5 calves can be carried to slaughter weight at 24 months of age or 1.6 cows and progeny to slaughter weight at 18 months of age on each hectare. In farm situations where peat and mineral land are farmed together we recommend that wherever possible the peats be used only for summer grazing leaving the mineral soil for conservation and slurry disposal. Some of our farmers are, under these conditions, realizing on a hectare basis a stocking rate of 2.5 cows and a milk production level of 11,400 litres. We have not measured the rate of release of N from our 'old' peat soils but we obtain as stated earlier a negligible N release from our 'new' peats. It is surprising therefore that similar stocking rates are achieved with similar fertilizer nitrogen inputs on 'old' Dutch and 'new' Irish peats. In how far could this be affected by differences in watertable heights?[6]

The paper raised the question of the over exploitation of grassland. What are the exact conditions whereby over exploitation is a problem?[7]

We assume the author is concerned about overstocking under poor drainage conditions. In our circumstances *Lolium perenne* and *Trifolium repens* withstands heavy stocking under rotational grazing systems. Species like *Poa annua* and *Stellaria media* only become a problem under open pasture conditions such as in new reseeds or where insect damage to pasture occurs. Nowhere in the paper did we find mention of the *Juncus* family. This is one of our worst weeds in poorly drained and managed peat pastures. Other weeds of widespread occurrence are: *Senecio jacobaea, Rumex obtusifolius* and *Cirsium arvense.*

Ireland is probably less conscious of maintaining old hay pasture vegetation types as described in the paper. Perhaps it is due to our abundance of vegetation types and a greater predominance of hedgerows. No doubt in the future emphasis must be placed on this aspect also. We believe this must be done now in areas of countryside specially selected for their amenity/recreational potential. In the Irish context it is probably more difficult to prove on cost/benefit grounds the present

value of such a proposal. Having proved it in The Netherlands we are interested in the mechanisms you have to ensure that the area in question will be conserved for the purpose intende.
The agricultural development of Dutch peatland has been taking place over a long period of time whereas most of the Irish agricultural developments have yet to be accomplished. Perhaps the author would like to speculate on the likely impact of modern technology and energy availability on the future developments and use of these peatlands taking into account the differences in their present stage of development.

Notes

(1-3 from the editors, 4-7 from De Boer)

1 The excavated peat in the western part of The Netherlands consisted of raised bogs (moss peat) and partly clay-poor sedge peat, the still remaining peat (Figure 1, Table 2 and Figure 4a in Chapter 5) is a clayey wood peat, partly covered with shallow fluviatile sediment. It is unknown if there was any burning practice as an agricultural system on the reclaimed raised bogs before they were cut for fuel contrary to the agriculture on the raised bogs in the northeast of The Netherlands and in the northwest of Germany (cf. Figure 1 in Chapter 8).

2 There is nothing known about marling in the time of the Big Reclamation (Chapter 3); marl is available at a distance of over 200 km; of course, in recent times there is liming, if necessary.
Claying is also not known in these early times; but, in the reclaimed bog floors with their calcareous loamy soils locally there are many circular depressions (3-5 m wide and a depth of 2-3 m) filled in with peaty material. Mr. L.W. Dekker of the Soil Survey Institute of The Netherlands in an article (in preparation) thinks it highly improbable that these holes date back from the times the raised bogs were reclaimed but rather from the time of the peat cutting.

3 We do not know anything about manuring practices in the early stages of the Big Reclamation. Coastal alluvial materials have not been used, dune sand (cf. Chapter 5.2.2 and 5.3.2) has been used but we do not know when this practice started.

4 In some cases slurry can increase weeds in grassland. But if the slurry is well mixed and applied by not too dry weather conditions no weed spread will occur.

5 The percentage clover in the sward of the zero nitrogen plots in the described experiments was only 3-5%. So only a very low percentage of the nitrogen comes of this wild white clover.

6 The stocking rates of about 2 cows per hectare on the 'old' Dutch pastures is limited only to the first 1/3 front part of the farms. The mineral status (also phosphate and potash) was favourable and if the watertable was optimal for plant growth and in most circumstances not so high that grazing damaged the sward.

7 It is no possible to put the exact conditions whereby overexploitation is a problem. It is a combination of too high nitrogen application (higher than 300-400 kg pure nitrogen per year per hectare for peat soil with an optimal watertable) and damage of the sward by cattle grazing and machinery during rainy periods.

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15 FARM MANAGEMENT ON PEAT SOILS

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15.1 Introduction

The area for agricultural land in the Netherlands amounts to two million hectares, table 1. It is composed of 60 % grassland, 34 % arable land and 4 % horticulture. Of the total area of agricultural land 17 % is situated on peat soil and mainly used as grassland, table 2 and 3. The total grassland area in the Netherlands comprises 1,2 million hectares. Fifty percent of it is found on sand, 27 % on peat and 20 % on clay soils. Roughly half of the peat soil areas are situated in the western part of the country and are mainly used as permanent grassland. This forms the western pasture district, fig. 1.
Some remarkable facts about the development of dairy farming in the Netherlands during the last two decades are given in table 4. It is interesting to note that despite a sharp decrease of over 60 % of the total number of dairy farms, the total number of dairy stock has increased with over 40 %, i.e. the total area of grassland has not increased, whilst the rate of stocking certainly has.

The number of milk cows per ha grassland has increased from an average of about 1.3 in 1960 to nearly 2.0 in 1979.
The cubicle house has gained rapid acceptance. At present about half of all our dairy cattle is housed in cubicle houses. The average number of dairy cattle per cubicle house is 65 as compared to 22 in other types of cowhouses.
The switch over to bulk milk is in full swing.

Table 1: Area of agricultural land according to land use in the Netherlands.

Pasture	1 210 000 hectares	60 % of total
Arable land	700 000 ha	34 % " "
Horticulture	80 000 ha	4 % " "
Others	40 000 ha	2 % " "
Total	2 030 000 hectares	100 %

Table 2: Area of agricultural land according to soil types.

Sands/sandy loams	820 000 hectares	40 % of total
Loams/clay loams	770 000 ha	38 % " "
Organic soils	340 000 ha	17 % " "
Others	100 000 ha	5 % " "
Total	2 030 000 hectares	100 %

Table 3: Area of grassland according to soil types.

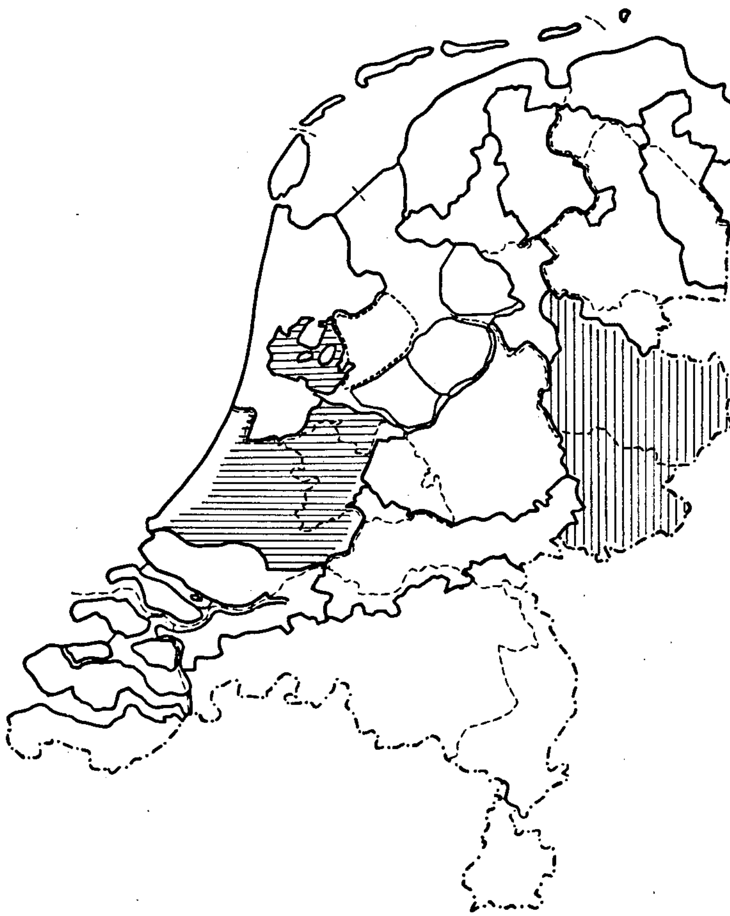
Sands/sandy loams	600 000 hectares	50 % of total
Loams/clay loams	240 000 ha	20 % " "
Organic soils *)	330 000 ha	27 % " "
Others	40 000 ha	3 % " "
Total	1 210 000 hectares	100 %

*) 180 000 hectares or 15 % of the total pasture area in the Netherlands is situated in the western region.

Table 4: Development in dairy farming in the Netherlands during 1960-1980.

	1960	1970	1980
Number of dairy farms	183 000	116 000	70 000
Average number of dairy cows per holding	9	16	34
Average milk yield per cow in kg	4 200	4 390	5 000
Number of holdings with cubicle houses	-	830	18 000
Holdings with milking machines (% of total)	22 %	70 %	97 %
Holdings with milk cooling tanks (% of total)	-	3 %	62 %
Total cattle stock	3 500 000	4 300 000	5 100 000
Number of dairy cows	1 600 000	1 900 000	2 300 000
Total area of grassland in hectares	1 200 000	1 300 000	1 200 000

Figure 1: The western pasture district in the Netherlands.



Western pasture district

Eastern sands district

The frontispice photo (p. 2) is a typical example of a dairy farm in the western Netherlands. It is situated in the hamlet Teckop (cf. Figure 6 on p. 56).

15.2 Farm size

"Organic soils" in comparison to "mineral soils"

Because of the fact that more than 50 % of our grassland is situated on sands, it is of interest to compare some typical records of a sandy region to those of a peat soil area of the western pasture district. The average records of the dairy farms in the Netherlands are both compared to the records of the eastern part of the sandy soil district and to those of the peat soil area of the western pasture district (fig. 1). In both districts over 80 % of the area of cultivated land is used as grassland for dairy farming. One would expect a difference between holdings on mineral soils and holdings on organic soils. However these differences in farm practices are not significant. In general the peat grassland farms have a slightly better farm size and production volume (tables 5 and 6).

Table 5: Percentage of holdings on the basis of total milking stock in 1979.

Number of cows-in-milk per holding	Average for the Netherlands in %	Eastern sand area in %	Western grassland area (peat) in %
< 30	53	49	41
30 - 50	25	25	33
50 - 70	13	25	24
> 70	9	1	2

Table 6: Classification of the grassland holdings by size of farm in %.

Size of holdings in ha	Average for the Netherlands in %	Eastern sandy soils in %	Western grassland area (peat) in %
< 10 ha	31	32	16
10 - 20 ha	38	47	49
20 - 30 ha	20	16	26
> 30 ha	11	5	9

Table 6 and 7 show that the holdings on the peat grassland area are in general a bit larger. That owing to the fact that in former years tenant farming was undertaken more often in the western than in the eastern part of the country. Reason for this development is, that amongst others, the merchants of the commercial cities in Holland bought land in the West as an investment of their capital. Therefore it was impossible for the holding to be split up between the tenant farmer's successors. Consequently proportionally less small farms were established, table 6.

Table 5 gives an indication of the size of the production volume of the grassland holdings. No more than about 10 % of our grassland holdings has a herd of more than 70 cows-in-milk. In the western peat grassland areas the holdings are on average not only a little bit larger, but they also have a larger herd. On sandy soils the number of milking stock per ha* grassland has increased more than on peat soils, table 7. it appears reasonable to assume that the differences in load bearing capacity of these types of soil are the underlying cause for this.

Table 7: The average size of the farms and the number of milk cows in a sandy and in a peat region in 1974 and 1979.

	Eastern sandy district		Western pasture district (peat district)	
	1974	1979	1974	1979
Area under cultivation in ha	146 000	134 000	155 000	144 000
Number of holdings	11 000	9 000	9 500	8 000
Average size per holding	13	15	16	18
Average number of milk cows per holding	25	33	30	36

*) ha ≈ 2.5 acres.

