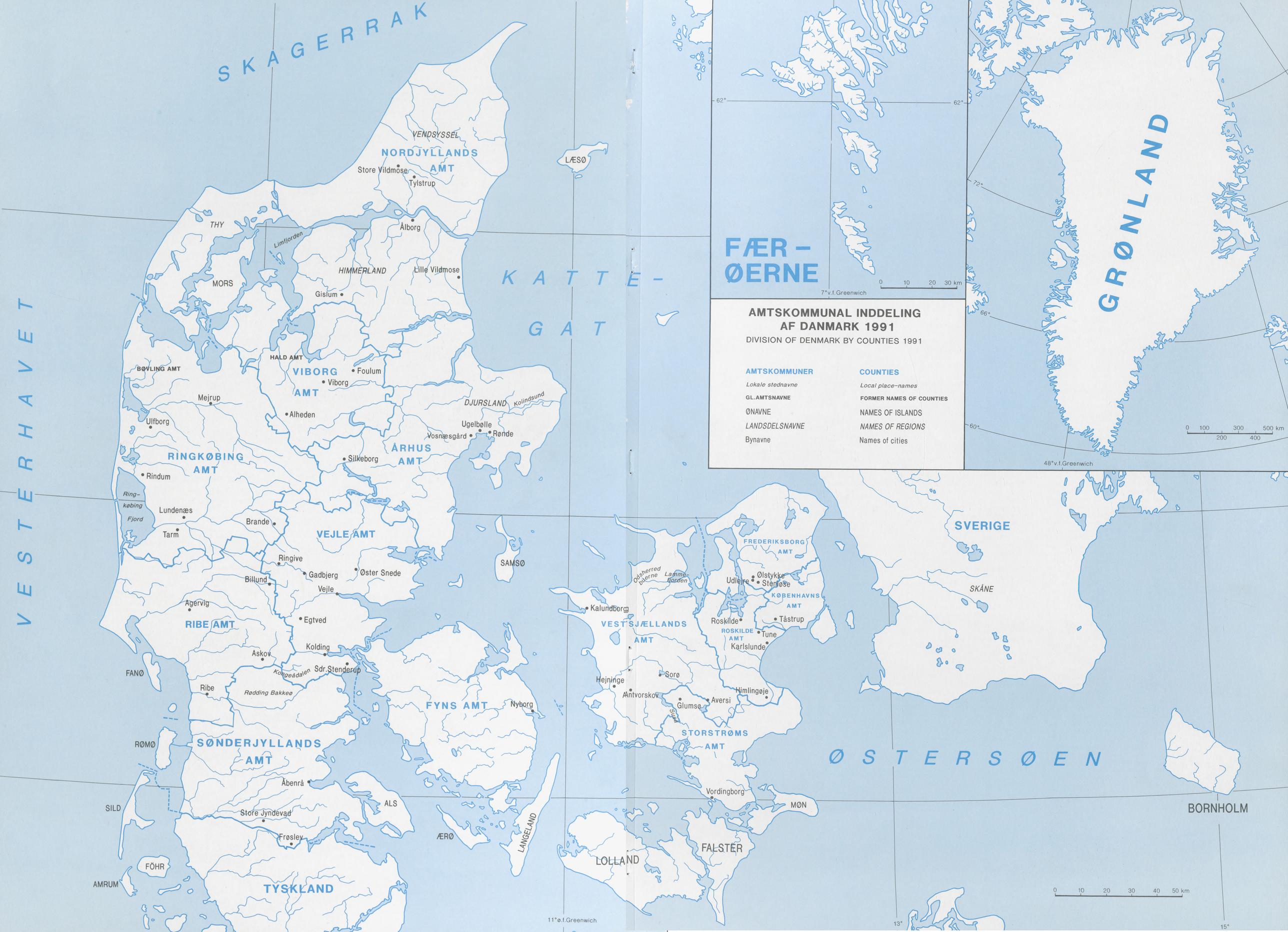
# ATLAS OVER DANMARK

## *ATLAS OF DENMARK*

SERIES I, VOLUME 3

THE DANISH SOIL CLASSIFICATION

By Commission: C.A. Reitzel, Copenhagen 1992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# ATLAS OF DENMARK

Edition: N. Kingo Jakobsen

”Atlas of Denmark” The First Series

Vol. 1. Axel Schou:
Landskabsformene. 1949. Atlas og Tekstbind.
(”The Landscapes of Denmark” - atlas and text)

Vol. 2. Aage Aagesen:
Befolkning. 1961. Atlas og Tekstbind.
(”The Population of Denmark” - atlas and text)

Vol. 3. Henrik Breuning Madsen, Axel H. Nørr & Kristian Aa. Holst:
Den danske Jordklassificering. 1992.
(”The Danish Soil Classification”)

The Second Series

Vol. 1. Kr. M. Jensen:
Opgivne og Tilplantede Landbrugsarealer i Jylland. 1976
(”Marginal Land-use in Jutland)

Vol. 2. Ruth Helkiær Jensen & Kr. M. Jensen (red.):
Topografisk Atlas Danmark. 1976.
(”A Topographical Atlas of Denmark”)

Vol. 3. Chr. Wichmann Matthiessen:
Danske Byers Vækst. 1985.
(”Urban Growth in Denmark”)

Vol. 4. Kr. M. Jensen & Anette Reenberg:
Landbrugsatlas Danmark. 1986.
(”An Agricultural Atlas of Denmark”)

## Editor’s Foreword

Topographical descriptions accompanied by maps have always been an integral part of the long geographical tradition in Denmark that dates back to the work started by King Christian IV’s cartographer, Johs. Mejer, who produced the maps of the ”Danckwerts Atlas” in 1652. The tradition was continued by P.H. Resen’s ”Atlas Danicus” (39 volumes, 1688) and E. Pontoppidan’s ”Den Danske Atlas” (I-II, 1763-64). In 1859, Cabinet Secretary, J.P. Trap, published his statistical and topographical account of the Kingdom of Denmark in 5 volumes, ”Kongeriget Danmark”, followed in 1861-64 by 2 volumes on the Duchy of Schleswig, ”Hertugdømmet Slesvig”. This prestigious and enormous topographical work has been continually updated. The fifth and latest edition ”Trap Danmark no. 5” was produced between 1953-72 and published in 15 volumes, including special volumes on the Faroe Islands and Greenland.

”Atlas of Denmark” represents a new concept within this tradition, as it lays particular emphasis on presenting the country, its people and its land-use, by means of maps and diagrams. A modem atlas thus becomes an analytical treatment of a country through the use of thematic maps, statistics and the latest research data on selected topics. Such an atlas gives a comprehensive presentation of a nation’s natural and cultural landscape.

The German occupation of Denmark, which started on 9th April 1940, gave an impetus to the Danes’ own wish to become more aware of their national heritage and improve the geographical knowledge of their own country. Isolation and occupation rekindled the national spirit, igniting the desire to produce a comprehensive atlas of Denmark along the lines of the existing ”Atlas över Finland”. Such a work would inform the Danish people of their natural regions, demographical characteristics and occupational structure. It would be regarded as a valuable aid to education in the Danish schools as well as an important tool in official planning and administration. Furthermore, the atlas would prove to be very much in the Danish public interest in the light of the historical circumstances prevailing at that time.

Not long after the German occupational forces had arrived, a start was made at the Geographical Laboratory of Copenhagen University (Københavns Universitets Geografiske Laboratorium). Professor Niels Nielsen was put in charge of a staff that rose to approximately 25 members after the first two years. In 1944, the complete work was ready to be published. There were to be five volumes in all: 1. The Landscapes of Denmark 2. The Physical Geography and Biogeography of Denmark 3. Danish Agriculture 4. Danish Industry, Transport and Trade 5. The Population and Settlement of Denmark. It was planned to publish the work in ”folio format”, 38 cm x 55 cm. The size of the maps was dependent on the subject matter, although normally the format 14 cm x 17 cm was chosen. In total, 800 maps and annotated diagrams were made in Danish and English.

The whole work was ready for publication and was being kept at Carl Allers Etablissement when, in January 1945, it was totally destroyed by a German act of sabotage during the war event known as the ”Schalburgtage”.

The reproduction work could not restart until 1946, and in 1949 it resulted in the publication of - Vol. 1. ”The Landscapes of Denmark” by Axel Schou. Official statistics gathered in 1950 allowed the publication of Vol. 2. ”The Population of Denmark” by Aage Aagesen in 1961. Other themes, which had previously been intended for the atlas, were published as theses. Settlement and Transport were treated in Aa. Aagesen’s ”Geografiske studier over jernbanerne i Danmark” 1949. Land-use was published in Aa. H. Kampp’s ”Landbrugsgeografiske studier over Danmark” 1959, while Industrial Location was treated in K. Antonsen’s ”Placering af Dansk Industri 1938-60” in 1964.

In 1976, it was decided to publish a second series, Serie II, of ”Atlas of Denmark” using the format 25 x 34 cm. Financial contributions donated in connection with the Royal Danish Geographical Society’s centenary were sufficiently large to enable the publication of two volumes. The first volume contained soil and land-use maps as well as a descriptive analysis of Marginal Land-use in Jutland by Kr. M. Jensen. The second volume was a special, centennial publication presenting the Danish Topography, ”Topografisk Atlas Danmark”. Later, in 1985, these two volumes were followed by a third volume on Urban Growth in Denmark, ”Danske Byers Vækst” by Christian Wichmann Matthiessen, and then a fourth volume in 1986 on Danish Agriculture, ”Landbrugsatlas Danmark” by Kr. M. Jensen and Anette Reenberg.

At this juncture, it might be appropriate to underline the fact that ”Atlas of Denmark” is published under the jurisdiction of the Royal Danish Geographical Society and based entirely on private funds and contributions. This contrasts markedly with the guaranteed state subsidies enjoyed by neighbouring countries such as Norway, Sweden and Finland, in connection with their production of national atlases. However, a guarantee of such state contributions would certainly be necessary if a proper national atlas were to be undertaken here in Denmark. On the other hand, it must be said that not being tied to any form of state scrutiny does have its advantages too, allowing us the freedom to concentrate our efforts on the specific current topics of our choice which lie at the frontier of geographical science, enabling us to then relay this information through our publications to a wider, international audience.