15.3 Parcellation

The historically established parcelling pattern in the western peat area has often caused unfavourable conditions for the further development of the present family holdings. The farms are usually located on ribbon shaped developments with their lands stretching in long narrow lots at the back of the farms. This development pattern in the western peat area has resulted in holding lots having a length of 1250 to 2500 meters and a width of 40 to 100 meters. Many plots have a width of two lots. If it is desirable that the milking is done at home also during the grazing period, then over 60 % of the land should be near the buildings and the walking distance for the cattle should preferably be less than 1000 meters. In line with this, on average, 60 % of the farming area is around the building and the average walking distance is 1090 m. The average lot size is ± 1.3 ha. Characteristic for dairy farming in the western peat area is the large area of surface water belonging to the farm. On many holdings over 15 % of the total surface consists of water. The total area therefore in most cases is larger than the area used for farming. A farm of 16 ha may include some 2.5 ha of surface water and in the case of a 36 ha holding the surface water may cover up to 6 ha.

When analysing the farm's production the size of the truly productive farming area is always taken into account. Well maintained surface water requires much labour. On a farm with 6 ha surface water the ditches are cleaned by hand once in five years. Ditch cleaning and maintenance usually takes place at the beginning of the housing period and is frequently contracted out.

Because of the present ditch pattern it is impossible to reallocate the plots of the peat land holdings, especially so when the ditches are wide. For farmers in the sand region however, it is not as difficult to revise the parcelling and to improve the opening-up of an area.

15.4 Drainage

The water level of the ditches in the western part of the country is generally high. The drainage of the grasslands is therefore insufficient for about 50 % of the peatland area. Consequently, difficulties with respect to the load bearing capacity of these grasslands arise frequently during the winter and springtime. On many farms it is impossible to spread the slurry during wet winters. Only when the upsoil is frozen it is possible to drive over the land for the distribution of the slurry. Spreading of too much slurry in too short a time during irregular frost periods may cause severe burning of the sod.

For good management of these farms, a large slurry pit is imperative. Additionally it may happen that the slurry cannot be distributed in time. Frequently in March and April the bearing capacity of the land is still insufficient for spreading the fertilizer. In order to be able to harvest the first crop of cut grass at the end of April, it is necessary to distribute the nitrogenous fertilizer around the middle of March. When during the grazing period the less well drained peatlands suffer from heavy rainfall, the bearing capacity of the grasslands, because of too high a groundwater level, becomes insufficient for grazing purposes and accessibility. Grazing losses can arise when, because of insufficient bearing capacity, the grazing of animals necessarely starts too late. Extra grazing losses may occur when the cattle is grazed on grass that is too long. Apart from these yield losses it is clear, that grazing on land with insufficient bearing capacity can cause trampling of the turf, which in turn causes deterioration of the structure of the soil, which results in problems concerning regrowth and a slow recovery of the sod density. Under such circumstances an increase of weeds and a decrease of production as a result there-of should be expected.

Harvesting may be slowed down due to insufficient bearing capacity. Also the necessity of fast transport of the cut grass for silage in order to prevent the cut product from decaying on the field, can result in serious damage to the turf. The grass drying period for silage lasts longer on wetter lots. Proper grassland management is difficult when grassgrowth becomes irregular. This happens especially on less well drained peatlands. The problems as mentioned above i.e., caused by insufficient bearing capacity, as a result of too high groundwater level, do not in general occur as frequently on sandy soils.

15.5 Harvesting

On peat soil farms hay winning is predominant over silage. Of the cut area in the peatland district about 40 % is gathered as hay. In the sand soil region this amounts only to 20 %. The reason for this is firstly the lack of sufficient storage capacity on the farm yard, which are small in general and secondly the fact that because of insufficient bearing capacity of the soil it is difficult to find suitable silage pits. During the winter season excess of water can spoil the silage. In addition, the silage pit may be inaccessible for driven transport. In the peatland region about 50 % of the cut grass area is used for silage. In the sandy soil area this amounts to 70 %.

15.6 Farm profits

A comparison of the characteristic farm profits is given in table 8. For 1978/1979, taken from the beginning of the grazing period of 1978 until the end of the housing period of 1979, which date in terms of bookkeeping is on the 31th of April, the average results for the Netherlands of the larger and smaller grassland holdings are compared to the average results of the peat soil pasture region and the sandy soil region. Also taken into account are the average results of the pilot farms of the agricultural economics research institute.

Table 8 shows the possibilities, as well as the differences between these areas. The pilot farms indicate the possibilities. During the last ten years the aim has been to increase the size of the farms. Especially the pilot farms in the Netherlands have increased their area under cultivation. In general, the large farms have a higher level of return on labour and thus a larger family income (table 8), especially the pilot farms. Returns on labour means: the difference between the returns and the total expenditure of the holding (based on tenancy).

It is clear that an increase in size of the holdings has been the most effective way to increase the family income. Also an increase in livestock units per ha, as on the pilot farms, may have the same result. The lower milk yield per dairy cow on the smaller farms should be seen in the light of a lower standard of selection on milk production of the dairy herd.

Table 8: Financial results and farm profits of large and small grassland farms in the Netherlands, in the western peat pasture district, in the eastern sand district and of the pilot farms of the Agricultural Economics Research Institute.

1978 - 1979	Average for the Netherlands		Large dairy farms on		Small dairy farms on		Average on pilot farms
	Large holdings	Small holdings	Peat soil	Sandy soil	Peat soil	Sandy soil	
Farm size in ha	27	15	25	22	16	15	29
Number of milk cows	58	24	51	52	25	25	76
Milk cows per ha	2.17	1.62	2.04	2.43	1.61	1.79	2.64
Livestock per ha	2.82	2.36	2.64	3.15	2.18	2.49	3.28
Milk yield per cow in kg/year	5 435	4 938	5 240	5 640	4 886	4 938	5 877
Milk yield per farm in kg/year	317 763	119 835	267 000	296 000	122 000	125 000	445 000
In guilders per milk cow: milk yield	3 350	2 974	3 151	3 408	2 932	2 990	3 629
In guilders sales and increment	818	1 105	773	872	900	962	783
In guilders total proceeds	4 168	4 079	3 924	4 280	3 832	3 953	4 412
In guilders feed costs	1 148	1 103	1 107	1 278	1 040	1 060	1 195
In guilders balance: proceeds minus feed costs	3 020	2 976	2 817	3 002	2 792	2 893	3 217
Return on labour	45 227	19 178	29 040	46 315	19 419	20 293	90 000
Cutting in %	157	110	122	149	118	105	143
Kg of concentrates per cow	2 370	2 258	2 165	2 773	2 030	2 150	2 358
Kg N per ha	327	234	222	356	200	254	410
Kg P_2O_5 per ha	8	23	15	26	32	-	-
kg K_2O per ha	3	18	12	31	96	-	-

The participation in milk control is proportionally less on smaller farms. On the whole, the peat soil pasture district is lagging behind slightly in comparison to the sandy soil district. The number of checked dairy cows in the peat soil pasture area is almost 15 % less than in the sandy soil area. The difference in number of dairy cows and livestock units per ha is partly due to the lesser bearing capacity of the peat soil pasture. However, the practice of retaining a number of young stock and the fattening up of young herd for slaughter has always been a traditional difference between the regions.
The red and white cattle of the sandy soil district is more in demand for slaughter than the black and white cattle of the peat soil region.
The slightly larger size of the average farms in the peat soil pasture district compensates for the smaller stocking rate per ha. Therefore the average number of dairy cows is about the same for both regions.
In general, more on the farm produced roughage per animal is available on peat soil, because of the smaller rate of stocking per ha grassland. Consequently a smaller amount of concentrated feeds need to be bought. The grass production of the peat soil grassland is, moreover, higher than the production of the sandy soil grassland. The reason for this is the subsequent delivery of nitrogen by the peat soil (table 9).
The optimum annual nitrogen application per ha grassland is approximately 420 kg (table 10). Because of this subsequent nitrogen delivery by the peat soil itself, a nitrogen gift reduced by about 100 kg per ha will be sufficient. This difference in nitrogen application is shown in the average farm profits.

Table 9: Lowest and highest yield in kg dry matter per ha grassland averaged over the period of 1964 until 1968.

Type of soil	Largely pastures		Kg N at
	lowest yield	highest yield	highest yield
Sand	8 750	13 300	450
Peat	9 600	13 050	300

(from Boxem, 1973)

Table 10: Recommended nitrogen gift (kg N per ha)

	Pastures	Cutting
First cut	80 - 40*	120 - 80*
2nd and 3rd cut	80	100
4th and 5th cut	60	80
Later cuts	40	

*) Plots that are pastured or cut last.

The fertilizer requirements of phosphate and potash are more than adequately covered with a stocking rate of 2.5 milkcows with young stock per ha (table 11).

Table 11: Supply and removal of phosphate and potash on a dairy farm with a stocking rate of 2.5 milkcows with young stock per ha and 130 % cutting, in kg P_2O_5 and K_2O.

	P_2O_5 in kg		K_2O in kg	
Supply per milkcow with young stock:				
- on the basis of 2500 kg of concentrated feeds	37.5		37.5	
- on the basis of roughage by cutting 130 %	11.2		35.2	
Total		48.7		72.7
Removal per milkcow:				
- through 5500 kg milk	11.5		9.9	
- through 200 kg gain in weight	3.4		0.4	
Total		14.9		10.3
Total left over in the slurry		33.8		62.4
Supply per ha with 2.5 milkcows with young stock		84.5		156
Removal through losses of slurry*		5		13
Rests a nett supply per ha of:		79.5		143
Required amount per ha grassland for pasturing and 130 % cutting		55		120

*) on cattle tracks

Therefore, the pilot farms set a good example by not buying any phosphate and potash fertilizer. In practice however, the unequal spreading of the slurry on the farming area, as a result of the poor accessability caused by the lack of bearing capacity of the peat soil, causes local shortages. To compensate for this local shortage of slurry, fertilizer is in fact purchased unnecessary.

In general, it can be said that the farm profits in the sandy soil region are slightly better than those in the peat soil region. Improvements can be made on both, as is shown by the data of pilot farms. The difference in farm profits are a consequence of the historical development and the limitations in possible use of the soil. Of old, the peat soil pasture district is exclusively exploited as grassland and mainly used for dairy farming. Formerly butter and cheese were made on most of the farms. Often pigs were kept simultaniously to make use of the side product: whey

This is not so any more.

Since world war II the farms have tended to specialize in the production of milk only. The processing of the milk into cheese, butter etc. is now-a-days left to be done by the milkfactories.

In the sandy soil region the modern development into exclusive dairy farming - especially since world war II - has become even more pronounced, due to the disappearance of the mixed farm. Now the still available arable land serves only for the growing of roughage, mostly maize for silage.

The management of holdings on sandy soil is in general more efficient, due to the more radical changes in set up. On sandy soils the latest developments in specialisation have been adopted more rapidly. The circumstances have made the peat soil holdings more conservative than the sandy soil holdings.

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15.7 Literature

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16 REVIEW OF CHAPTER 15:

A COMPARISON WITH SOME DATA FROM SCHLESWIG-HOLSTEIN

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Developments as shown by Mr. Schneider can be seen similar to those in Schleswig-Holstein: livestock increases and the number of cattle in the land is rising. Preferred also will be cubicle stable houses.
42.4 per cent of the agricultural area in Schleswig-Holstein (total 1.1 million hectare) have been registered to be permanent grassland. It is spread about in the lowlands, the prehistorical river basins. Ground-water in the winter always is near the surface of the soil, in summer time it goes down about 60 to 100 centimeters. Also the permanent grass-land we find on clay, on loam and on sandy soils.
During the last twenty years we have noticed a remarkable change in using the soils (Table 1).

Table 1. Grassland* and milk cows** in Schleswig-Holstein (see Figure 1)

Site	permanent grassland		milk cows	
	1979	since 1970	1979	since 1970
Marsch (Holocene)	19.3%	- 1.1%	12%	-
Geest (Pleistocene, older periods)	58.3%	+ 4.2%	60%	+ 8%
Hügelland (Pleistocene, younger periods)	22.4%	- 3.0%	28%	- 8%
Schleswig-Holstein, total	100.0%	-	100%	-
Absolute figures	467968 hectares		511000 cows	

* additional grass production from arable land: 87330 hectares

** the average figure per hectare: 0.92 (cows)

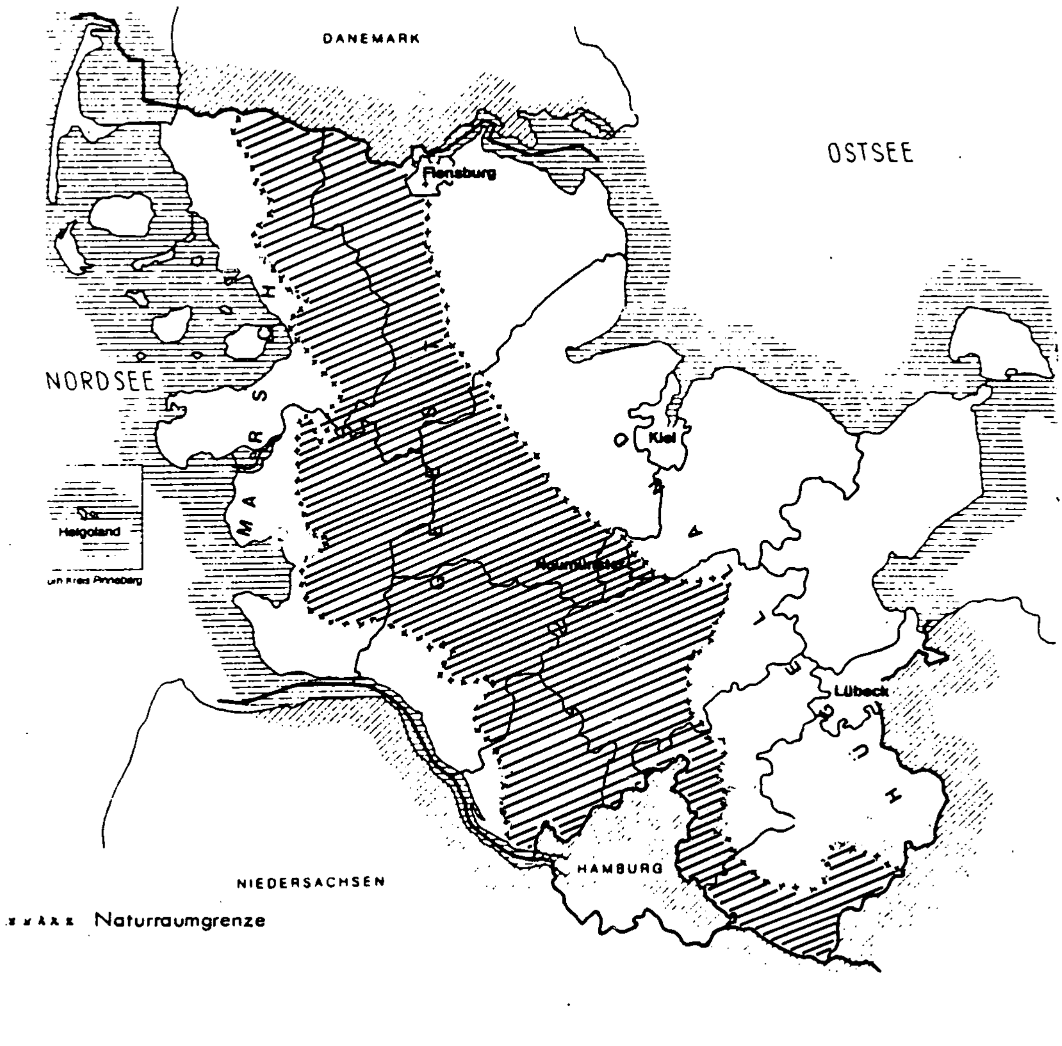

Figure 1. Federal State Schleswig-Holstein. Left: *Marsch* (Holocene), middle: *Geest* (Pleistocene, older periods), right: *Hügelland* (Pleistocene, younger periods).

As growing grains is more profitable, the better soils no longer are to be used for grass production. On the other hand grains disappear from inferior land. There nowadays we see grass, and somewhat corn for silage on mineral soils. Producing milk only there is lucrative.
30-35 per cent of this permanent grassland (that is 130.000 hectares) is covering the reclaimed peat areas. Each peat bog has a certain ecological character, which is realized even after draining and reclamation took place. The exact quote of the reed bogs related to the moss bogs we do not know; mainly there are reed bogs, contrary to the situation in Niedersachsen (Low Saxony).
From the permanent grassland in Schleswig-Holstein we cannot present such a good work of illustrative statistical materials like Mr. Schneider produced for The Netherlands. We looked out for a few test farms, observed by the Chamber of Agriculture in our land, to be characterized with the following particulars:

a) most of the farm grassland is found on peat soils,
b) relative long time in these farms book-keeping is practised,
c) the economic data may be evaluated by special experts from the Chamber.

This means too, that the farms chosen can be classified: we say *Fütterbaubetriebe* (fodder-producing farms). The latest official judging paper dealing with the economic situation of the Schleswig-Holstein farms (results from 1979/80) Burchardi states:

> the *Futterbaubetriebe* - about 65 per cent of the actual number of farms - exist in unfavourable regions, practising intensive diary on smaller parcels with relatively high manpower. In comparison with the other farm types this groups exists on the lowest level with regard to income, so again in this year, when the income decreased by 15% to DM 24.000 per agricultural labourer. This we do regret.

You may consider the economic situation in Schleswig-Holstein at all: yield and income figures are the lowest in Western Germany! You can calculate, that nowadays no more intensity is required, not at all on the peat soils.

Some data from the *Futterbaubetriebe*, mainly on peat soils, are listed against the data from Mr. Schneider (Table 2).

Table 2. Financial results of grassland farms in The Netherlands and in Schleswig-Holstein.
The Netherlands: dairy farms on sand and peat (78/79)
Schleswig-Holstein: dairy farms on peat-soil and from mixed regions (*Geest*, almost sand and peat in each farm)

country	The Netherlands		Schleswig-Holstein	
site	sand	peat-bog	peat	mixed
land use intensity	high	high	(rel.high)	moderate
Farm size in ha	22	25	40	45
Number of milk cows	52	51	48	33
Milk cows per ha	2.34	2.04	1.18	0.73
Livestock per ha	3.15	2.64	3.09	2.00
Milk yield per cow in kg/year	5640	5240	5330	4873
Milk yield per farm in 1,000 kg/year	293	267	255	158
in guilders/in german marks*				
Milk yield per cow	3408	3151	3251	2973
Sales and increment per cow	872	773	829	768
Total proceeds per cow	4280	3924	4080	3741
Feed costs per cow	1278	1107	906	685
Balance: proceeds minus feed costs	3022	2817	3174	3056
dt concentrates per cow	27.7	21.7	21.6	16.3

* 1980/81: value 0.90:1.00

Some trends are similar:
more cattle in the land, increasing production of milk, more concentrates.
The differences are:
our farms are relatively large, the structure of livestock is more

traditional, young cattle stays in the stock; income may differ because prices vary from season to season (fertilizer, food, etc.).

All the other statements about soil- and water regimes pointed out for the management on peat soils in The Netherlands correspond with the essential conditions for the peat farms in our country.

Concerning the grassland advisory work, done by a few experts, it is very important to maintain the level achieved to date concerning the optimal production. Therefore it is necessary to keep up the sward quality by elaborated methods and to improve the knowledge about manuring or fertilizing the pastures and the meadows and about seeding the proper species into the grassland.

In the lowland swards we prefer sodseeding with intensively tested and ecological adapted species out of the European grass range. Only the following species are qualified for this:

Lolium perenne - Perennial Ryegrass

Phleum pratense - Timothy Grass

... and until now: no other grass!

Suitable machines are ROTASEEDER and VREDO.

You may see three examples to this problem in Table 3, sodsown species there are marked.

More experience with the draining of peat and with the control of the water-level is desirable.

Trouble - we must confess - is building up with increasing slurry quantities to be re-used being a considerable source of nutritive substances. The farms ought to have some profit of it. Unfortunately just the swards on the peat soil do suffer more and more! The plant composition is breaking down, weeds then increase and consequently the bearing capacity decreases. Having learned this, farmers no longer want to bring out slurry on the peat grassland, they have better experiences on the sandy soils.

Slurry banks and slurry pools are not yet in use. Not yet solved either is the problem of evaluating the nitrogen efficiency when slurry is spread out upon the sward.

Table 3. Composition of Grassland-Swards on typical Low-Grounds in Schleswig-Holstein. Noted in meadows and mown pastures before cutting the first time in 1981 (9.6-10.6.81) Species in % of the total sward.

nr. of experiment	1	2	3
location	Tielenhemme	Tielenhemme	Ahrenviöl
soil	clay above peat	peat, somewhat silty	peat
soil moisture	temporary moist	moist	temporary moist
using of grass land	mow-pastures	mow-pastures	meadow
Lolium perenne	38*	10*	34*
Phleum pratense	9	+	15*
Dactylis glomerata	+		11*
Festuca arundinacea			1*
Agrostis prorepens	5	5	+
Alopecurus geniculatus	8	20	+
Glyceria fluitans	+		5
Holcus lanatus	1	2	1
Deschampsia caespitosa	+	20	+
Poa trivialis	9	25	13
Festuca pratensis	6	2	8
Poa pratensis	9	10	7
Agropyron repens	1	3	
Poa annua	+	1	
Bromus mollis	2		+
Trifolium repens	2	+	
Ranunculus repens	3	1	3
Taraxacum officinalis	3	+	1
Ranunculus acer	+	+	+
Cardamine pratensis	+	1	+
Stellaria media	+	+	
Cerastium caespitosum	+		+
Rumex acetosa		+	+

only found once	
in experiment 1:	Urtica dioica, Cirsium arvense, Rumex crispus, Polygonum amphibium terrestre, Potentilla anserina, Plantago major, Achillea millefolium
in experiment 3:	Caltha palustris, Lychnis flos cuculi

* On clay-covered peat: main part from sod-seeding
On peat-soils: only from sod-seeding (not seen in the sward before sod-seeder had worked)

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17 THE USE OF PEAT AND PEAT SOILS FOR HORTICULTURE

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As has been shown in previous papers, a rather large part of the western part of the Netherlands was covered with peat. The part which consisted of moss peat, has been removed to a great extent by mans activities some centuries ago and used for fuel. With the invention of the dredging technique it became possible to remove all the peat, and deep lakes (4-6 m) with a clay bottom were left behind. Only small isles of peat remained between those lakes. Partly because they were occupied by settlements, but mostly because they did not consist of moss peat but of sedge or wood peat.

Now, most of the lakes have been drained and reclaimed. In these polders a rather large-scale agriculture has been developed. The reclamation was financed by merchants from the near-by towns, who earned their money in the oversea-trade. Therefore, most of the farmers in the polders did not originate from the peat region. The original inhabitants on the 'peat isles' only had small farms. To earn a living they were forced to very intensive exploitation: expensive crops, like vegetables, and several crops per year. A good market was at hand: the rapidly growing cities of Holland, whose inhabitants developed intensive industrial and trade activities. The industrial activities were originally partly based on the availibility of peat (De Zeeuw, 1978).

In this way a râther intensive horticulture was developed around Leiden, Haarlem and Amsterdam.

The horticultural development was also promoted by some favourable physical properties of the peat soils: workability, a high pore space with a high amount of easily available water and yet enough air (table 1).