This current volume of ”Atlas of Denmark” showing the results from the Danish Soil Classification returns to the original format of 1945. This is in order to accomodate the richness in detail rendered by the various maps in this volume. The maps have been produced using the very latest cartographic techniques. Point data, focusing on characteristics from specific sites (e.g. soil profiles), or areal data, focusing on phenomena covering a wider area or region (e.g. wetlands) has been digitized based on national ordnance survey grid references. Hence, it has been possible to present the findings on maps, using visual techniques ranging from dots and lines to screening methods such as shading or cross-hatching. Selected information retrieved from different databases has also been combined for use in simulation models to investigate certain themes or test certain theories or hypotheses. The results of these calculations have been presented in the form of thematic maps. Such maps are highly convenient and practical tools in national and regional planning and are also being used in education today in Denmark.

The material used for the current volume stems from many very different sources. The most important of these are the databases at the Department of Land Data, the institution responsible for establishing the framework of the Danish Soil Classification. Furthermore, for the presentation of a historical review of soil classification in Denmark, another important source has been the archives at the National Cadastre and Survey (Kort- og Matrikelstyrelsen) as well as those at the National Archives (Rigsarkivet). The redrawing of the maps that accompany the texts has been undertaken by the Geographical Institute of Copenhagen University.

My colleagues and I wish to express our deep gratitude to all those who have contributed to the production of this atlas. The authors; Henrik Breuning Madsen, Kr. Aagaard Holst and Axel Nørr have all been connected to the Department of Land Data during the greater part of the 15 years that have been devoted to the enormous collection and treatment of data which have provided the basis of this national atlas. The heart and soul of the atlas project has been Professor Henrik Breuning Madsen who wrote most of the text. Axel Nørr has particularly worked with the historical account of land assessment and the first part of the Danish soil classification. Finally, we are very much indebted to Kr. Aagaard Holst who was responsible for the undertaking of simulation model experiments and the drawing of the many maps.

*N. Kingo Jacobsen*

# ATLAS OVER DANMARK

## *ATLAS OF DENMARK*

## SERIES I, VOLUME 3

## THE DANISH SOIL CLASSIFICATION

**Authors:**

***Henrik Breuning Madsen, Axel Henry Nørr, Kristian Aagaard Holst***

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# Authors' Foreword

This atlas describes the evolution and results of the Danish Soil Classification during the 1970's and 1980's. In order to give this recent soil mapping greater perspective, a historical dimension has been added. This has been achieved by including a section on the history of land assessment in Denmark dating back to medieval times. This represents the background to the current Danish Soil Classification. Furthermore, a brief account of other important Danish soil maps by other institutions and bodies has also been included.

The impetus for starting the Danish Soil Classification came from the fact that an unacceptably large amount of excellent agricultural land was being converted to alternative forms of land-use after the Second World War. This was at a time of high economic growth in Denmark, characterized by rapid urban and industrial expansion, road and motorway developments and a proliferation of new recreational areas. This often occurred at the expense of very fertile, productive farmland. In fact, it is estimated that an area as large as Bornholm, Lolland and Falster combined was lost to other land-use purposes.

Gradually, the fact that high-quality, agricultural land is a limited resource, and therefore ought to be protected, began to be realized in planning circles. Future disposition of agricultural land and the open countryside should be given more careful consideration. However, it was not until the 1970's protection of agricultural land was incorporated into local and regional planning legislation.

In 1975 it was decided to carry out a national soil survey mapping the texture of the plough layer, slopes and surface geology. These maps should be incorporated in the land use planning legislation. Therefore the soil mapping had to be carried out very fast and it should be finished within a period of less than four years.

The first phase of the Danish Soil Classification ended with the production of a basic data map series showing the most important findings, and the establishment of a geographical database system in which all the analyses and maps were stored.

The soil mapping was undertaken under the jurisdiction of the Ministry of Agriculture, and the soil classification structure was fixed on the advice of an expert group. The head of this group was director Aage Henriksen. Owing to a tight budget and a limited amount of time due to the pressure of impending local and regional policy-making, it was decided to keep the initial classification methods simple, with a view to developing and intensifying them later. The classification was to be based on measurable, stable, common, soil characteristics, so that the value of the soil to agriculture could be assessed. The majority of experts agreed that it would not be possible to carry out proper soil profile analyses, and that it would be necessary to focus on the plough layer, classifying it on the basis of its texture, organic matter, and calcium carbonate content. Once these characteristics had been defined, the nutrient status of the soil, the soil water retention and so forth could be deduced or empirically determined. The possibility for estimating the amount of plant available water was given high priority when the classification system was established due to the fact that, in Denmark, fertilization and drainage had counteracted many of the other traditional agricultural soil problems caused by deficiencies in plant nutrients or air circulation. Finally, it was agreed to undertake an analysis of the slopes and drainage conditions of the farmland.

The mapping was carried out by Sekretariatet for Jordklassifikation in Vejle. The head of the Institute was Fl. Duus Mathiesen. The mapping was based on the determination, in the laboratory, of the soil texture, humus content and calcium carbonate content on samples from about 36,000 sites. The work was achieved with the aid of local plant breeding consultants who collected most of the soil samples. The soil maps were presented at a scale of 1:50,000, showing the soil type, slope gradient class, drainage class and the surface geology. The computerization of all the data at ADK represented the start of the national soil database. The head of the establishment of a GIS-system and storing of data was Lic. scient. Steen W. Platou.

The databases are being continually expanded. One of the most important developments within the Danish Soil Classification during the 1980s was the construction and storing of maps showing the landscapes, slopes, wetlands and subsoil textures. Equally important, was the establishment of the first Danish soil profile database containing soil profile descriptions and belonging laboratory data on physical characteristics and chemical properties.

During the 1980s, the databases were used in several administrative and scientific investigations. Such work necessitates the treatment of basic data by the use of pedotransfer models. In this way thematic maps showing the amount of nitrate loss from the farmland have been constructed just like the irrigation needs of different crops, the potential drainage requirement and the potentially marginal land. The last part of this atlas gives examples of how the primary data of the Danish Soil Classification have been used to construct such thematic maps.

The historical account of land assessment in Denmark describes how the medieval land registers were specifically made for taxation purposes. Thereafter came the great land registration works of the 17th century, in particular King Christian V's Great Danish Land Register of 1688, followed by the land assessment necessary for the land redistribution and parcelling out reforms of the 18th century. In the 19th century the Great Danish Land Register of 1844 came to represent a milestone in Danish land assessment. This land register was continuously updated and used for taxation until the beginning of this century. In 1949 a land assessment commission was established for discussing the principles and making the guidelines for a new national land assessment. The work was finished in 1970 but at that time there was no political will to start the soil classification and carry out the land assessment.

The Danish Soil Classification, which was started in 1975, represented a break with the soil mapping tradition and is therefore a new milestone in Danish soil mapping. All previous land assessment work had been accomplished in order to provide a taxation basis which would distribute the tax burden among land-owners as fairly as possible. By contrast, the aim of the modern Danish Soil Classification has been to provide decision-makers with soil and land information so the best agricultural land could be protected from being converted to alternative land-use. Furthermore, the new soil classification has witnessed a definite shift away from the subjective, sensual determination of the soil to one based on more empirical methods and techniques by way of analysis in the laboratory. Finally, at the end of the historical section, there is a short account of the soil map production that has been carried out in Denmark by other institutions and bodies. These include the mapping of the Danish surface geology as well as areas of special geographical and environmental interest.

At last it must be underlined that this account of the history of land assessment in Denmark focuses primarily on the principles behind land assessment procedure rather than a description of the measuring techniques, map-making or the leading characters.

The production of this atlas has been long and complicated. Many people, institutions, organizations and companies have been involved, and we owe them all our heartiest thanks for their willingness and interest to take part. In particular, we would like to highlight the part played by the three leading institutions; the Institute of Geography at Copenhagen University (Geografisk Institut, København's Universitet - KUGI), Danish Institute of Plant and Soil Science Department of Land Data (Statens Planteavlsforsøg Afdeling for Arealdata og Kortlægning - ADK), and the National Cadastre and Survey (Kort- og Matrikelstyrelsen - KMS). A special thanks must also be given to John Jønsson (KUGI) for his technical drawing of all the diagrams and figures as well as his preparation of the map-sheets. Moreover, we are indebted to Joan Dahm Nielsen (ADK) and Jørgen Mygind (ADK) for typing the total manuscript. Richard Barnes was responsible for the translation of the atlas from Danish into English. Finally, we wish to show our gratitude to the following people who have contributed to the production of the atlas through their written articles, proof-reading etc.:

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Henrik Breuning Madsen
Professor dr. scient.
Institute of Geography
University of Copenhagen

Axel Henry Nørr
Chartered Surveyor
National Cadastre and Survey

Kristian Aagaard Holst
Scientific Assistant, Ph.D.
Danish Institute of Plant and Soil Science,
Department of Land Data

# CHAPTER 1

# A Historical Review of Soil Surveying and Land Value Assessment in Denmark

## The First Land Registers with Land as a Taxation Basis

For centuries in Western Europe, land utilization was accepted as the normal basis for taxation. Those who benefited from using the land had to pay towards the general welfare of society, and not least towards rearmament and warfare. It was also accepted that a land or property tax, whether valued in kind or ready money, should be graduated according to the size of a property and the value of its land.

During the Middle Ages, there were three different ways of assessing the Danish land for taxation purposes (Mosbech 1922 and Pedersen & Steffensen 1966):

- Number of ”ploughs” (Plough Tax)
- Amount of seed
- Gold value

### *The Plough Tax*

A ”plough” was a unit of taxation based on the estimated normal amount of land that could be managed and worked by a peasant farmer and his family. It was defined as the area of land that could support a peasant family and which could be worked by one plough. This amount of land tended to be similar for each farmer within the same village. ”The Law of Jutland”, made by King Valdemar the Victorious in the year 1241, describes the term ”plough” as being a unit of measurement for assessing property - ”the maximum employment of a plough”. The ”plough” unit of taxation was used by many a medieval monarch because of its uniformity and simplicity. King Erik ”Plovpennig” has usually been ascribed the honour of having formally introduced the ”plough” measurement, as well as the concept of land registration, about the year 1250. According to historical opinion, King Valdemar’s real estate records contain the remains of ”plough” records, and show the number of ”ploughs” registered on the largest Danish island, Zealand, and on Lolland, Falster and Møn. This register totalled some 2,000 ploughs. Taxation based on ”ploughs” continued in the Duchies of Schleswig and Holstein until the 1870’s, after which time these areas, having been annexed by Prussia in 1864, were subject to the German Land Tax System based on the ”Reinertrag” principle.

### *Amount of Seed*

This taxation method was based on the presupposition that the amount of seed to be sown was determined by the size of a property. The amount of seed was the taxation basis for King Christian V’s Great Danish Land Register of 1688.