A		B		C		D	
air %	moist.%	air %	moist.%	air %	moist.%	air %	moist.%
19	12	10	18	10	5	11	5

Table 1. Air content at pF 1.5 and easily available water (between pF 1.5 and 2.7) in a peat soil (A), a peat subsoil (B), a clay topsoil (C) and a clay subsoil (D). (According to Van der Knaap, 1976)

As a result these soils are very suitable for a rapid growth of vegetables like lettuce, cauliflower, celery. Under glass cucumbers and tomatoes give very high yields, but in spring, under low light-intensity, it is difficult to force plants into the generative stage (flowering). So one can not use these soils for earlies (e.g. tomatoes).
Most of these soils used for horticultural purposes, consist of a subsoil of sedge peat or wood peat, covered with a toplayer of decomposed ('earthified') peat mixed with clay or sand. This mineral enrichment is man-made. The clay was dug from the banks of old streams, which after the drainage of the peatland, by inversion became higher than the surroundings. The sand was dug from the dunes and shipped to the stables. This sandy manure was then mixed with mud dredged from the ditches and brought on the land.
The groundwater table must be kept high to prevent the peat from shrinking and oxidation (see Schothorst's paper). As a result of the high air content at low pF-values, roots can grow into proximity of the groundwater. A considerable amount of the necessary water-supply for the crops is therefore ensured by capillary rise. At the other hand, fluctuation of the groundwater level must be restricted between very narrow boundaries. To ensure both water supply and level control, a restricted distance between the ditches is necessary.
The growing demand for vegetables early and late in the season, lead the growers to the use of Dutch lights and afterwards to the building of heated glasshouses. Partly they switched over to the growth of flowers, especially around Aalsmeer, perhaps also stimulated by the short distance to the airport Schiphol. Today the horticultural area has extended from the peat uplands into the polders on the drained lake bottoms. The financial results made the growers economically stronger than the far-

mers, and at last the 'gardeners' outmatched the 'farmers'. As the parcelling in these polders is much better, the big modern 'flower-farms' are found on the loamy soils of the former bog floors.
During the last ten years the suitability of peat and loamy soils for growing roses, has been compared in the regio of Aalsmeer (Van der Knaap 1976, 1977; Van Rijssel, 1977, 1980). There is a very clear difference between these soils. The great amount of easily available water in the peat soils make high production possible if .... there is enough light for assimilation. If not, the availability of water is disadvantageous for the number of flowers, flower quality and firmness of the stem. As a result there is on the mineral soils a bigger production at a higher price a piece in winter, whilst in summer the production on peat soils outmatches the mineral soils. It depends on the price-ratio in summer and winter whether the higher production in summer on peat soils can compensate the losses in winter, with respect to the mineral soils. Improving the quality in winter can be done by enlarging transpiration, which requires higher energy demands. With the increase of energy prices the disadvantage of peat soils will grow.
The need of stronger heating on peat soils is caused by a high heat conductivity, resulting in a higher value of the thermal diffusivity. This means a rapid decrease of temperature differences between top and bottom of a layer, or, with other words, great energy losses to the subsoil. Van Wijk (1969) calculated the course of soil temperature with depth and time in a mineral soil with a groundwater depth of about 100 cm, and a peat soil (moss-peat) with a groundwater depth of 40-50 cm, when in spring, after a period of winter-rest, roses are forced at a mean air temperature of 20°C (Figure 1).
Annex to this is the problem of sterilization of peat soils between two growing periods. Steaming may cause structural damage (shrinkage) and also takes a lot of energy because of the high heat capacity. Often a high manganese content is found in these organic soils, which becomes temporarily available after heating, and may then cause severe damage (e.g. in lettuce and roses). Now that the 'normal' chemical way by methylbromide (CH_3Br) is forbidden, this problem must be studied again.
The combination of a high organic matter content and a certain amount of clay causes a rather high cohesion of the topsoil, without the problems of bad workability that are inherent with heavy clay soils. Together

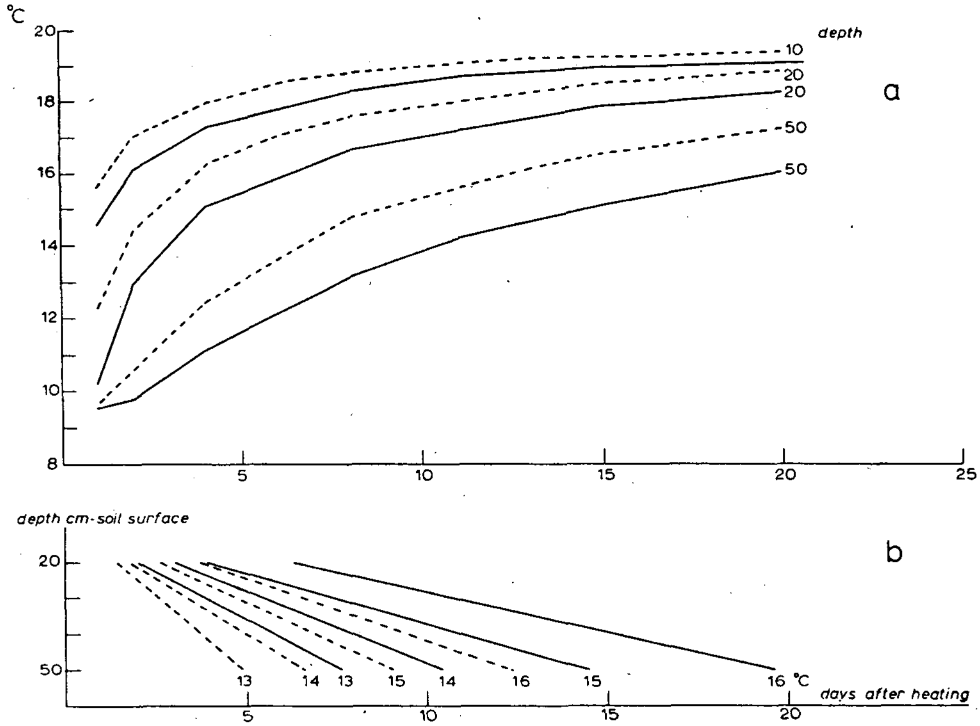

Fig.1. Comparison of the calculated course of soil temperature in the clay (--) and peat (—) soil at egual air temperature conditions; a. Course of soil temperature at 10, 20 and 50 cm below surface; b. Isotherms.

with a limited rooting depth as a result of the high groundwater level, very good root balls are formed. This property made these soils especially suited for the growth and forcing of Lilacs. These are grown for two years in the open air, brought into the glasshouse with the root ball, and after harvesting the flowers, planted again in the open air for the next two years.

These splendid root balls are also one of the fundaments of the nurseries around Boskoop. It enabled the growers to sell ornamental trees and shrubs with a high chance of success in regrowth. Around this village there is a concentration of rather small but very intensive nurseries, with a total area of about 900 ha. Already in the 15th century this activity is mentioned. The region belonged then to the rather rich monastery of Rijnsburg. Because of the bad quality of the peat for fuel, and the absence of direct need of money, the peat was not dug, but the use for intensive nursery was promoted. It gave less money at the time, but lasted for centuries!

The subsoil, mostly wood peat, has a rather high water permeability, so water supply by subirrigation is possible. The high groundwater table (50-60 cm below surface) allows very little fluctuation, so the distance between ditches should be kept small. Originally, fields were 110 m wide (see Van der Linden's paper). For compensation of the loose of organic material by shrinkage and by the selling of root balls, sludge dredged from the ditches was used and often a ditch was dug in between. Fields then became about 52 m wide and sometimes even these were split up again into lots of 22-23 m wide. The transport for these very long and narrow strips was done by barges through the ditches. On the fields there was only a very narrow path, only wide enough for a wheelbarrow. Off-the-road transport was after all impossible because of the low bearing capacity of these soils. Planting was even done standing on planks, in order to protect the ideal soil structure.

After World War II a big improvement in the water management took place. A soil scientist (H.Egberts) strongly advocated subsurface drainage, consisting of a closed system of tiles ending in a pit with pump, consequently the water table can be controlled independently from the ditch level. Mechanization, especially for soil treatment, now became possible, because by a temporary lowering of the groundwater level the bearing capacity can be increased. These drainage systems also can be used for subirrigation when the land level is high enough (that is over 60 cm) above the water surface in the ditches. If the land lies lower, then subirrigation is impossible, because of a too high groundwater level. The capillary fringe never may reach into the regularly cultivated layer, that is 35-40 cm below surface. Nowadays a rather large part of this area has not enough height for this subirrigation, so sprinkling irrigation is often necessary.

As goes from Schothorst's paper, there are several causes for the sinking of the land level. In horticulture some of these factors are stronger than in grassland farming. The better drainage in wet times causes a certain settling of the subsoil. Another consequence of the better drainage system was the possibility of filling in the 'middle ditches'. After filling these ditches these strips are used as a transport road,

60% of the holdings now has a road of at least 2,5 m wide. This enforced the mechanization and as a result the need of deeper groundwater level. But the main cause of the sinking of the land level in horticulture however, is the removal of topsoil with root balls, and an insufficient replenishment with material from elsewhere.
Originally the nursery-men used mud from the ditches, but soon the demand was much larger than could be dredged. So, a 'soil trade' was born. Out of the lakes east of Aalsmeer, with the village of 'Vinkeveen' as a centre, thousands of tons of peat mud were dredged and shipped to Boskoop. Nowadays, dredging in the peat area around Vinkeveen is almost totally forbidden, because of environment-protection. The demand for completion material however is tremendous. A supply of about 75.000 m^3/y is estimated to be necessary only to compensate the normal losses, not to mention the backlog of the foregoing years (Aendekerk, 1979).
The completion material from Vinkeveen was a mixture of partly decomposed and fresh peat, with 60% organic matter, 40% mineral parts of which only 15% > 50 µm. Naturally there was a substantial loss of volume by shrinkage and oxydation in this fresh 'filling-soil', a loss that can be estimated between 25% and 35% by volume in the first and second year after filling. As a result, the remaining topsoil got slowly enriched in clay and more sticky. To improve workability and soil structure, a mixing of the topsoil with dunesand is now becoming quite a common soil improvement. The best results have been achieved with sand with a median around 200 µm. Dunesand fulfils this requirement, but has the disadvantage of a rather high pH. Normally these topsoils have a pH of 4.5 – 5.0 (pH-KCl), but after mixing with sand it may rise till 5.0 -5.5. For some species that is rather high (e.g. Rhododendron).

Because this is a rahter wet growth, with a mean moisture tension of about pF 2.0, high demands are made upon the air content. 'Good' topsoils have a water retention curve like given in table 2.

pF	-∿	1,0	1,4	1,7	2,0
moisture % by volume	70	60	56	52	48

Table 2. Water retention curve of a 'Boskoop' topsoil

Nowadays, there is a frenetic search for substitutes. Among others one is making trials with mixtures of e.g. heather, grasses and sand. The problem is not yet solved.

At last, there is another way of using this peat material for horticultural purposes, namely as a very important component of soil-blocks. For the growth of seedlings of lettuce, tomatoes and cucumbers small blocks are pressed and seed is put on top. Blocks from pure moss peat are not enough coherent. But a mixture of half-decomposed moss peat, clay and mud from the Vinkeveen region was particularly suited. It was not only more 'sticky' than the moss peat, but also higher in pH (pH-KCl 5.0-5.5) and rather rich in trace elements. Millions of blocks have been pressed of the 'Vinkeveen' peat. But also for this purpose no more digging or dredging is allowed.

If we summarize, we can conclude that the peat soils of Western Holland have been very important for the birth of intensive horticulture. They offer very favourable growing conditions for the growth of vegetables and some flowers, but are not as well suited as mineral soils for earlies or winter-flowers. So, as a whole, for the growth of vegetables and flowers in heated glasshouses, mineral soils are preferable. The peat soils have great advantages for nurseries, especially when they grow ornamental trees and shrubs that are sold with root balls. As a result of this selling, and of shrinkage and oxydation, replenishment of topsoil is an urgent problem.

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18 REVIEW OF CHAPTER 17:

THE SIGNIFICANCE OF PEAT SOILS IN NORTHWEST GERMANY FOR HORTICULTURE

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Peat soils are in Germany also very important for horticulture, special for the growth of rhododendrons, azaleas and conifers.

In the northwest of Germany we find in the district of Ostfriesland a large part of this country covered with peat. In earlier time the peat was used for fuel and for electric power, mainly in the small town 'Wiesmoor'. The steam from the power station heated glasshouses for production of vegetables. Now you will find in these glasshouses production of ornamental plants.

More important in this district is the growth of plants in the open land. The start of this nursery centre was the year 1928, when two nursery men started growing rhododendron and azaleas. Today here are 22 nurseries with a production of about 200 ha areal. The production is: rhododendrons in many sorts, so as hybrids and seedlings, azaleas for gardens and parks, conifers for gardens and cemetery plantation. 1,000,000 plants from calluna and ericas in several sorts are grown every year. So the district of Wiesmoor is important for the growth of nursery plants. The production is sold to other nurseries and garden centers in Germany. The production of this nurseries got an award of prices by many garden shows.

The nursery men learned horticulture in other nurseries, studied at an horticulture school and started with their own nursery. The earlier years were very heavy to raise plants, to sell them and to have money. After 5 to 10 years the production brings a turnover for living.

The production of nursery-plants in sorts as described brings many problems. At first the *knowledge* about the different plants, their propagation, their cultivation and also their selling. Young people have many to learn about these different plants.

Problems in the growth of these plants on peat ground. Plants start growing very late in spring, because the soil is cold and the warming is late in the year.

Fertilizing problems. The pH is 3.0-3.2 ($CaCl_2$), P_2O_5 here is no problem, but very important for the growth of conifers and the colour of these plants is K_2O, because peat has no sorbtion power for potassium[1], so every year potassium has to be applied. Microelements, like Fe, Cu, Mo and Mg cause many problems, special manuring with these fertilizers is necessary. Liming of peat soils is very important. The growth of roots and the growth of the plants is dependant on Ca.

The transplanting of rhododendrons and other plants is only possible in spring, so the nurseries have in this time much work. The nurseries have 1.5 workmen on 1 ha, that is compared with other types of horticulture and with agriculture very high.