### *Gold Value*

Assessing the gold value of a property for the purposes of taxation was carried out during the 12th century, although it was only used on the island of Funen and in Jutland. It also appears in King Valdemar’s real estate records and belonged to the ”Jutland Law” land registration practice. Later, this method of land assessment was carried out in other parts of the country. The gold values allotted were expressed in terms of ”field value gold” or ”field value silver” according to the designated commercial value of the land on the basis of its yield potential. There are several historical interpretations as to the exact value indicated by these gold values. One ”plough” could equal a ”field value gold” ranging from as little as 3 to as much as 40. In other instances, the unit values expressed in gold and silver indicated different sizes in property.

Apart from the continued use of the Plough Tax in the Duchies, the other methods of taxation gradually lost their importance during the 14th and 15th centuries.

### *The Introduction of Yield Potential as a Land Assessment Basis during the Late Middle Ages*

The method of paying dues to the landlord was widespread by the late Middle Ages. These land duties and tithes paid by tenants were recorded by estate owners or the Church in special ledgers or real estate records. The duties were usually paid in kind, as quantities of; rye, barley, butter, lamb, poultry etc. In order to simplify the assessment of the duties to be paid, a conversion unit was introduced, based on their value in terms of ”hard grain” (rye or barley). This conversion unit was called ”tønde hartkorn” in Danish and was used as late as the 20th century. Skonnings book on rates and duties, written in 1647, shows how the conversion unit ”tønde hartkorn” worked in practice (Knudsen 1919, Pedersen & Steffensen 1966):

| | |
|---|---|
| 1 ”barrel” rye or barley was equal to | 1.0 ”tønde hartkorn” |
| 1 ”barrel” groats or wheatmeal | 2.0 ”tønde hartkorn” |
| 1 ”barrel” wheat or peas | 1.5 ”tønde hartkorn” |
| 1 ”barrel” honey | 6.0 ”tønde hartkorn” |
| 12 geese | 1.0 ”tønde hartkorn” |
| 24 hens | 1.0 ”tønde hartkorn” |

Although the duties to be paid based on the ”hartkorn” value could vary from region to region, and were not connected to direct land valuation, they laid the foundation of the first national land register in the middle of the 17th century. The conversion of land duties to an aggregate ”hartkorn” value was not only important for land properties as a taxation basis, but also as an evaluation basis for inheritance, parcelling out, land redistribution and changes in ownership (Nordlund 1978).

## The Land Registers of the 1660’s

Due to the war against Sweden, a bill was put forward during the 1660 parliamentary session requesting the introduction of a property tax using the conversion unit ”hartkorn” as the basis for land assessment.

### *The Commissioners’ Land Register of 1660-62*

Work in connection with this register was undertaken between 1660 and 1662. It represented an attempt to find a basis for land tax assessment. It was hoped to achieve this by gathering all the ”hartkorn” values from the duties and tithes and using them as a basis for taxation based on yield potential. The heads of the registration were appointed commissioners who were persons of high rank in each diocese. It was their task to report on the various real estate records owned by vassals, tithe collectors and other estate owners. Their official reports were sent to the Royal Exchequer. The towns not using land duties as their tax basis had their ”hartkorn” values fixed by specially empowered priests. However, the difference in the reported ”hartkorn” rates was sometimes so great, that the Commissioners’ Land Register had to be abandoned in 1663, as it was proving to be an unsatisfactory taxation basis.

### *The County Clerks’ Land Register of 1664*

In 1664, the land assessment problem was tackled by a new body under the command of the chief administration officer of each county. The officers were in charge of appointing the local commissions, which this time included a number of selected farmers. Once again, the work was undertaken too hastily, and resulted in little more than a revision of the previous land register. In reality, it included too few adjustments to the existing land records. However, the land register was completed and made effective the same year. The total ”hartkorn” value for the whole country came to about 443,834 t.h., and acted as the basis for taxation during the next 20 years, until King Christian V’s Great Danish Land Register of 1688 came into force.

As with the previous Commissioners’ Land Register, the County Clerks’ Land Register failed to introduce a fair basis for taxation. Neither register had been founded on any measurement or evaluation of the yield potential of the soil. Instead, they were entirely based on land duties. Land duties were a reasonable basis on which to assess individual properties and their closest neighbours, seen from a local point of view, but regional differences were too great. In fact, many properties that had been allotted a particular ”hartkorn” rateable value differed markedly in their real value. Thus, some properties were overtaxed and others undertaxed.

## King Christian V’s Great Danish Land Register of 1688

The Danish government was well aware of these shortcomings. In 1679, the newly-formed Royal Exchequer was given the task of producing a proper land register to cover both Denmark and Norway (Exchequer Decree of 16.4.1680). Norway at this time, and until 1814, belonged to the Danish Crown. Initially, it was only thought that a revision of the existing land register, based on land duties, would be necessary. However, this was quickly overruled. Instead, inspiration came from the contemporary Swedish land tax assessment, which was based on property evaluation in the southernmost Swedish district of Skåne during the 1670’s. Until 1658, Skåne had been a part of the Kingdom of Denmark. The Swedish method of land assessment gave the Danish government fresh ideas (Knudsen 1931, Heering 1932).

This new approach led to a comprehensive project, incorporating far-reaching land evaluation methods and tax assessment calculations. The national land assessment lasted from 1681-86 and resulted in King Christian V’s Great Danish Land Register of 1688.

### *Land Assessment on the Danish Islands*

Apart from the peninsula of Jutland, Denmark consists exclusively of many islands. Some of the largest islands are; Zealand, Funen, Lolland, and Falster. Based on the instructions laid down by the Royal Exchequer, preliminary work was started on these islands. Measurements and calculations were made by 7 regional commissions that were in charge of a large field staff which, among other important participants, comprised managers, clerks, and surveyors. During the land evaluation, 4 farmers living in each district and possessing a comprehensive knowledge of the local farmland and soil, and who were known to be reliable citizens, were chosen to assist in the work. According to the Royal Exchequer’s decree of 16.04.1681, they should judge and evaluate the land in accordance with the instructions given to them by the surveyors in the field (Pedersen 1928). These farmers functioned as land appraisers. However, they were not allowed to evaluate the land of the parish to which they belonged.

The land registration work consisted of measuring properties, evaluating the land and fixing the ”hartkorn” value.

Rules applying to the measuring and evaluating procedures are to be found in the aforesaid Royal decree. The arable land of individual fields was normally measured by means of specially made chains. The arable area was divided into a number of triangles or rectangles. The lengths and widths were measured by the chains, and the areas calculated. The total area of the arable land could thus be calculated in a simple way. The account given by Hansen and Steenberg explains how the areas of the most difficult geometric shapes were calculated. The surveyors led the work, noting the results of measurements, names of properties, yields of the meadows, woodlands and commons, as well as recording crop rotation practices and periods of fallow. These procedures and their findings are found in different editions and accounts, but are named under the general heading of real estate records (field books). Often, the work was quickened by order of the Royal Exchequer, such as the royal decrees of 28.05.1681 and 15.02.1682, which demanded a simplification of the measurement and recording procedures. The first decree abandoned the original plan of producing maps for each village, although their replacement by more general county maps never came about either. Neither do any official maps of the Great Danish Land Register of 1688 exist at the Danish National Cadastre and Survey (Jensen 1991). The second decree forbade the time-consuming measurement of meadowland, ordering that this land-use be given an estimated rateable value instead.

Along with its measurement, the yield potential of the land was evaluated. On the island of Zealand, the land surveyors and clerks were instructed to fix the rateable value for farmland that was to be sown with hard grains (rye, barley etc.). There were to be 3 soil fertility classes (Pedersen 1928):

1) Fertile Soils
- Soil consisting of a pure mull.
- Soil consisting of sand and mull in equal proportions.
- Soil consisting of clay and mull, not prone to waterlogging.

It was decided that these fertile soils were not to be found in woodland, where shade hindered the growth of com. Hence, woodland soils were to be equal to only half the value of soils found in open fields.

2) Soils of Average Fertility
- Soil consisting of clay and mull, but where clay predominates.

3) Soils of Low Fertility and Unusable Soils
- Waterlogged, stony clay and mull soils.
- Coarse-grained sandy soils.
- Marshy clays and sands.
- Red sands and gravels.
- Pure sands.
- Waterlogged acid soils.

Based on their area calculations and value assessment, the Commissioners, in their recommendations of 1681 for the island of Zealand, prescribed that the ”hartkorn” rateable value be allotted according to 3 soil fertility classes. Each of these 3 classes was subdivided into 4 subclasses based on the area used for sowing a definite amount of sowing seed. At the same time, the normal field area used for sowing 1 ”barrel” of the actual com crops was defined as 14,000 old Zealand square units (ells). The length of one square unit (ell) was about 0.63 m which is approximately 0.56 hectares in square metric units. In Danish, this surface area was named ”1 tønde land”. In this chapter it is called ”t/l”. However, in practice, these detailed specifications were not usually followed, and ”hartkorn” rateable values were allotted according to 4 broad classes based on those crops to which the soil was best suited:

1) Good/Average barley, rye or peas. 2 t/1 equivalent to 1 t.h.
2) Mixed barley, rye, or buckwheat. 3 t/1 equivalent to 1 t.h.
3) Good quality oats..... 4 t/1 equivalent to 1 t.h.
4) Average/Poor oats..... 6 t/1 equivalent to 1 t.h.

In this classification, soil quality, expressed in terms of yield potential, became inferior going down the list, and automatically led to lower ”hartkorn” rateable values.

The average value for the total classification came to 3.75 t/1 as equivalent to 1 t.h. (1 unit of hartkorn). The average for the two Zealand rateable values amounted to 4.02 t/1 as equivalent to 1 t.h.. This value was of great importance during the subsequent land evaluation in Jutland.

In order to calculate the ”hartkorn” rateable value, the commission reduced the property area to be assessed by the amount of land that normally lay fallow each year, all according to whether this was done in conjunction with a particular rotation practice or whether the land was normally under cultivation. Regular crop rotation practice was more common on the Danish islands such as Zealand and Lolland, whereas in Jutland it was difficult to recognize any characteristic pattern. In connection with three-fold rotation, a third of the total seed amount was subtracted, in order to represent the size of the fallow area at any given time. However, the methods were unreliable. Therefore, the Royal Exchequer voted to group all agricultural land areas of the same quality, irrespective of the length of the fallow period. Then, each soil class was allotted a uniform period of fallow, irrespective of quality. This procedure was enforced with a view to increasing the ”hartkorn” rateable value of the land, which had been unsatisfactorily low according to the results of several test cases.

As previously mentioned, there were discrepancies on the Danish islands as to how the rateable value should be classified. The recommendations written in the royal decree were ignored in practice. As a means of evaluating the farmland, more attention was paid to the kinds of crops to which the soil seemed to be best suited, rather than to the actual consistency and nature of the soil itself. Based on the village records on the island of Zealand, land assessment and classification was carried out on the basis of the 4 soil quality classes below (Hansen & Steenberg 1951):

1) All average or good barley soils
2) All poor barley soils and all mixed grains soils
3) Good oats soils with clayey subsoils, and other oats soils that have not been qualified further.
4) All average to poor oats soils, and very poor oats soils. Oats soils lacking a clayey subsoil, but possessing a subsoil of sands and gravels. Buckwheat soils as sands, gravels, stony soils. Rye and buckwheat soils, partially overgrown by heather, or possessing a long period of fallow.

## *Land Assessment in Jutland*

The survey on the Danish islands was completed in 1682, but land assessment continued on the peninsula of Jutland, and was likewise based on the organized work of 7 commissions. In Jutland, the evaluation of the land was to be undertaken in the same way as on the islands, although based on an elaboration of the 4 rateable value classes determined by the fertility of the soil. By its decree of 24.03.1683, the Royal Exchequer laid down the soil definitions that were to be valid for the land assessment of Jutland (Pedersen 1928):

1) Fertile Soils
   Soils containing a high amount of pure mull (high humus content), slightly sandy mull, chalky clay, well-drained clayey mull.
2) Average Soils
   Blacky grey, sandy mull where sand predominates, and clayey mull where clay predominates.
3) Poor Soils
   Clays or mulls prone to waterlogging, and grey or chalky marginal soils.
4) The Poorest Soils
   Coarse sands and gravels, marsh clays, waterlogged clays, heathland soils, stony red sand soils, sand dunes, beach soils, cliff soils, forest soils.

Furthermore, it was the duty of the Jutland land surveyors to report on the extent of the great sand-dune migrations that had plagued some parts of the peninsula and to propose methods to halt their advance.

The Assessment results in Jutland, based on the 4 rateable value classes, gave an average land value of 7.75 t/1 per t.h.. This value was almost twice that of Zealand. The great difference was partly due to the problem of assessing the fallow period of the poorest areas, where the land often lay fallow for years. In order to avoid an unfair basis for taxation, it was realized that the Jutland rateable values would have to be based on alternative factors. In order to improve the basis for assessing the rateable value of the land in Jutland, the royal decree of 1685 ruled that the allocation of the ’’hartkorn” rateable value would be based on 6 classes for arable land, so that the average value for all classes would be equal to 8 t/1 per t.h., and that fallow periods would be ignored. This alteration made to the land assessment classes was tried in 21 parishes in Jutland. The regulations, and 6 classes, stipulated by the decree of 22.03.1686 are as follows:

1) Most Fertile Soil: 2 t/1 = 1 t.h.
2) Fertile Soil : 4 t/1 = 1 t.h.
3) Average Soil : 6 t/1 = 1 t.h.
4) Poor Soil : 9 t/1 = 1 t.h.
5) Very Poor Soil : 12 t/1 = 1 t.h.
6) Poorest Soil : 16 t/1 = 1 t.h.

In certain parishes a rate as low as 20 t/1 per 1 t.h. was fixed.

Rates were also fixed for other land-uses; hay production (by load), grazing of meadows and commons (by head of cattle) and woodland (by head of swine grazing on beech mast etc.).

Based on the above resolution, a satisfactory classification table evaluating the land had at last been reached, accounting for all the land areas belonging to rural areas and towns, irrespective of whether the land was for arable, meadow, grazing or woodland purposes. This was based on a just means of measurement, using a ”divisor”, so that all kinds of soils could be compared. By using the classified rates, the quality of the soil could be neatly showed by an index number, and this is illustrated in the example below (Pedersen 1928):

The soils of a particular village have been classified based on fifths of the total village area as follows: 1/5 most fertile, 2/5 fertile, 1/5 average, 1/5 very poor.

The mean figure, the ”divisor”, indicating the average fertility of the soils of the village, may be calculated as follows:

1/5 most fertile soil = 1 x 2 = 2
2/5 fertile soil = 2 x 4 = 8
1/5 average soil = 1 x 6 = 6
1/5 very poor soil = 1 x 1 2 = 1 2
total 28:5 = 5.6 t/1 per 1 t.h.

The lower the ”divisor”, the better the soil in the village. The fixing of the ”hartkorn” rateable value was more superficial for meadows, commons and woodlands than for arable land. It was not based on soil fertility evaluation, but on information reported in field books or harvest records, where the amount of hay cut, value of pastures, number of heads of cattle per grazing area, swine production of the woodland sties etc. were used as reference material (Pedersen 1928, Hansen & Steensberg 1951).

## *The Results of the 1688 Land Assessment*

Figure 1 shows different land value maps for the Zealand village of Hejninge, which lies west of the town of Slagelse. The land value map from the Great Danish Land Register of 1688 was made by Hansen and Steenberg (1951). The two other maps date from the mid-18th century and the Great Danish Land Register of 1844.

The ”hartkorn” results of King Christian V’s Great Danish Land Register of 1688 led to a lower national total value of ”hartkorn” than for the 1664 national land register. A certain amount of adjustment was made by the government in order to avoid a deficit in the domestic balance of payments. The taxation level was therefore increased by 1/12 for each property on Funen, and by 1/16 in Jutland.

The new Danish land register became law by order of King Christian V on 8th May 1688, although the determination of the ”hartkorn” rateable values was first completed in 1690. It was the first ”hartkorn” land register to be based on the areal measurement of properties and land evaluation by soil analysis. The ”hartkorn” value, plus the size of the property, determined the amount of tax to be paid. Only Bornholm and southern Jutland were excluded from the register.

More detailed studies of the methods of property measurement are given in the works by Hansen and Steensberg (1951), Pedersen and Steffensen (1966), Balslev and Jensen (1975), and Nordlund (1978). A description of the chief characters responsible for the production of the Great Danish Land Register is given in the work by Heering (1932).

Different opinions have been expressed as to the authenticity of King Christian V’s Great Danish Land Register of 1688. Professor Dinesen Oxendorph, responsible for leading the preparatory work, naturally praised the register as being ”a perfect land assessment”, whereby the land was justly and accurately measured and evaluated, while all the facts and figures were recorded in a protocol that he was sure would last for eternity! This contrasts with the later criticism by the author C. Thestrup in 1756. In his opinion, the surveyors had been no better than drunken, greedy leacherous louts. Most of the staff involved were former soldiers and officers, who were only appointed to do the work as a way of thanks for their earlier war service.

In spite of these conflicting views, King Christian V’s Great Danish Land Register of 1688 is to be regarded as a pioneer work, a milestone in land assessment, whose principles on how to divide the land tax burden among the inhabitants of the Danish rural areas lasted until the next Danish Land Register which appeared in 1844.

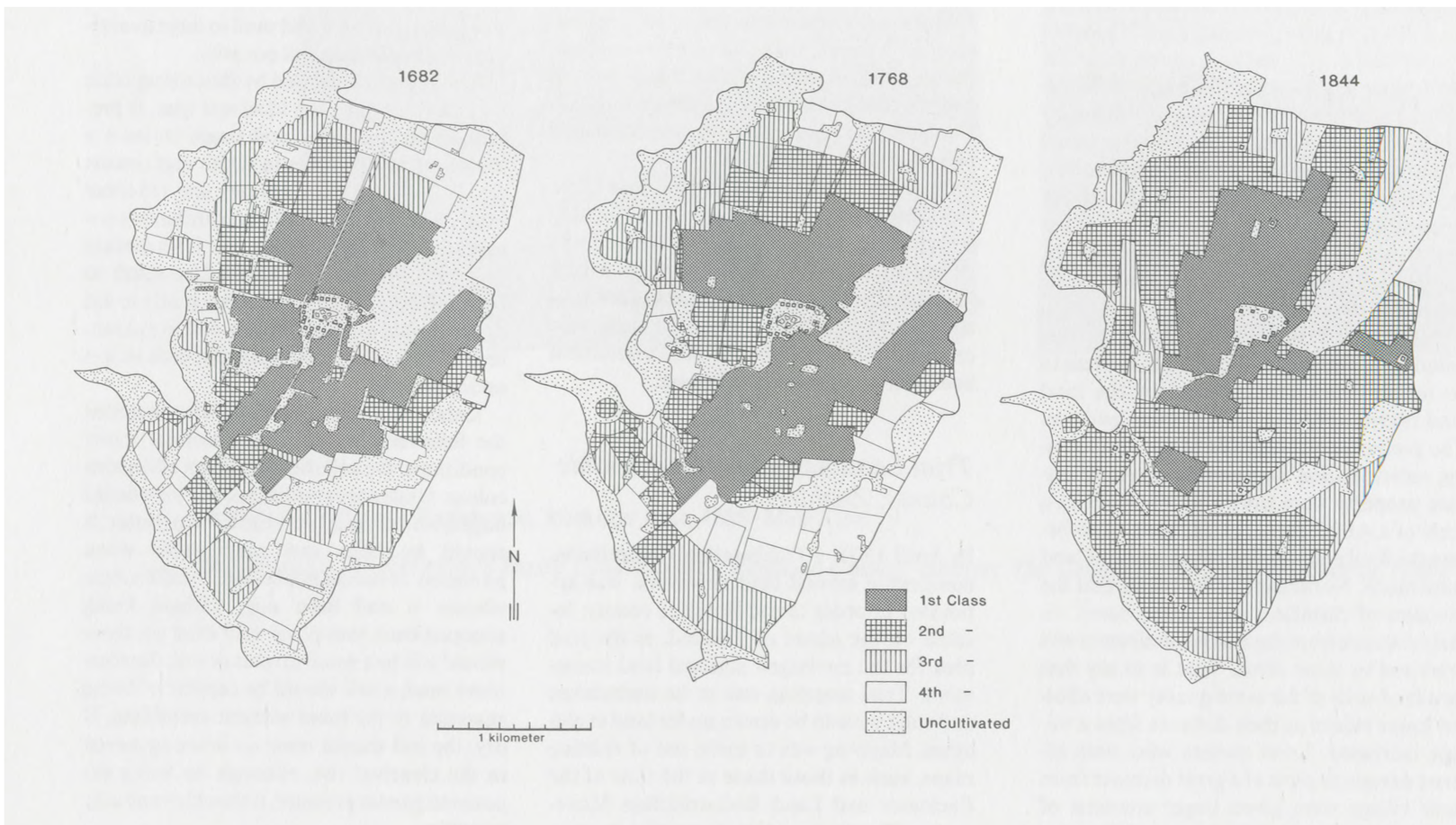



*FIGURE INDEX*

*Fig. 1: Land value assessment map for Hejninge, a village west of Slagelse, Zealand.*
*a) LVA map of 1688*
*b) LVA map of 1768-72*
*c) LVA map of 1844*

## Land Assessment in connection with the Land Redistribution Surveys, Parcelling Out Procedures and the Enclosure Movement of the Late 18th Century

Subsequent to the completion of King Christian V's Great Danish Land Register of 1688, a good deal of mapping was carried out within the Danish Kingdom. The first significant phase occurred between 1720-23 (Balslev & Jensen 1975). This was the mapping of certain Crown Estates, (in Danish known as "Rytterdistrikter"). These particular estates were dissolved and sold to the nobility later that century. The areas of Limfjord in northern Jutland, and the former Great Heathland of Jutland ("Alheden") were measured and mapped a little later.