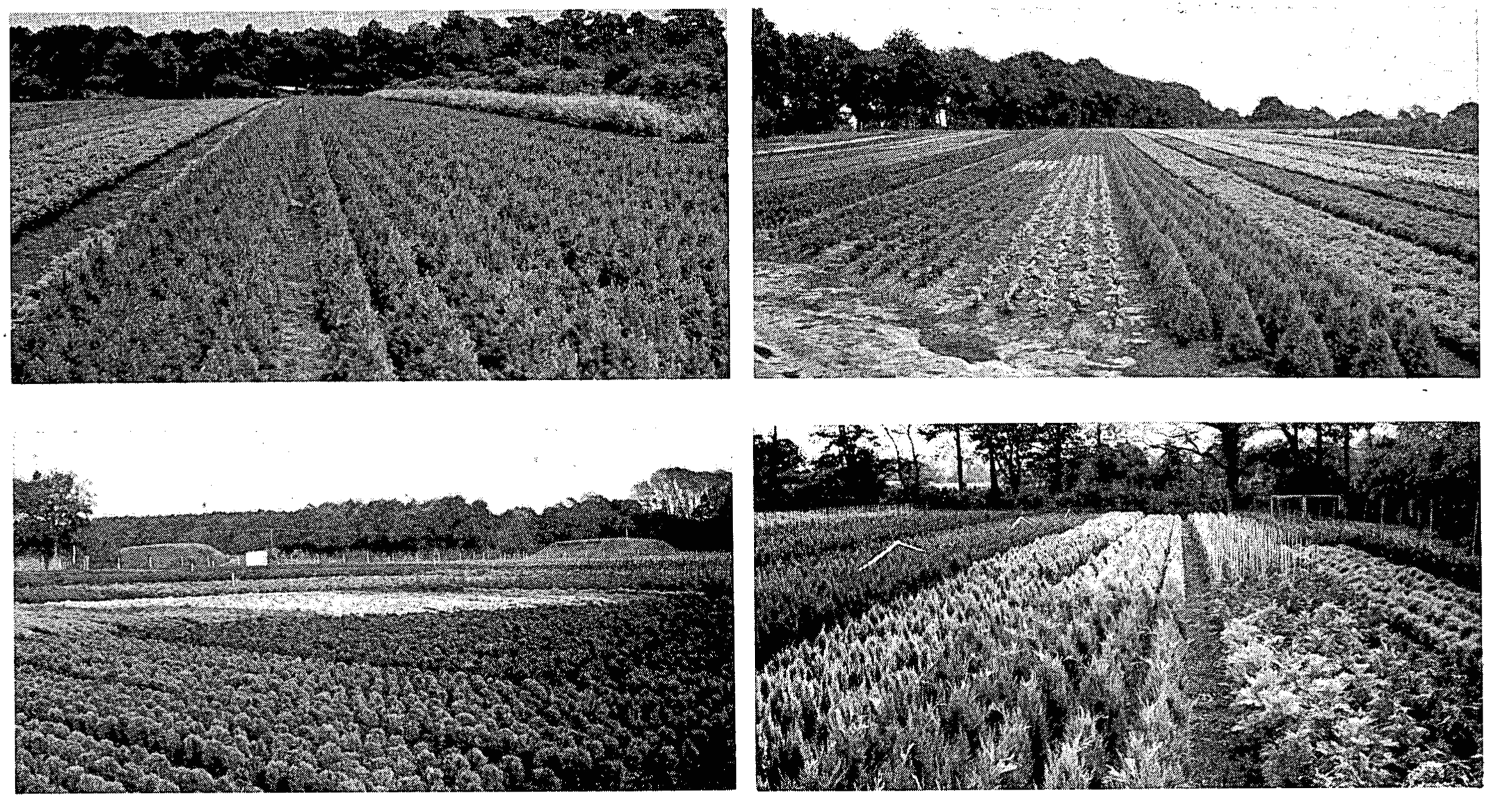
To *use machines* for transplanting and digging out plants is not possible, because the peat is too soft for tractors and machines. All work is done by hand.

Another problem is *frost* in the month April, May and June. All nurseries have a sprinkler system for overhead-irrigation against the frost for protection of the plants.

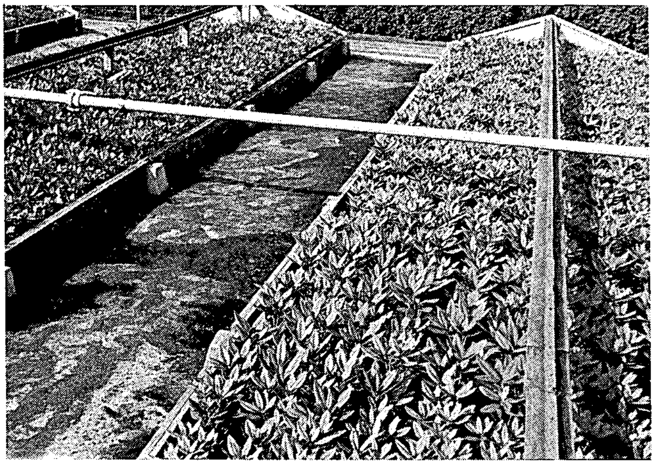
Weed-control is on this peat soil a special problem, because the effect from different chemicals is not specified. Weed-control has to be done by hand.

The *maturing* from the different sorts needs 3-5 years, coming up from cutting and grafting, so rhododendrons needs 5-6 years before being marketable.

This kind of growing plants on peat soil is found especially in the northwest district of Germany and here you will find a special culture from rhododendrons, azaleas, erica and callunas and conifers in several sorts and arts and also here are many evergreen plants with a good result.



The production of conifers in several sorts and arts on peat soil in the distric northwest Germany, Wiesmoor
Photos Burchards



Propagation and growing-up of rhododendron-hybrids

Rhododendrons in the open ground

photos: Burchards

Note (from the editors)

[1] This problem is unknown in the Boskoop area in The Netherlands with its clayey wood peat soils, although fertilizing with potassium is of course necessary. The difficulty must be caused by the ash-poor oligotrophic peat of Wiesmoor.

19 MAIN PROPERTIES OF HORTICULTURAL PEAT

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In plant production, peat is used both for soil amendment and, after adding fertilizers, as growing medium. These different forms of utilization require different properties:

1) Soil amendment peat
   The task of peat is primarily to improve the water retention capacity, airiness and exchange capacity of mineral soil. Most weakly or medium decomposed peat types are suitable for this purpose.
2) Peat growing medium
   Peat is used or may be used alone as growing medium - supposed that it is properly fertilized.

Peat properties are discussed solely with regard to the second alternative in the following.

Main properties of growing medium from the plant's viewpoint

The plants take up water, oxygen and nutrients from their growing medium. These activities of roots require from the growing medium

1) the maximum nutrient storage capacity, and
2) certain structural properties.

The nutrient storage capacity in other than water-soluble form is determined by the exchange capacity. In peat it varies according to botanical composition and degree of decomposition, and it is usually remarkably high, about 70-160 me/100 g.

When the properties of horticultural peat are considered from the viewpoint of practice, main attention must be paid to the structure of peat. The structures of separate peats deviate greatly from each other. Due to these structural differences, primarily only Sphagnum moss peat has become popular as horticultural peat. While the intensity of cultivation has been increasing the requirements set on the growing medium have also continuously increased. As a consequence, there is need of classifying Sphagnum moss peat further. Problems connected with these questions are discussed in the following.

Ideal soil structure

From experience, an ideal growing medium is generally considered to have a pore space that is as large as possible and divided about equally to water and air spaces. When a mineral soil rich in humus is concerned, this goal is sought after by combining small mineral particles to larger porous aggregates.

Weakly decomposed organic material has proved to be an effective glueing material. The problem of optimum particle size distribution should still be solved. In some experiments the correlation of aggregates of > 0.5 mm and the harvest has been 0.99, and according to the common experience the best water and air regimes are produced in soil with a fine crumb macrostructure in which the aggregate size is 1-3 mm.

Structure of moss peat

The structure of Sphagnum mosses is peculiar, not met with other plants. Thanks to the porous water cells, mosses are capable of retaining large quantities of water. The size and the corresponding free energy value of these cells in some typical Sphagnum moss species are presented in Table 1.

Table 1. Sizes of water cells and corresponding F values for some Sphagnum moss species

Species	Size of water cell µm	F cm
Sphagnum fuscum	18	170
Sphagnum papillosum	36	80
Sphagnum cuspidatum	14	210

In greenhouse cultures the free energy of water should not exceed 100 cm. Preferably it should not be more than 70 cm. According to Table 1 this involves that the water cells of mosses are filled with water at a culture moisture content. Hence the particle size should be as large that the air space between the particles is able to meet the oxygen demand of roots.

The leaves of Sphagnum mosses get readily loose from stems and branches. The sizes of stem and branch leaves of three typical Sphagnum moss species are presented in Table 2.

Table 2. Lengths and widths of stem and branch leaves of some Sphagnum species

Species	Stem leaves		Branch leaves	
	Length mm	Width mm	Length mm	Width mm
Sphagnum fuscum	0.8-1.2	0.6-0.7	0.6-1.3	0.3-0.5
Sphagnum papillosum	1.1-1.9	0.7-0.9	1.6-2.0	1.0-1.4
Sphagnum cuspidatum	1.0-1.4	0.6-1.0	1.6-3.0	0.3-0.5

As is seen from Table 2, a considerable proportion of Sphagnum moss leaves are less than 1 mm in diameter. Furthermore, the leave points easily break. Hence there is a risk that the proportion of too small particles grows too high with regard to an ideal structure. This involves that when keeping the free energy of water adequately low, less than 70-100, the air space of peat remains easily too small.

Determination of peat structure

The structure of peat varies in wide limits. It is of utmost significance to measure it in one way or other. However, it is a complex phenomenon that cannot be characterized precisely by a single physical measurement. Quantitative methods in use evaluate only a part of the overall phenomenon.

IPS Commission V has recommended the measurement of peat structure with two different methods, sieve analysis and determination of water and air capacities. Should both these methods give the same results at an adequate reliability, the use of one method would of course be adequate. The equality of the methods is discussed in the following.

In the determination of water and air capacities, the volume weight, pore space and its division into water and air capacities are measured while the free energy of peat water remains unchanged. The method is called air capacity method in the following discussion, as the main attention is usually paid to the air capacity of the minimum factor in the results.

Comparison of sieve analysis and air capacity method

A total of 200 samples were drawn from industrially produced light Sphagnum moss peat for the study. Part of peat was fertilized, part unfertilized. For these samples, the particles size distribution was determined with the sieve analysis, and the air capacity, the suction force applied to peat water being on average 5 cm. The mesh sizes used in the sieve analysis were 1, 4 and 8 mm. The peat sample was thus sieved to four coarseness grades.

Earlier studies on pure coarseness grades have proved that the fraction of less than 1 mm is of decisive significance to the air and water capacities of peat. This particle size limit is also used for indicating the coarseness grade of peat in the Scandinavian peat standards. Hence, the peat samples were grouped to subgroups in accordance with this fraction for the statistical treatment of the material. The correlation between the particle size distribution and the air capacity seemed, however, be very slight.

For a further treatment, the peat samples were divided to two groups on the basis of visual determinations, i.e. extremely pure Sphagnum moss peat and peat containing small quantities of cotton grass and subshrub residues. The results obtained for the material grouped in this way are presented in Tables 1 and 2 and in Figures 1-4. The following conclusions can be drawn from the results:

1) the particle size distribution and the air capacity of pure Sphagnum moss peat are clearly dependent on each other.
2) Fractions of both 1 mm and 8 mm can be used for indicating the particle size distribution.
3) The particle size distribution and the air capacity of peat containing subshrub and cotton grass residues seem to be independent on each other.