### *The Land Register Project of 1768-72*

As a result of new land coming into agricultural use and the fact that hartkorn value was unevenly divided among the parcels of land, the Royal Exchequer, acting on a royal cabinet decree, embarked upon land register measurements with the production of maps at a large scale 1:4,000 and associated areal calculations and land assessment. The aim was to achieve a national survey, but the measurements only reached as far as a few "Rytterdistrikter", primarily Antvorskov and Vordingborg, from which new land assessments were made, using the same method of the 1688 Great Danish Land Register. The soil type is described in the same way, and the same division of land is made according to its suitability for com cultivation etc. The assessors qualified the soil with such terms as "good mull and sand for rye and barley", or, "average sandy mull and clay for barley, poor coldish sand with gravel for oats" etc. (Larsen 1929). Making their recordings in special protocols, the assessors registered properties according to property association and parish. The special protocols included information on the specific area under cultivation and the area of land assessed etc. The maps were used for the parcelling out process during the land redistribution work and, in fact, laid the basis for the maps made during the Great Danish Land Register of 1844. In Hansen and Steensberg (1951) the land assesssments of some of the mapped town areas on Zealand are described in detail (see also fig. 1). No real hartkorn evaluation was carried out in connection with this project. The work was stopped in 1772 by the Guldberg government, which was not so reformist.

### *Land Assessment during the Enclosure and Land Redistribution Movements of the Late Eighteenth Century*

The liberal movements of the mid-18th century resulted in two important Acts of Parliament. Firstly, the Enclosures Act of 1769 allowed farmers to have their part of the community land defined and separated. Secondly, the Abolition of Joint Ownership Act of 23.4.1781 freed villagers from having to own and work the land in common. It allowed them to become freeholders. Land re-allocation was at its height between 1780 and 1820, changing much of the rural landscape.

After 1769, the methods of redistributing and enclosing land in Denmark were based partly on an earlier land redistribution on the island of Zealand and in the Duchies of Schleswig and Holstein (Pedersen & Steffensen 1966, Nissen 1934). The law of 1769 stated that if just one peasant desired land enclosure, it became valid for the whole village. In principle, the idea was to amalgamate the numerous, fragmented strips into larger fields, which would come under one freeholder. Fundamentally, this aggregation process was tantamount to an enclosure movement. Either the new freeholders remained housed in their nucleated village settlements with a wedge or star-shaped field pattern radiating outwards from the village centre, or else they moved a few kilometres away to build new farmsteads in the surrounding fields.

The measures taken to introduce enclosures can be summarized as follows:

1) Measurement of the potential area to be enclosed
2) Drafting a provisional land distribution plan
3) Provisional land assessment to estimate the rentable value
4) Production of the final land redistribution and enclosure plan.

For the purpose of this article, only the land assessment procedure will be described in detail. Land assessment was normally the forerunner of any local land redistribution. The appointed land surveyor undertook the measurement and assessment aided by impartial appraisers. Their task was to evaluate the quality of individual plots as to their suitability as cultivable land. The plot owners had to accept the rateable value allocated.

As the statute failed to stipulate the specific assessment procedure to be used, different methods were incorporated. The most common method was to call the best land of the village "normal soil", the rest of the land was judged in relation to this soil.

The land was valued in rudimentary sub-units of "hartkorn". These sub-units were called "skæpper" in Danish. The best land of the village was allocated the value of 8 "skæpper" per t/1 The poorer the soil, the higher the sub-unit value. In fact, values as high as 96 "skæpper" per t/1 were recorded for the worst land. Should a strip of land be equal to 24 "skæpper", 3 t/1 were awarded for every t/1 of the best land (24/8=3). Normally 24 "skæpper" was the maximum value given to the poorest land of a village.

The aforesaid Acts of Parliament necessitated a satisfactory method of soil evaluation. A quest was therefore made to locate the best soil in Denmark. Once found, it would be used as the standard on which to base future land assessment. This soil was judged to lie in northern Zealand, in the county of Frederiksborg, between the villages of Stenløse and Ølstykke. This ideal soil type was described as being a mixture of clay and mull, reaching a depth of 12 inches, with a clayey subsoil, having been formed on land sloping gently from north to south. It was given a soil quality value of 24, and in connection with land assessment it was to act as the optimal quality. All other soils to be examined were to be given a value of 24 or less. The higher the value allotted, the better the quality.

This unit value was used to evaluate the Crown Estates as early as the 1780's, and gradually became common as a means of assessing land values in conjunction with the land redistribution and parcelling out movements whereby private estates sold off their land to the peasant farmers. The renowned diocesan surveyor, C. Ehlers, who was one of the planners of the Great Danish Land Register of 1844, proposed that the term" 12 inches of mull and clay", which was used to define the former soil value of 24, ought to be replaced by "a topsoil of a satisfactory depth, as a plough share will not cut down deeper than 6 inches". He reckoned that such topsoils, reaching a depth of 12 inches, were just about impossible to find, with the exception of the well-manured areas close to paddock gates, due to the stationing and passage of cattle (Hansen & Steenberg 1951).

Not every local assessment in t.h. was based on the quality of the soil. Many areas to be redistributed were assessed by the local land inspector on the basis of their land-use. The preliminary proposals to the forthcoming redistribution and parcelling out of private property were drawn up on maps at a scale of 1:4,000. Negotiations took place before the final plans for the distribution of land were made. Nordlund (1978) claims that the division of farmland into zones based on their distance from the nearest settlement was practised in some areas. That is to say that farmland soils of the same quality were allotted lower values as their distance from a village increased. Land owners who were offered parcels or plots at a great distance from their village were given larger amounts of land as compensation. In the case of disagreement between different parties, a local farming jury was called upon to mediate and make decisions that would be binding for all parties.

It is worth noting that the 24-Point Scale used in land assessment was the basis for the later Great Danish Land Register of 1844. Furthermore, it should be noted that the national land assessment methods for fiscal purposes, using the 24-Point Scale as the national norm, were very different from those used to evaluate a restricted, local area of land or property in connection with the land redistribution movement of the late 18th century. During an evaluation of the latter, the best local soil was often used as the optimum on which parcelling out was to be based.

In connection with the mapping procedure used during the land redistribution movement, greater detail is given in the work by Balslev and Jensen (1975). The redistribution of woodland areas is dealt with in the article by Pedersen and Steffensen (1966).More general information on land redistribution has been written by Flint-Jensen (1981).

## The Great Danish Land Register of 1844

The need for an improved basis for national taxation was urgent at the start of the 19th century. The Danish Land Register of 1688 had not been regulary updated and tax rates varied too unjustly between properties. Furthermore, having been allocated a particular "hartkorn" rateable value did not automatically mean that tax was paid, as certain manorial estates and the properties of royal officials still enjoyed tax exemption. This led to a greater tax burden for the other citizens.

The general dissatisfaction with the existing taxation basis led to the Royal Decree of 1802 which called for the creation of a new, national land register for all properties, which was to be assessed in "hartkorn". This was to include the Kingdom of Denmark, the Duchies of Schleswig and Holstein, and Norway which was still part of the Danish Kingdom until 1814.

In a report issued by the Royal Exchequer in May 1804, the King laid down the principles to be followed during the undertaking of the new, national land register (Rothe 1844). The work would involve a comprehensive, detailed national survey with the production of new, cadastral maps. However, the "hartkorn" assessment was to include only arable land and meadowland. Woodland was excluded. The land was to be evaluated according to the goodness of its soil and related characteristics. The best soil was to be valued according to a 24-Point Scale and the best soil would be allotted the optimal quality value of 24. The land assessment and the measurements taken during surveying would be the basis for determining the new "hartkorn" values. In the same year, 1804, the Act of Parliament was passed, although the initial work was now to be limited to Denmark. Preliminary work was necessary in order to establish the working procedure. The object was to keep the task as uniform and simple as possible so that the whole country could be quickly and sensibly re-assessed.

Based on the previous statute from October 1802, county commissioners had already been working hastily for two years in order to group all properties attributed an earlier "hartkorn" value into taxation classes irrespective of whether they had previously been exempt from tax or not. No land assessment had been undertaken at this stage.

### *Trial Land Assessment in Roskilde County, Zealand*

In April 1805, a Deliberation Commission, comprising several land surveyors, was appointed in order to use Roskilde county, located on the island of Zealand, as the trial area for the envisaged national land assessment. Trial mapping was to be undertaken and rules were to be drawn up for land evaluation. Mapping was to make use of existing maps, such as those made at the time of the Enclosure and Land Redistribution Movements. The Deliberation Commission completed its work in June 1805. Its views and findings were written down in the "Deliberation Protocol" of 1805 (Rothe 1844). This was a draft proposal that outlined the following procedure for the forthcoming land assessment. The new land register would be based on an evaluation of the soil of the whole country. All soils were to be assessed in relation to an ideal soil judged as being the best possible for cultivation. This soil would be given the optimal value of 24 and therefore represent the maximum quality attainable by any soil. All soils would receive a value based on a scale of 0 to 24. Priority was directed towards judging the physical nature and properties of a soil, as well as its importance to cultivation. The Deliberation Commission decided that it would not be practical to examine soils in the laboratory as many local factors played their part in determining fertility and farming conditions at any one site. For example, the nature of the subsoil, drainage conditions, slope, directional aspect in relation to the position of the sun, and farming practice were all vital variables, and would have to be judged more subjectively "by the use of one's senses".

Thereafter, the Deliberation Commission gave its definition of the different soil components, with regard to their respective importance for cultivation, based on the knowledge of the time. These components were primarily mull, clay and sand. Calcareous or limey soils are seldom found in Denmark, and the report included little information on such soils. Their definition was as follows:

"Mulls are the product of decomposed plant and animal remains, where carbon is a basic component. Experience shows that mulls are the best soils for cultivation. Mulls turn to mud during wet conditions, but become friable, turning to dust particles during periods of drought and strong winds.

Clay soils are cold, being slow to warm up or cool down. They contain neither carbon nor plant nutrients. They are able to retain water during dry summers, but during wet periods they have a tendency to become waterlogged and can damage crops. When desiccated, clays harden and crack, severing roots or preventing their penetration, and air cannot circulate.

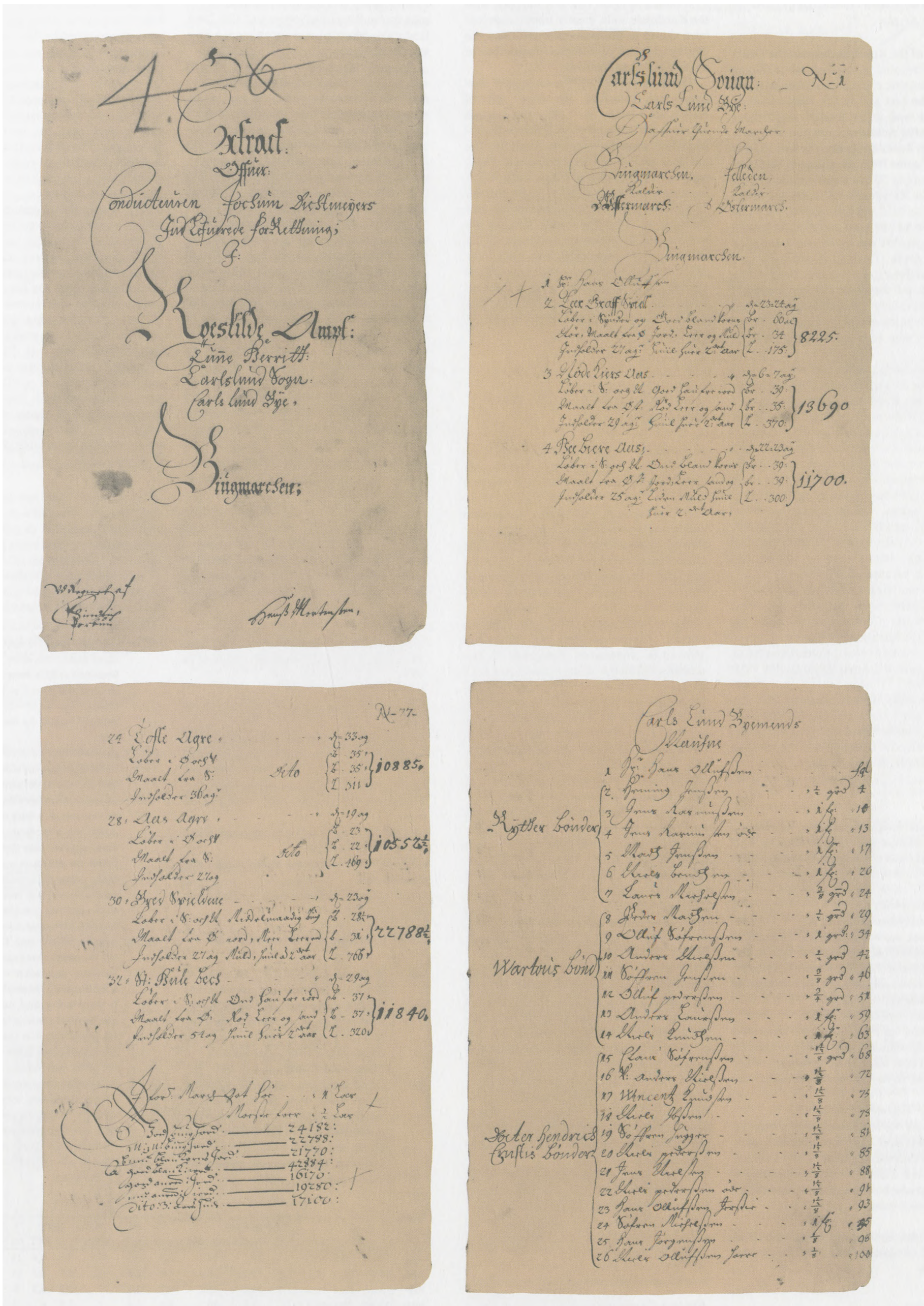
Sandy soils are warm, being quick to warm up and cool down. They do not contain any plant nutrients either. They allow a rapid percolation of rainwater, being the opposite of clay soils. As a result, plant roots may lack water during summer droughts."

The Deliberation Commission reported that these soil types were unsuitable to cultivation in a pure, unmixed state. Mull contains plant nutrients. Clay has the correct moisture content. Sand warms and aerates. All three must be present in a soil to make it cultivable. Where all three exist in correct proportion to each other, the soil can be most fertile.

Lime, or chalk, is also mentioned for its warming and soluble properties. Its absence in many areas may be compensated by the co-existence of mull and sand in large quantities which increases soil porosity.

The report proceeded by describing what it considered to be the ideal soil type. It prescribed that the ideal soil ought to have a topsoil of 10-12 inches in depth and consist of; 1/3 mull, 1/3 sand, 1/6 clay and 1/6 lime/chalk. The subsoil should be similar or contain more clay. Thereafter, the land surface on which the soil lies should face south to benefit from sunshine and slope gently to aid drainage and run-off. Such a soil is guaranteed to be a reliable farming soil, both in wet or dry periods.

Other ideal soil characteristics included the following points. Under normal moist conditions, the soil should take on a blackish colour. Under dry conditions, the soil should be greyish. It should not smell acid or bitter. It should be light and manageable when ploughed. It should not be able to refill a hole whence it had been dug, without being stamped back into place, and even so, there should still be a small surplus of soil. Furthermore, such a soil should be capable of being squeezed in the hand without crumbling. If dry, the soil should resist on being squeezed in the clenched fist, although on being exposed to greater pressure, it should eventually crumble.



Protokoludskrift fra Karlslunde, Roskilde Amt, 1688-Matriklen.

*Extract from the Karlslunde Parish Land Register, Roskilde County. (source: The Great Danish Land Register of 1688).*

## *Fixing the Land Assessment Soil Quality Scale*

By order of the Royal Exchequer, the Deliberation Commission was required to find an area of land that could be described as representing the best soil in the whole country. This area was to be located in Roskilde County. After a close examination of the arable land in Roskilde county, the best soil was judged to come from the village of Karlslunde, lying about 30 km south-west of Copenhagen. The Karlslunde soil consisted of approximately 5/12 sand and gravel, 3/12 clay with adjoined fine sand particles, 4/12 mull. This composition was found in a topsoil of 18 inches in depth. The land sloped gently in a southward direction. It was decided that the Karlslunde soil should be allotted the optimal assessment value of 24 points on the 24-Point Scale. This proposal was put before the Royal Exchequer who then would make the final decision.

The completion of the preliminary investigations by the Deliberation Commission resulted in the Royal Exchequer appointing a new Land Register Commission in 1805. Its task was to judge the findings of the Commission of Land Surveyors and thereafter draw up the plans and procedures for the national land registration. These would incorporate all the major tasks such as surveying, measuring, land assessment, and the calculation of the "hartkorn" rateable value for taxation purposes. These rules may be found in the Land Registration Instructions of 14.06.1806 (Heering & Sørensen 1935).

After examining the findings of the Deliberation Commission, the newly appointed Land Register Commission accepted the choice of the Karlslunde soil as being the national representative for the ideal Danish soil, and it was given the maximum quality value of 24 points.

Furthermore, the Land Register Commission ordered 3 other soil descriptions to be carried out in the Karlslunde area, and one in central Jutland at Ringgive in order to define soils with lower hartkorn values.

The results of soil examinations are as follows:

1) Karlslunde: Assessment Value 20. (24-Point Scale)
   The topsoil depth was 15-16 inches. It consisted of 11/24 sand with a little gravel, 7/24 mull and 6/24 clay. No chalk was found by treatment with saltpeter acid. Lower down the subsoil became more sandy and gravelly.
2) Karlslunde: Assessment Value 16.
   The topsoil was 9-10 inches deep. It consisted of 12/24 sand with more gravel than in Value 20. 4/24 was mull and 8/24 was clay. No chalk was found by treatment with saltpeter acid. Lower down the subsoil became half clay, half sand.
3) Karlslunde: Assessment Value 10.
   The topsoil was 8-9 inches deep. It consisted of 10/24 sand with a little gravel, 2/24 mull and 12/24 clay. No chalk was found by treatment with saltpeter acid. Lower down the subsoil became more clayey.
4) Ringgive: Assessment Value 3.
   The topsoil was 9-12 inches deep. It consisted of 20/24 black sand, 4/24 brown peat containing essentially decomposed plant remains and particles of manure or fertilizer. No chalk was found. Lower down the subsoil became reddish brown with gravels and small stones.

These soil descriptions and assessment values have been tabulated (Table 1 ) by Dalsgaard et al. (1976).

Table 1. The Soil Composition of the Ideal Soil, the Four Soils from Karlslunde, and the Soil from Ringgive - The Land Register Commission of 1805. Based on Dalsgaard (1976).

| Soil Components shown as l/24ths | | | | | Depth in Inches |
|---|---|---|---|---|---|
| Value | Mull | Sand/gravel | Clay | Chalk | Topsoil |
| Ideal | 8 | 8 | 4 | 4 | 10-12 |
| 24 | 8 | 10 | 6 | * | 18 |
| 20 | 7 | 11 | 6 | * | 15-16 |
| 16 | 4 | 12 | 8 | * | 9-10 |
| 10 | 2 | 10 | 12 | * | 8-9 |
| 3 | 4** | 20 | - | - | 9-12 |

* not detectable ** 'plaggen'

It should be noted that in connection with the Karslunde soils, greater importance had been shown to the amount of mull and the depth of the mull layer (topsoil) rather than to the size of the clay content.

During the early 1970's, Dalsgaard analyzed and described the ideal soil of Karlslunde (value 24). Today the original sampling site is found in an ornamental garden. The soil has developed on clayey till. The top layer consists of a 50 cm deep mull (Apl, Ap2) containing about 20% clay, under which the clay-rich horizons (B21t, B22t) contain 20-30% clay. Deeper down, the clay content decreases to 20%. The upper horizons are well-drained, but below there are signs of the initial stage of a pseudogley formation, indicating drainage problems. At a depth of about 150 cm, the lime-containing till is reached. Table 2 shows Dalsgaard's Soil Profile Description and the analytical results of selected soil horizons.