Table 3. Division of pure Sphagnum moss peat according to the particle size of < 1 mm and corresponding air capacity

Number of Samples	< 1 mm Percentage class	< 1 mm Mean %	> 8 mm %	Air space, % Mean
17	0-10	7.3	65.9	33.5
22	10-20	15.6	45.7	28.5
13	20-25	21.5	38.4	29.6
27	25-30	27.2	31.9	27.2
21	30-35	32.1	27.5	25.4
15	35-40	36.7	22.6	24.7
11	40-50	44.1	20.5	23.5
8	50-60	54.4	16.0	19.
3		91.1	-	12.1
137				24.9

Table 4. Division of peat containing subshrubs and cotton grass residues according to the particle size of < 1 mm and corresponding air capacities

Number of samples	< 1 mm Percentage class	< 1 mm Mean %	> 8 mm %	Air space, % Mean
5	0-10	7.6	49.9	27.0
25	10-20	14.8	39.1	24.2
14	20-25	22.7	36.6	22.7
7	25-30	26.5	25.1	23.3
8	30-40	33.5	25.4	25.8
2	40-50	44.4	15.2	22.3
2	50-60	52.9	12.4	24.2

Reasons for different results of particle size distribution and air capacity determinations

The reasons for the deviation in the results of particle size distribution and air capacity determinations may be numerous. The following reasons may be of most significance:

1) the quality of pure Sphagnum moss peat is homogeneous. That of peat containing residues of other plants is not homogeneous and the shape of particles varies for this reason. This results in a deviating structure.
2) Pure Sphagnum moss peat does not contain lignin practically at all and hence neither its derivates, humin acids, which
   a) change the water retention properties of peat, and
   b) compress peat by glueing small particles to each other.

Completion of peat type classification

It has been noted at the Peat Research Institute that small quantities of residues of other plants may also change the properties of Sphagnum moss peat in a decisive way. These effects should be considered in the use of horticultural peat. Hence, the botanical peat type classification used at the moment does no more meet the requirements set by horticultural peat. Therefore, the Peat Research Institute proposes that the classification of horticultural peat should be completed as follows:

Sphagnum moss peat according to the classification Proportion of Sphagnum moss residues not less than 75%

Proposal:

Class I

Proportion of subshrub residues not more than 3% w/w

Proportion of cotton grass and sedge residues not more than 6% w/w

Proportion of Sphagnum moss residues not less than 90%.

20 FUNDAMENTALS OF THE THEORY OF PEAT DEPOSIT DRAINING

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The principal problem of peat deposit draining is the creation of favourable conditions for its further utilization. In case, when peat deposits are used as a basement for engineer constructions, the task is to increase its strength and rise the bearing capacity of its surface. When growing plants, the drainage is necessary as a method for improving and regulating the water and air properties of the root layer. For peat production, the main aim is the reduction of moisture content in the peat deposit layer under exploitation. Thus, when applying the surface and layer-by-layer (for example, milling) method of peat winning, the reduction of moisture in the peat layer to be milled by 1% increases the seasonal peat yield, and consequently, the effectiveness of peat production by 5%. That is why just for peat winning, the problem of intensification of the peat deposit draining is very important.
To know the degree of peat deposit drainage is necessary for a quantitative evaluation of the efficiency of the measures to be carried out during the peat deposit drainage and for determining the quality of draining. More often the degree of drainage is determined as an average depth of the groundwater-level during a rather long period (vegetation period, peat winning season) and is called the drainage rate. Not toughing upon the problem of unsynonymous conceptions of the drainage rate and normative average groundwater-levels, it should be noted, that the drainage rate reflects the hydrotechnical characteristics only, not taking into consideration, in a proper way, the technological conditions of peat winning. It should be mentioned, that there does not exist any definite quantitative relation between the drainage rate of the upper

peat layer and the depth of the groundwater-level, because the degree of drainage is defined not only by the depth of the groundwater-level, but also by meteorological conditions of the period in question. During the period of considerable precipitation, the dryness of the upper layer will be low even in case when the groundwater-level is deep-lying. Sometimes the degree of drainage is evaluated by the peat moisture content, since it is known, that between these values there exists an inverse relation; however, this evaluation is suitable only for a definite species of peat. For peat having a different degree of decomposition, another inverse relation is necessary. We have demonstrated, that the most valid method to evaluate the degree of drainage of some peat layer is according to the value of the moisture potential (tension in water) in the layer. The value of the moisture potential includes the influence of the depth above the groundwater-level, as well as, the meteorological conditions of the preceding period, taking into account the water-physical properties of the peat deposit. The moisture potential of the upper layer, expressed in J/kg, is numerically equal to the effective depth of the groundwater-level expressed in decimeters. Regardless the dependence on the type of peat and the actual groundwater-level, it can be considered that at a bad draining the moisture potential is less than 5 J/kg, at a satisfactory draining it is 5 to 8 J/kg and at a good one - more than 8 J/kg. The value of an effective groundwater-level can be determined experimentally by using a tensiometer (moisture potentiometer) or computed from the calculation of the differential equation of the moisture flow in the zone above the groundwater-level.

The peat deposit drainage process results in the achievement of the given degree of drainage. For the upper layers of a deposit to be drained, it takes an average of 2 to 4 years for low-moor peats possessing a good filterability and of 4 to 6 years for peats of the high-moor type; the duration of the drainage process in the deep-lying bottom layers of thick high-moor deposits is about 10-20 years. Subsequently, the average values of the degree of drainage get stabilized and the main process is the transportation of moisture from precipitation and snow melting through the peat deposit into the drainage network.

The movement of moisture in a peat deposit is, strictly speaking, a non-stationary process. Periodical annual changes in the water regimes and accidental changes because of the precipitation can be singled out distinctly. The changes of the moisture potential in the upper layers of a peat deposit because of precipitation in average seasons take place, in general, at a depth up to 40-60 cm. That is why for the deeper layers it is possible to consider, in the first approximation, the movement of moisture as a stationary process, that simplifies considerably the theorical methods of calculation.

Below the groundwater-level the stationary moisture movement can be described according to Darcy's law. When applying the law, in general, there occur two difficulties: heterogeneousness (banding) of the peat deposit structure and changes of the filtration coefficient during the drainage process, that can be approximately expressed by an exponential function of the peat porosity factor. For calculations it is possible to use the EGDA method (electrohydrodynamic analogies). With a non-stationary movement it is necessary to insert a correction into the law, proposed by Prof. N.M. Gersevanov, considering the shrinkage of peat during drainage.

The filtration coefficient included into Darcy's law for peat deposits can be approximately accepted as average data, recommended by Prof. K.E. Ivanov, depending upon the type of peat and its degree of decomposition. For an experimental determination of the filtration coefficient directly in a deposit up to 6 m depth, the All-Union Scientific Research Institute for Peat Industry has designed a sounding device. Its principle of operation is based on an additional creation of a local stationary non-uniform water flow in a restricted volume of the deposit and measuring the density of the water flow.

Above the groundwater-level the distribution of the moisture potential or moisture content, depending upon the depth and the time, can be determined by computing a differential equation of the moisture potential. By taking into account the changes of the moisture coefficients (coefficient of moisture conductivity and specific moisture capacity) of peat at different potentials, there is a satisfactory coincidence of the computation with full-scale measurements during the summer season. The usual difficulty while computing this problem is the vagueness of the initial distribution of the moisture potential because of little knowledge about the state of a peat deposit during the thaw of the frozen ground. For the surface layers of a peat deposit it is necessary to take into consideration thermal phenomena and mutual influence of the heat-and moisture transfer with regard for the thermodynamics of irreversible processes. There are not obtained as yet satisfactory solutions of the system of differential equations of the heat and moisture transfer with variable coefficients.

In well drained peat deposits with a groundwater-level 1 m and more below the surface, one can observe a phenomenon called the depression of the moisture potential. The point of that is that due to the moisture flow, practically present all the time in a deposit from the top to the bottom, and a small value of the moisture conductivity coefficient (especially for deposits of high-moor type), the value of the moisture potential at any depth of the deposit is significantly lower than at an equilibrium state. This leads to the fact that the degree of draining of the surface layers is much lower than the expected values and the increase in depth of the groundwater-level has little influence on the drainage. The depression of the potential can be reduced by increasing the coefficient of moisture conductivity with artificial measures (good results have not been achieved) or by preventing the moisture entry from precipitation into the depth of the deposit. The last mentioned measure is partially put into practice by using the transverse profiling of the field surface, adopted in peat industry, or by applying the shallow drainage (about 0.5 m) for removing spring waters and storm rainfall.

Coefficients of moisture depend very much upon the type of peat, the density of its solid phase and the moisture potential. The dependence of the moisture conductivity coefficient upon the potential is expressed by an exponential function. At present, there are still no average data for different types of peat, therefore, when it is necessary, the moisture coefficients are to be defined experimentally. There exists a series of laboratory methods for determining the moisture coefficient, the method of a constant flow of moisture over the surface of a sample being the most effective one. The method was worked out in VNIITP. When applying this method, there arises a quasi-steady distribution of the moisture potential depending upon the height of the sample to be dried, that allows to define the dependence of moisture coefficients from the potential (or humidity) during several (4-6) days.

The drainage of peat deposits with strong seepage, offer great technical difficulties. If at the bottom of such deposits there are grounds of high permeability, the drainage is not effective. In such cases it is expedient to transport peat from the deposit to well drained fields for drying. This method has been experienced by the All-Union Scientific Research Institute for Peat Industry in using it in the Colchis lowland (Georgian SSR). Applying this method the excavation of deposit under water is performed by means of a multibucket floating excavator and not by suction dredgers that leave small concentrations of dry substance. When the grounds at the bottom have a low permeability, deposits with strong seepage can be drained according to ordinary schemes by using artificial pumping of water out of the main channels. A number of peat enterprises of the Soviet Union are working successfully using this scheme.

21 THE GEOLOGY OF THE DEPOSITS AT THE EXCAVATION HAZERSWOUDE

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For the Symposium on Peat Lands below Sea level a study was made of the geology of the deposits in and underneath the peat excavation Hazerswoude. The excavation is situated about 8 km to the southeast of the town Leiden (just north of the polder reclaimed in 1847 on Figure 1, in Chapter 5), about two km south of the river Oude Rijn (Figure 1).

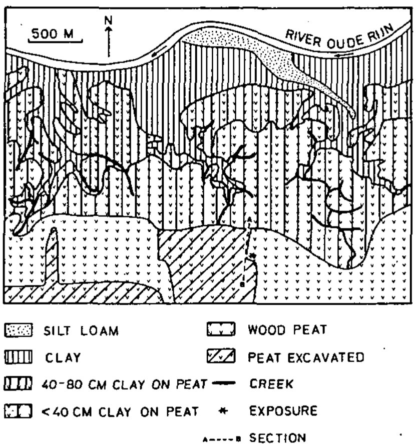

Figure 1. Map of the Hazerswoude area. After Markus en van Wallenburg (1972)

The section Hazerswoude (Figure 2) can serve as a scheme for the Holocene development of the inland part of the marine area.
The top of the Pleistocene subsoil lies between 11 and 13 metres below Dutch Ordnance Level (NAP). No soil is developed on this surface, indicating very wet circumstances in the area in the Early Holocene.
Five clastic and four peat units can be recognized in the Holocene de-

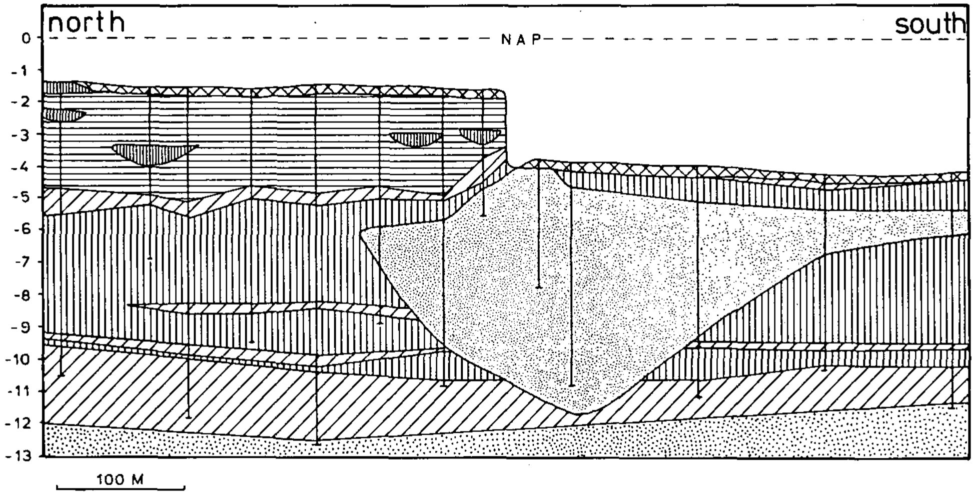

Figure 2. The section Hazerswoude. For location see Figure 1

posits. The lowermost peat unit is the Basal Peat. It consists of a *Carex* peat with some wood remains, grading upwards into a *Carex-Phragmites* and then into a *Phragmites* peat. Over this peat lies the lowermost clastic unit, consisting of humic clay, with many remains of *Phragmites*. The clay was deposited in a very low- energy environment. As the influence of the sea decreased the second peat unit was formed consisting of a *Phragmites-Carex* peat.