## *The Practical Work of the Land Assessment*

According to the Land Register Instructions of 1806 (paragraph 34), the land assessment in the field was to be undertaken by two land assessors (normally land surveyors). However, in practice, by 1807, the work was often conducted by one assessor, while the evaluation was put under the greater scrutiny of the Land Register Commission. Right from the start, the Commission made efforts to undertake trial assessments so as to train the newly-appointed land surveyors and assessors.

Based on the nature of the land, a suitable number of soil excavations and assessments were to be undertaken. Paragraph 25 prescribed a minimum of one examination per 2 t/1, which today would be equal to approximately one site per hectare. The land values allotted to each site were to be based on the existing 24-Point Scale and ranked according to the definition of five soils in the Deliberation Protocol. However, the instructions stipulated that the relationship and allocation of different land values were also to be moderated according to estimations of the potential, annual net profit based on yield (Paragraph 23). Furthermore, basic improvements to the farmland, such as the removal of stones from the fields or better drainage, were also to be considered when fixing land values. Finally, attention was to be paid to the farming methods to ensure that the soil was not likely to be impoverished or exhausted through over-cultivation or incorrect fertilization.

Of special importance was the fact that non-arable land, such as meadows, fen and heathland, was to be evaluated separately, according to a special scale based on its potential for hay production and grazing. The Act of 1811, originally passed by the Royal Exchequer to implement the existing 24-Point Scale, was overruled, as a result of recommendations made by the Land Register Commission in 1812. This special evaluation procedure has been elaborated in the works by Pedersen and Steffensen (1966) and Falbe-Hansen and Scharling (1885).

Initial experience in allotting land values based on the 24-Point Scale was limited to the four initial trial areas at Karlslunde and Ringgive, using the concept of "normal soil". That is to say, that only five values existed, being 24, 20, 16, 10 and 3.

## *Fixing Exemplary Soil Values for the Land Redistribution and Parcelling Out Procedures*

Acting on the 1819 Parcelling Act, the Land Register Commission allotted values for certain non-registered properties in Jutland which would serve as guide-lines for land surveyors undertaking land redistribution surveys. The interesting point is the fact that the land assessment in Jutland produced several land values not previously allotted. The results for the different counties of Jutland were as follows: Vejle 14 to 18 points, Ribe 8, 10 to 13 and 16 points, Ringkøbing 4½, 8, 9, 12 to 15, and 17 points, Randers 15 and 18 points, and finally Aarhus 17, 18 and 20 points. The Land Register Commission reported its results to the Royal Exchequer in 1820. Each land value recorded was accompanied by a soil description.

It is not clear whether the above Jutland values in connection with land assessment for redistribution purposes were also used for the general, national land assessment for the new Land Register. Laws governing land assessment stated that it was unlawful to use the national land assessment methods during local land assessment related to land redistribution and enclosure procedures (Pedersen 1951).

Christian Rothe, one of the most important characters engaged in directing the national land registration work from 1804 until 1840, wrote in his report from 1844 on the Land Assessment work that only the "normal soil" optimal quality value of 24 points, and the guiding test sample values of 20, 16, 10 and 3 points were used as the basic guide to land assessment. No mention was made of the other assessment figures from Jutland. However, he concluded that too little attention had been paid to the evaluation of poorer soils. He argued that the values for the lighter soils, (values lower than 6), were too high for the land properties of the Danish islands (Zealand, Funen, Lolland, Falster, Møn etc.), yet too low for the land properties of Jutland with its large areas of poor soils in the western parts characterized by their large expanses of heathland. The result was that Jutland benefited unjustly by being subjected to lower land tax payments to the Exchequer. Rothe concluded that the national land assessment work was not satisfactory due to the inadequate guidelines for evaluating lighter, poorer soils. The work had been hampered by the difficulty of assessing the importance of other factors, such as physical characteristics and cultivation practices, or the extent and nature of heathland expanses, comprising mainly heather, that were far more extensive at that time, during the mid-19th century. Rothe admitted, however, that absolute fairness and justice were not possible. Christian Rothe repeated that the heathland had been underestimated, and claimed that the people of Jutland had "no right to complain about their tax rates". Later works by Trap (1860) and Falbe-Hansen and Scharling (1885) agreed that only "normal soil" 24, and the exemplary test values of 20, 16, 10 and 3, were used as guidelines during the national land assessment. The latter added that values were often modified according to the net profit deemed obtainable through sensible farming practice.

Table 2. Description of the Soil Profile at the site of Soil Quality Value 24 at Karlslunde, Zealand, and Analytical Results of selected Soil Horizons, (Dalsgaard 1983).

Type : Value 24 points, Karlslunde - Colour Code 5/Soil Type 7, clay soil (Danish Soil Classification def.)
Geology : Clayey Till
USDA Class: Antropic Agrudalf. FAO Luvic Phaeozem
Location : SW. of Holgersen's residential property, Karlslunde, shown in the national topographic map series: Sheet no. 1513 II NV. UTM 029632 (published by the National Cadastre and Survey).
Topography: Land surface gently sloping southwards.
Drainage : Pseudogley at 90 cm., restricted natural drainage below that depth.
Land-use : 1982 ornamental garden. Until 1974, farm allotment.
Origin : Clayey till containing chalk, Weichsel Glaciation
Profile : Description by K. Dalsgaard 1971-74.

Apl (0-20 cm): Black (10 YR 2.5/1 moist, 4/1 dry) sandy loam to sandy clay loam. Moderately coarse-edged or rounded polyhedron structure, which crumbles into a fine, granular structure. Surface, plastic and slightly sticky. Many pores of all sizes. Clear, even boundary.

Ap2 (20-52 cm): Very dark grey (10 YR 3/1 moist) sandy loam. Moderately coarse-edged polyhedron structure whose surface is often dark grey (10 YR 4/1 moist), shiny, plastic, and slightly sticky. Many pores of 8-10 mm, thick rainworm passages and many minor pores.

AB (52/60-70 cm): Transition horizon, whose upper part is similar to Ap2 horizon, and lower part as B21t. Boundary is very irregular, and many vertical broad bands of A material are to be seen in B material. Strongly marked by dark rainworm passages.

B21t (66-70/90 cm): Greyish brown (10 YR 5/2 moist) aggregate surfaces and brownish yellow (10 YR 4-5/6 moist) matrix. Sandy, clayey loam to clayey loam. Coarse prismatic structure with thick clay skins, breaking down into a moderate, medium, polyhedron structure with thinner clay skins, as found on prismatic surfaces. In matrix, many yellowish brown shiny grains of fine sand size, probably biotite. Many 1-2 cm. thick rainworm passages per 10 cm., whose interiors have same colour as Ap.

B22t(g) (approx. 90-140 cm): Greyish brown (10 YR 5/2 moist) changing to olive grey (2.2 Y 6/2 moist) and then to yellowish brown (10 YR 5/6 moist). The greyish colours are partly found in a vertical, polyhedron structure and partly as a matrix in which the yellowish brown colour is found in patches, covering half of the upper part and a third of the lower part. Sandy, clayey loam, very coarse polyhedron structure with secondary coarse ployhedron structure. Thick clay skins on vertical surfaces and continuous skins on horizontal surfaces. Plastic and sticky surface. Dark rainworm passages down to 130 cm. Traces of calcium carbonate at 148 cm.

| | | Texture (m) | | | | | | % | % | pH | | | bulk den. | porosity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <2 | 2-20 | 20-63 | 63-200 | 200-2000 | gravel | org.C | $CaCO_3$ | $H_2O$ | KCL | $C/_N$ | g/cm³ | % |
| Ap1 | 0-10 | 20,0 | 15,5 | 9,4 | 29,2 | 25,9 | 5,6 | 3,0 | 1,6 | 7,0 | 6,4 | 11 | 0,94 | 64 |
| Ap2 | 30-40 | 18,2 | 15,1 | 9,5 | 30,5 | 26,6 | 7,0 | 2,8 | 1,2 | 6,9 | 6,3 | 11 | 1,30 | 50 |
| AB | 50-60 | 24,9 | 16,4 | 13,1 | 24,4 | 21,2 | 4,3 | 0,6 | * | 7,3 | 6,3 | 8 | 1,62 | 40 |
| B21t | 70-80 | 30,8 | 14,3 | 12,0 | 22,7 | 20,2 | 4,0 | 0,4 | * | 7,5 | 6,1 | 7 | 1,72 | 36 |
| B22t | 110-115 | 25,9 | 17,3 | 11,5 | 24,6 | 20,8 | 4,2 | 0,2 | * | 7,5 | 6,4 | - | - | - |
| BC | 140-150 | 18,5 | 18,4 | 13,4 | 31,5 | 18,1 | 5,8 | - | 2,9 | 8,0 | 7,1 | - | - | - |

* Trace

| | | exch. cations and CEC m.eq./100g | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Na^{+}$ | $H^{+}$ | CEC | B.S. % | total P %0 | org. P %0 |
| Ap1 | 0-10 | 22,7 | 1,9 | 1,6 | 0,3 | 4,2 | 30,7 | 86 | 1,40 | 0,29 |
| Ap2 | 30-40 | 24,1 | 1,8 | 1,4 | 0,3 | 3,9 | 31,5 | 88 | 1,38 | 0,24 |
| AB | 50-60 | 14,9 | 1,7 | 1,1 | 0,3 | 3,6 | 21,6 | 84 | 0,73 | 0,11 |
| B21t | 70-80 | 14,9 | 1,9 | 1,0 | 0,3 | 3,1 | 21,2 | 85 | 0,52 | 0,05 |
| B22t | 110-115 | 12,4 | 1,5 | 0,8 | 0,3 | 2,1 | 17,1 | 88 | 0,61 | * |
| BC | 140-150 | - | 1,6 | 0,8 | 0,3 | 0,5 | - | - | 0,54 | * |
| C | 160-170 | - | - | - | - | - | - | - | - | - |

* Trace exch. $H^{+}$ determined at pH 8,1, exch. cations at pH 7,0

## *The Completion of the National Land Assessment*

The national land assessment took decades to complete. There were several delays. Firstly, the Danish economy was hard hit at the beginning of the 19th century due to the national engagement in the Napoleonic Wars. Secondly, these events necessitated the submission of land surveyors to war duty, as many of them were indeed former army and naval officers. Few authorities had the finance necessary, and the work was given low priority. Even so, Zealand, Lolland, Falster and Møn had been assessed by 1813, Funen by 1820, and Jutland by 1826. Southern Jutland was not however assessed, except for the royal enclaves within Ribe county. On the other hand, Bornholm was included this time.