Over this peat layer two marine clastic units can be recognized, in several borings separated by a layer of *Phragmites* peat: the third peat unit. The second and the third clastic units consist of marine clay that is in part calcareous. In the third clastic unit a gully, filled with calcareous sand, can be recognized. Over the third clastic unit lies the fourth peat unit that is in part excavated (for a description of this unit see Chapter 22). In this peat unit clay lentils occur that form the fourth clastic unit, consisting of dark humic clay with many fragments of wood. In following the excavation it could be observed that the clay occurs in shallow and mostly very narrow meandering gullies in the peat. Most probably these gullies drained the sphagnum-peat area more to the south. In the gullies clay was deposited during high water stages of the river Oude Rijn.

The fifth clastic unit consists of a very humic clay that forms a sheet over the fourth peat unit. From Figure 1 it can be seen that this clay

is thickening to the north. The clay is a back-swamp deposit of the river Oude Rijn.
No direct datings of the deposits are available. The fourth peat unit dates the top of the third clastic unit as Late Atlantic or Early Subboreal (see Chapter 1, Table 1 and 2, and Figure 4). This dating is confirmed by a radio-carbon dating in the boring Nieuw Groenendijk about three kilometres west of the profile Hazerswoude. There the peat growth started at 4780 ± 60 BP (GrN 8088; Bosch & Pruissers 1979). The third clastic unit is thus a Calais III deposit (see Chapter 1, Table 2).
About seven kilometres to the southwest of the section Hazerswoude, at Boskoop-Puttepolder, a radio-carbon dating was made of a wood peat at about 7.7 metres below Ordnance Level. The age of this peat layer that is probably the same as the second peat unit is 6000 ± 60 BP (GrN 1013; archive Soil Survey Institute). Thus the first clastic unit can be a Calais I deposit and the second clastic unit a Calais II deposit.
The profile at Hazerswoude represents a profile that is often found in that part of the western Netherlands that was early protected by coastal barriers. After about 4800 BP no marine influence is found in the deposits. The Calais IV and Dunkerque deposits are thus missing.

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22

VEGETATIONAL DEVELOPMENT OF A WOOD PEAT DEPOSIT, AS READ FROM ITS POLLEN CONTENT

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Most of the Dutch province of South Holland consists of the low-lying 'Holland peat', mainly formed during the Sub-Boreal period. Near the estuaries behind the coastal dunes and along the present and former, now fossil, river courses, the peat gives way to a marine or river clay deposit. Outside these deposits a thicker or thinner bed of clay often overlies the peat deposit depending on the distance from the supply base of the clayey sediment (cf. Figure 1, Chapter 5).

The Holland peat generally shows a clear zonation parallel to a (fossil) river course, i.e. near the levee along the river course where flooding was frequent, river clay was deposited and peat formed in a more or less simultaneous and joint process, resulting in the formation of wood peat with a varying amount of clay. At an increasing distance from the levee the mass of wood remains and the clay content of the peat decreases the wood peat finally merging in a deposit of sedge peat. At a relatively great distance from the levee, where the flood waters reached their farthest point, the sedge peat adjoins a vast area of Sphagnum peat.

At a site near the village of Hazerswoude (Figure 1) peat soil is being excavated to obtain peaty earth for use in horticulture. Here a vertical peat face was visited during the excursion. It is located about 2 km south of the Oude Rijn river, inside the wood peat zone.

In order to show how the various plant species contributed to the formation of the peat deposit at this site, the peat was investigated by means of pollen analysis (Figure 2, see page 277). A number of pieces of wood taken at random from the peat face were analyzed[1]; most of them proved to be alder. A few remains of oak and poplar were also ident-

Figure 1. Location of the sampling site

ified.

Having regard to the purpose of the study and the time available a more thorough analysis could not be conducted. This explains why the pollen spectra are often calculated from fairly low pollen counts.

The percentages of the various plant species relate to a pollen sum which includes all species (AP + NAP = 100%).

The pollen diagram clearly shows how the vegetation developed during the formation of the peat deposit and after reclamation of the peat soil. It can be divided horizontally into three sections, viz.:

265-253 cm, coinciding with the top of the old marine Calais III deposit at the base of the peat. The later Calais IV deposit is out of the question as Fagus does not appear in the pollen spectra at this depth (cf. De Jong, 1970-1971).

253-47 cm, comprising the total depth of the undisturbed peat deposit.

47-35 cm, coinciding with a thin layer at the top of the peat deposit, where the peaty material is mixed with sandy material and some shards from the overlying bed of man-made soil. The latter was not subjected to pollen analysis.

In the bottom section the percentages of the various tree pollen types are not very representative of the vegetation in the environs of the

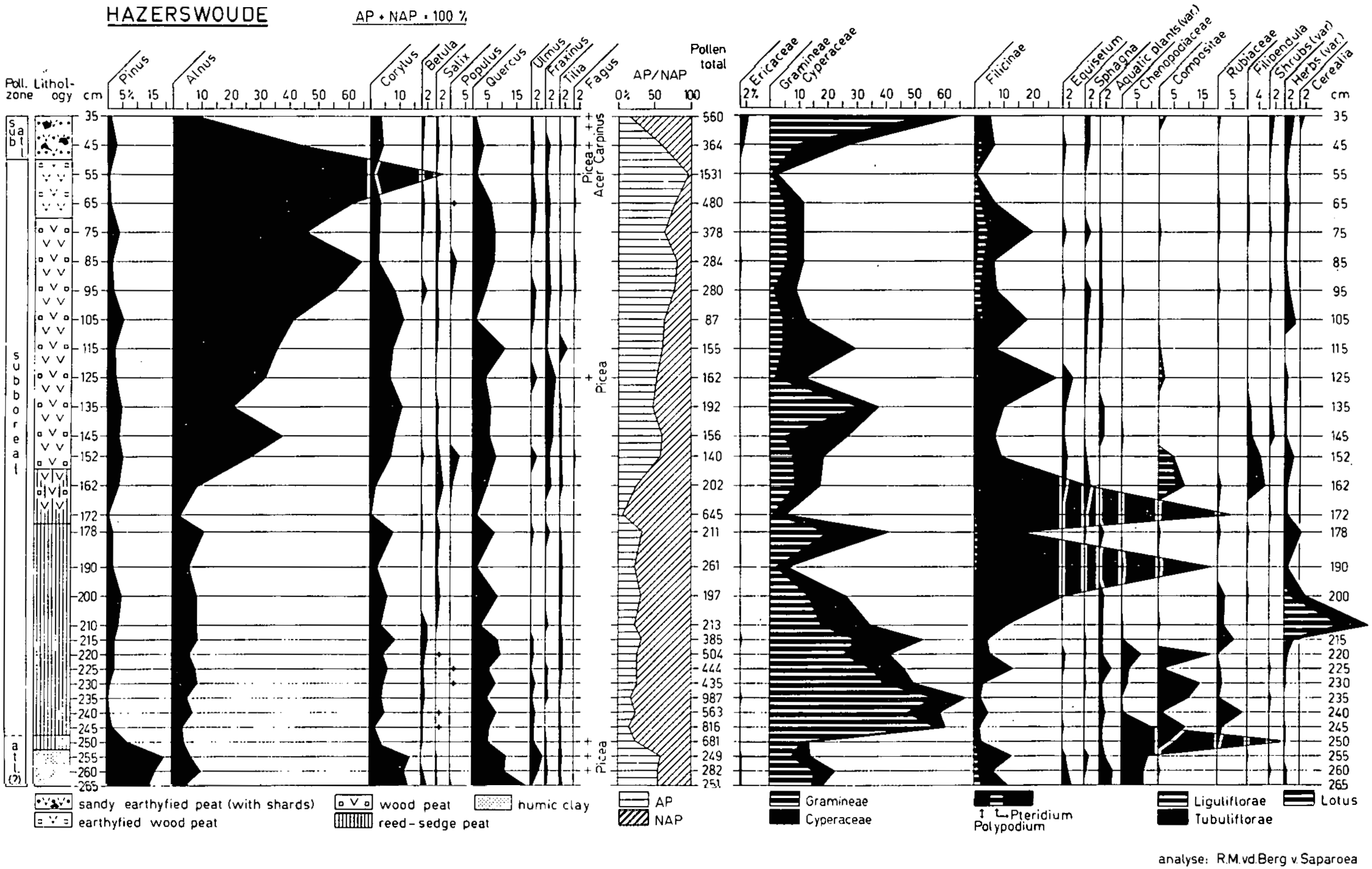

Figure 2. Hazerswoude pollen diagram

sampling site. The Pinus pollen is highly over-represented. This is a common feature of pollen spectra from marine or fluvial clay deposits and has still to be satisfactorily accounted for. The relatively high *Corylus* and *Quercus* values are probably due to pollen supplied from a secondary source, for instance an eroded river deposit originally covered with oak forest. It cannot be assumed that *Corylus* and *Quercus* grew in the marine or brackish environment of the Calais III deposit. The relatively high *Chenopodiaceae* percentage are in agreement with such an environment.

The section of the diagram representing the undisturbed peat spans the Sub-Boreal period, with the possible exception of its base, which may date from the end of the Atlantic period. Up to 178 cm the deposit consists of slightly clayey reed-sedge peat. The pollen spectra have a high non-tree (NAP)/tree (AP) ratio, reflecting a dense and extensive vegetation of grasses, sedges and ferns, here and there in an alternating sequence (cf. Janssen 1966). The main source of the fern spores is no doubt the marsh fern *(Thelypteris palustris)*. The fern curve shows very marked peaks and troughs. This is a quite normal feature and is due to a combination of high spore production and low dispersion capacity of the ferns. The sedges, grasses, *Compositae* and trefoil (probably *Lotus paluster*) also show highly fluctuating curves due to local occurrences of these plants. It is noteworthy that the irregularities in the various curves come together in such a way that the joint curve (see the AP/NAP column in the diagram) is fairly straight.

The *Chenopodiaceae* maintain relatively high values near the base of the peat deposit, showing that after the sedimentation of the marine deposit was completed more or less brackish soil conditions first prevailed in the wider environment.

The tree pollen is now a faithful picture of the forest vegetation in this region. Since the *Quercetum-mixtum* and *Corylus* show high percentages as compared with *Alnus*, most of the tree pollen must have originated from the forests on the levees along the Oude Rijn river. The upper part of the peat deposit consists of a rather more clayey wood peat having a composition approximating to an alder carr peat. The varying composition of the successive pollen assemblages parallels the change in vegetative remains; the non-tree/tree ration decreases considerably above the reed-sedge peat; further up the diagram the *Alnus* percentages reach very high values. Other tree pollen decreases in proportion to total tree pollen but like the *Alnus* it increases as compared with the total non-tree pollen. This may be due to the fact that the pollen spectra in the wood peat mainly reflect tree growth near the sampling site, whereas the spectra in the reed-sedge peat reflect regional tree growth. Although the differences are slight, the percentage of *Corylus*, *Populus* and *Fraxinus* are significantly higher in the wood peat than in the reed-sedge peat. The *Salix* curve already shows a small increase half-way between the bottom and top of the reed-sedge peat. The increase in *Quercus* and *Ulmus* is rather more doubtful.

Considering the fact that *Fraxinus*, *Salix*, and *Populus* in particular are usually highly under-represented in pollen diagrams as a result of their poor pollen dispersion capacity (Andersen 1970) or severe differential decay of their pollen, we can assert that *Fraxinus* and *Salix* made a continuous contribution to the stand and that *Populus* was also involved. It is well-known, however, that the percentage of the latter is impossible to assess from pollen counts. *Corylus*, *Quercus* and *Ulmus* grew as scattered shrubs or trees in the peat wood. *Salix* acted as a pioneer prior to the development of the wood (cf. Ellenberg 1963, p. 371).

We should, however, bear in mind that the stand may have shown local variations which are outside the scope of the pollen diagram.

Not all pollen is of local origin, some of it being carried over long distances, by air or by flood waters. This is particularly true of the pollen of pine, a tree which is represented with relatively high percentages in both the wood-peat and reed-sedge peat section of the pollen diagram.

The low representation of *Betula*, *Tilia* and *Fagus* shows that these trees were absent from the wood on the peat soil. The appearance of *Fagus* at 95 cm is connected with the immigration of the beech into The Netherlands during the Sub-Boreal period.

The *Alnus* curve begins to rise at the same level as the base of the wood peat, showing that alder first had very shallow roots. The slow rise in the curve is an index of the long period of time required for the full development of the alder vegetation.

Guelder rose *(Viburnum opulus)*, elder *(Sambucus nigra)* and hop *(Humulus lupulus)*, all of which are commonly found in the shrub story of an alder carr or 'peat wood'[2], are only sporadically represented in the fossil pollen flora. Apart from hazel they are the only shrubs of which pollen was found.

The appearance of *Filipendula*, probably *Filipendula ulmaria* (meadow-sweet) in a relatively large quantity coincides with the start of the growth of the wood on the peat soil, as determined by the subsequently drier and more clayey soil conditions (cf. Ellenberg 1963, page 371).

The *Sphagna* curve is frequently interrupted and only represented in small percentages. The *Sphagna* spores originated from the vast ombrogenous raised bog which once adjoined the sedge-fen peat area about 2 km south of the sampling site. The oligotrophic *Sphagnum* peat was excavated for fuel in historic times the loamy bog floor being reclaimed for arable land. In the short top section of the diagram the total tree pollen falls sharply and finally cereals appear for the first time. The pollen spectra here represent the Sub-Atlantic period when the more Eutrophic fen-peat soils were reclaimed for farmland. In time they became covered by a bed of man-made soil resulting from the application of manure mixed with sandy soil material (cf. Chapter 5, Section 5.3.2). The *Ericaceae* pollen in the two uppermost spectra must have been conveyed with it. It was taken from the older dune landscape west of the peat soils where a heather vegetation occurred on a podzolized soil.

Hitherto pollen analysis has only rarely been applied to a profile from a wood peat area. The only published evidence is by De Jong (1971-1972) who gives a series of pollen diagrams from a fill of a fossil river gully containing wood peat (1), the flank of an accompanying levee (2) and a pure alder-carr peat soil at some distance from the levee (3). The Hazerswoude diagram shows a marked resemblance to De Jong's diagrams (1) and (3) and occupies an intermediate position. Diagram (2) shows much higher values for the *Quercetum-mixtum* than diagram (1).

Notes

1 The wood remains were kindly identified by Mr. J.M. Fundter.

2 Alder wood mixed with more or less ash and other elements of the *Quercetum-mixtum*, depending on the clay content and hydrological conditions of the peat soil.

Literature

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23 EXPERIMENTAL FARM IN ZEGVELD

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23.1 Introduction

The "Foundation Regional Research Centre for cattle husbandry in the Western pasture district" is operating the experimental farm in Zegveld. The purpose of this foundation is the promotion and development of the cattle husbandry in this area. The foundation tries to attain this goal by executing practical research concerning cattle husbandry and by propagating the results.
Originally the experimental farm was smaller (20 ha) and located elsewhere. After a reallocation in 1966 the farm was resettled and enlarged with 10 ha, today the experimental farm is 49 ha.

23.2 Data on the farm

Farm buildings

The cowhouse has been renovated and expanded in 1978. The measurements of this building are 51 x 34 m and the building is based on 476 piles with a length of 11 à 12 m. This building consists of a cubicle house with 70 lying boxes in two rows, a lock-stall with 30 cow-catcher-boxes used for individual feeding tests, a two-row open-air-stall for 30 cows and 30 yearlings, a disease-stall with two places, a calving pen for five cows, a walk-through system milking parlour with 2 x 5 places and 10 milking units. Beside the milking parlour is the milkroom with a

milktank for 8000 kg milk. The open-air-stall has a mixed manure pit below-floor with a storage facility of 450 m^3, sufficient for more than two months.
The barn, built in 1966 with a surface of 450 m^2, includes an equipment-shed, a hay stack and an open-air calfpen. There is a concrete clamp silo (8 x 30 x 1.20 m) and a concrete silage-slab (12 x 30 m) for Dutch mows, both resting on 176 piles.

Grassland

The grassland area is 49 ha. Behind the farm buildings 44 ha grassland is situated in one block and the remaining 5 ha is situated at about 500 m distance from the farm. Most of the plots have a good accessibility by means of a concrete farmroad. The soil is a clayey wood peat, about 7 m thick, overlying Pleistocene sand.
Some analytical data:

	Average	Variation
pH-KCl	5.1	4.8- 5.3
% clay	21	14 -34
% organic matter	45	35 -57

Drainage experiments

These experiments are described in Chapter 9.2, and the consequences of the different drainage depths are discussed at length in Chapter 9.

Livestock

The Friesian-Dutch black-and-white herd in mean consists of 100 dairy cows, 25 yearlings and 30 calves.
The average milk yield is 5500 kg per head.

Nitrogen application

The next sketch is used for the nitrogen application:

Nitrogen gift in kg N per ha.

Apply to	1st		2nd		3rd	4th/5th	6th cut
	C	G*	C	G	C and G	C and G	C and G
High ditch water level (shallowly drained)	90	65	65	45	45	40	26
Low ditch water level (deeply drained)	70	50	50	26	26	26	26

C = cutting

G = grazing

* For the first cut 50% of this area gets a lower gift (45 and 35 kg respectively) to get a more continuous supply of grass.

Grazing

It is all permanent grassland. The milking stock is put to grass at about 1700 kg dry matter per ha. The length of the grass is then about 8 à 10 cm. The cows are being housed at night. The calves that graze for the first time are put on aftermath to prevent gastro-intestinal nematode and lungworm contamination.
Supplementary feeding. In addition to 8 à 9 hours of grazing the following amount of concentrates is being given:

Milk production in kg/cow	34	32	30	28	26	24	22	20	18	16	14
kg concentrates per cow	7	6	5	4	3	2	1	1	1	1	1
kg concentrates per heifer					5	4	3	2	1	1	1

Winning of roughage

In spring about 3 weeks after the cows have been put to grass, the winning of roughage starts. The first cut extends to about 60% of the total farm area and is being harvested within three weeks. This means that 20% of the total farm area (= ca. 10 ha) is cut weekly. In preference this cutting takes place on Mondays. The duration of the wilting period should not exceed 5 days. If weather conditions are still bad after a wilting period of 3 to 4 days, salt is being added as a preserver. The salt (300-500 kg per ha) is spread by a fertilizer distributor on the dew-wet crop before this is windrowed. After this the grass is put into silage.

Farm experiments

- Sodseeding of bad, old grassland
- Application of Roundup (a herbicide) before sodseeding
- Consequence of not cutting after grazing periods
- Loss of harvest under farming conditions
- Sprinkling fluid slurry
- Storage of wilted silage
- Consolidation of farmroads
- Subsidence of surface level of deeply and shallowly drained peat soil (see Chapter 9)
- Housing of calves in open stalls
- Housing of young stock on dung grid and in cubicles
- Influence of concentrates and straw on the fat content of the milk
- Detergent tests and mats used in cubicles.

Economic results of the Experimental Farm

Financial year 1 May - 30 April	1977/1978	1978/1979	1979/1980	1980/1981
Ha. grassland	49	49	49	49
Mowing percentage	130	130	110	170
Average number of calves	30	30	34	32
Average number of yearlings	31	30	30	32
Average number of dairy cows	100	101	102	103
Average number of livestock units	124	126	127	129
Dairy cows per ha	2.0	2.0	2.1	2.1
Livestock units per ha	2.5	2.6	2.6	2.6
Total milk production	543 800	569 800	561 300	601 800
Kg milk per cow	5 450	5 620	5 520	5 810
Fat percentage	3.94	4.01	4.06	4.04
Protein percentage	3.35	3.40	3.36	3.34
Winter milk percentage	51	50	48	48
Milk price	61.75	61.85	64.10	63.50
IN GUILDERS PER MILK COW				
Milk yield	3 365	3 476	3 540	3 685
Sales and increment	588	566	606	618
Total proceeds	3 953	4 042	4 146	4 303
Concentrates	897	833	1 270	992
Milk products	29	39	32	35
Roughage	56	58	194	94
Total feed costs	982	930	1 496	1 121
Balance:				
Proceeds minus feed costs	2 971	3 112	2 650	3 182
Ditto per ha grassland	6 050	6 440	5 500	6 700
Kg of concentrates per cow	2 160	2 240	2 980	2 520
FERTILIZATION				
Kg N per ha	220	282	252	290
Kg P_2O_5 per ha	28	32	20	27
Kg K_2O per ha	43	96	29	45

24 RESEARCH STATION IN BOSKOOP

B.C.M. van Elk

Research Station for Arboriculture

Boskoop

The Netherlands

Boskoop is the most important nursery-centre of The Netherlands, ca. 1000 nurseries with a total area of 900 ha, concentrated in Boskoop and the surrounding villages.

The topsoil is composed of about equal parts of humus, sand and clay. The pH varies between 4.5 and 5.5. The watertable is about 60 cm below the surface. This peaty, moist and acid topsoil has the advantage of quickening re-establishment of the young plants, is very well suited to the growing of ericaceous plants and further the forming of good root-balls. A drawback is the permanent shrinking of the topsoil, so that new soil (peat soil or mud from the canals) has to be brought up regularly. The subsoil consists of 3-4 m peat overlying 9-10 m of peaty clay. This softness of the subsoil causes the construction of roads and buildings to be extremely expensive (piles of 13-16 m).

The production of Boskoop is composed of ornamental plants only, the main products being a) ericaceous plants, b) ornamental conifers, c) ornamental shrubs, d) roses (esp. miniature), e) perennials. Within these groups an enormous variety of plants is grown.

The total Boskoop production in 1976 is estimated at Dfl. 100,000,000.-

The nurseries have all the same typical shape: narrow strips of land (approximately 30 m wide) surrounded by canals. The average area is only 0.8 ha, the larger nurseries being approximately 6-8 ha. The culture on these smallholdings is very intensive, it needs mostly 2-3 persons per ha. Some nurseries are more or less specialized but usually a very large amount of species and varieties is grown. A typical aspect of the Boskoop nurseries is the very intensive propagation (especially by cutting

and grafting) in greenhouse and frames. Other means of propagation are budding, layering and dividing. Nearly all nursery-activities are done by manual labour.
The soil-properties, the growth of so many different varieties and the intensive utilization of every square inch prevent any considerable mechanization. We can divide the Boskoop nurseries into 2 categories, those with and those without trade.
The export-trade is the source of life of the Boskoop nursery-centre, as 90% of its products are exported all over the world, especially to Great Britain, West Germany, Sweden, France, Italy, Belgium, Switzerland and Canada. A large share of the production in other districts of The Netherlands is also exported via Boskoop. The entire Dutch export of nursery products in 1967/1977 was ca. Dfl. 172,000,000.-.
Every year the exporters go abroad to visit their clients. The plants, which the exporters themselves do not grow, are bought from the other nurserymen. During the export season these plants are delivered at the packing sheds, which is mostly done by barge but in future, if possible, plants more and more will be transported by car too. After the inspection by the Plant protection service they are burlapped and packed in cases or baskets to be forwarded by ship, truck or train.
The research station is an association, founded by the nurserymen and governed by a board, which includes representatives of all Dutch nurseryman-organizations. Close cooperation with the extension service and research is ensured by the fact that the horticultural advisor is director of the Research Station at the same time. Both the assistants of the extension service and the research workers of the research station are cooperating in the research work. The research station is financed by the subscriptions of its members and by grants of the national organization of nurserymen, the government, the country and the municipalities. The staff is formed by 4 scientific workers, 2 assistants and 10 labourers.
The experiments are mostly focused on: propagation (cutting, grafting, rootstocks, etc.); soil- and manuring problems (drainage, pH, etc.); control of pests and diseases; chemical weed control; breeding evaluation and distribution of selected plant material; economics; work-engineering.
The extension service consists of the horticultural advisor and his 7

assistants, the staff of the research station also lending a hand. The advisory work is supported by articles in horticultural and local papers and popular folders.

Horticultural educations at Boskoop can be obtained in different ways.

a) The secondary horticultural school, corresponding with the 4 year secondary school, has a 3 year course. The students are working in the nurseries one day a week and half a day attended instructions at school. The college affords a thorough training in horticulture (especially arboriculture) much attention being given to general education (3 foreign languages, economics, surveying, botany, dendrology, phytopathology, chemistry, manuring, pedology, physics, horticultural engineering, etc.).

b) The college for landscape-gardening, corresponding with the horticultural college, has a 4 year course.

c) The primary horticultural school corresponds with the ordinary elementary school. It affords a fundamental training in arboriculture. It has a 4 year course: during the first and second year lessons are given 5 days weekly, the two following years 4 and 3 days weekly.

d) The evening-classes are the most elementary form of horticultural tuition. They correspond with the elementary school. Lessons are given two years, 3 evenings weekly.

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