Simultaneously, surveying and other land measurements were being made in connection with the production of the new land register maps, which along with the existing approved maps from the Enclosure period represented a new economic map series for the districts (predominating map scale 1:4,000). This series still represents the backbone of present-day land register map administration at the National Cadastre and Survey Department.

The results of the land assessment are shown by maps, on which each parcel of land is labelled, showing its rateable value. Map 2 shows the land register map of Karlslunde in Roskilde county. On the right-hand side is the original work, whilst the redrawn version is on the left. The map was redrawn as the property and field boundaries on the former map had faded. Figure 2 shows a generalized extract of maps taken from the Great Danish Land Register of 1844 (Dalsgaard 1989).

## *Calculating the New "hartkorn" Values*

The area of each property converted to the 24-Point Scale was calculated by dividing the geometrical area of each parcel of land by 24, multiplying the result by the parcel taxation value of the 24-Point Scale, then aggregating the values of all the parcels to give the total taxation area figure for each property.

In this way, the final result for each property was expressed as an overall area figure which was the calculated area size related to the taxation value of 24.

No taxation value awarded was to be higher than 20. This reduction rule was intended to represent compensation for the lower valued soils which were expected to give higher yields due to improvements in cultivation, fertilization etc.

By 1804, the Royal Exchequer had already decreed that the new land assessment should maintain the same amount of "hartkorn" (land taxation amount) as that found in King Christian V's Great Land Register of 1688. This was a political wish in order to prevent an increase in the tax burden.

To achieve this, it was necessary to introduce a correction factor, (known in Danish as the "unitet"), to moderate the tax amount to be paid by each property. The "unitet" was derived by dividing the total taxation figure aggregated for all Danish properties by the total (1688) "hartkorn" amount. The final taxation basis (hartkorn) for each property was its taxation area figure divided by the "unitet". In 1831, after several trial calculations, the King approved of the fixed value of the "unitet" as being 2.8369 td per t.h. (72,000 old Danish square units (ells) per t.h.). This became the official conversion unit to be used for all properties. The calculation of the final taxation basis was protocolled for each parish. More detailed specifications are given by Pedersen (1951) and Nordlund (1978).

Although the land register work and the fixing of the "hartkorn" land values had been completed, there were still many obstacles to overcome before the new tax system became law. There was much political debate, where it was claimed that the new taxation system would be an attack on property owners' rights. However, there was also a political desire to terminate the Assessment work, especially endorsed by the Assembly of the Estates of the Realm which, in the 1835-36 session, beseeched the government to put the new taxation system in force. Due to such delays and the considerable amount of time that had elapsed since the assessment, certain adjustments were necessary. Revision resulted in the allocation of new land values to some 4,200 properties. However, the government persevered, and the Great Danish Land Register became law as of 1st January 1844, (Heering 1930, Jensen 1944, Pedersen & Steffensen 1966).

*Fig. 4: Denmark: former county boundaries*

With the exception of Bornholm, the total "hartkorn" value for the whole nation was estimated at 372,221 t.h. for arable land and meadow land. After the 1864 peace treaty with Germany, alterations were made to the German border in southern Jutland resulting in an increase in the national "hartkorn" value to 382,512 t.h. in 1875 (Falbe-Hansen and Scharling 1885). The figure for Bornholm was equal to 6,049 t.h., although it must be made quite clear that Bornholm was assessed using a specially devised "unitet" which was lower. Trap, who was responsible for the most comprehensive Danish Atlas series in ancient times, estimated that the national average in 1860 was 17.25 t/1 per 1 t.h., with the exception of southern Jutland.

The Great Danish Land Register of 1844 revealed that there was great variation in the cultivable value of the land in Denmark, Figure 3 (Falbe-Hansen and Scharling 1885). Figure 4 shows the former county divisions that are used in Fig. 3. Falbe-Hansen and Scharling attempted to make a direct comparison between Jutland and the Islands (Zealand, Funen etc.). That is why heathland, marsh areas and sand dune areas were omitted. The average land value for Jutland was just over 6 points, whereas that of the Islands was between 11 and 12 points.

In particular, it must be mentioned that the Great Danish Land Register of 1844 did not include market towns which had special taxation privileges. Neither had they been included in King Christian V's Great Danish Land Register of 1688. However, a law passed in 1863 determined that town properties were now to be given a "hartkorn" value. This was based on special rules whereby all land used as building sites, yards, gardens and storage areas was automatically allotted a value of 24 on the 24-Point Scale. Other land within town boundaries was assessed according to the rules of the Great Land Register of 1844, although land for special purposes was excepted from taxation. The allocation of the "hartkorn" value was based on the 1844 Land Register "unitet" of 72,000 old square Danish units (ells) per t/h. This special land assessment method is often called the "Market Town Land Register" and the "hartkorn" value as "townland hartkorn". Because of these special land assessment procedures and the resulting value allocations, "townland hartkorn" is not normally taken into consideration in statistical reports.

Map 3 shows the distribution of "hartkorn" per geographical square mile (about 55km²). This is illustrated by means of iso-hartkorn contours which divide the country into areas of different "hartkorn" values. The poorest areas are valued at less than 100 t.h. (units of hartkorn), slightly richer areas between 100-200 t.h. etc.

In 1902, Westermann investigated about 100 properties in order to compare the land values recorded during the Great Danish Land Register of 1844 with the average com yield as reported by the farmers. Based on this work, Dalsgaard (1976) later illustrated the relationship between these two figures (see Figure 5). His result indicates a favourable correlation on the Islands, although in Jutland yields tend to be higher than one would expect for their land values, particularly for values of 2-8 points. Dalsgaard explains that this was probably due to improvements in drainage, marling, or the fact that Jutland had been undervalued, as claimed by Rothe in 1844.

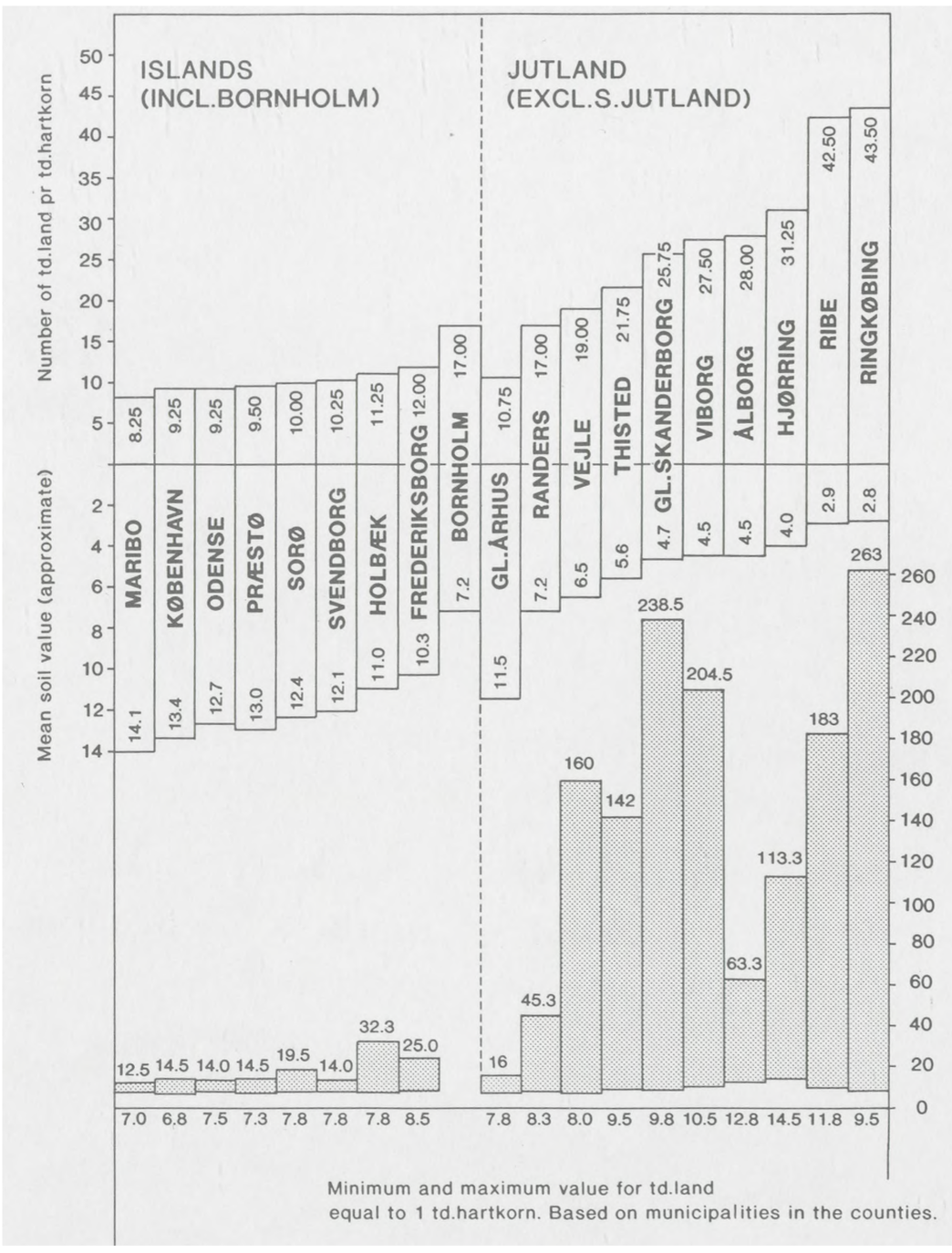


*Fig. 3: The 1844 Danish Land Register. Average land values by county. (Falbe-Hansen and Scharling 1885)*

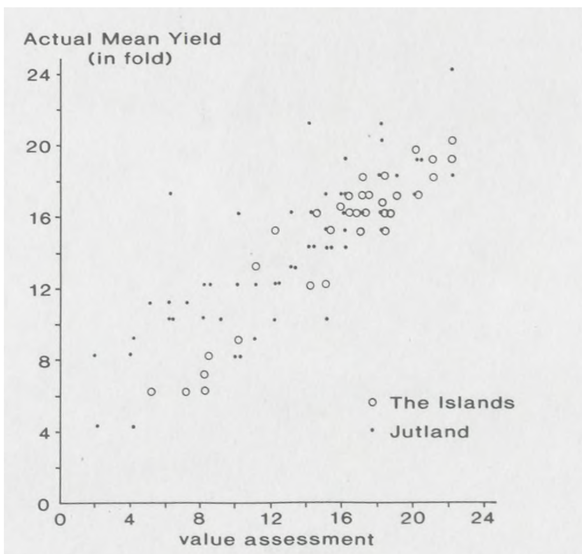
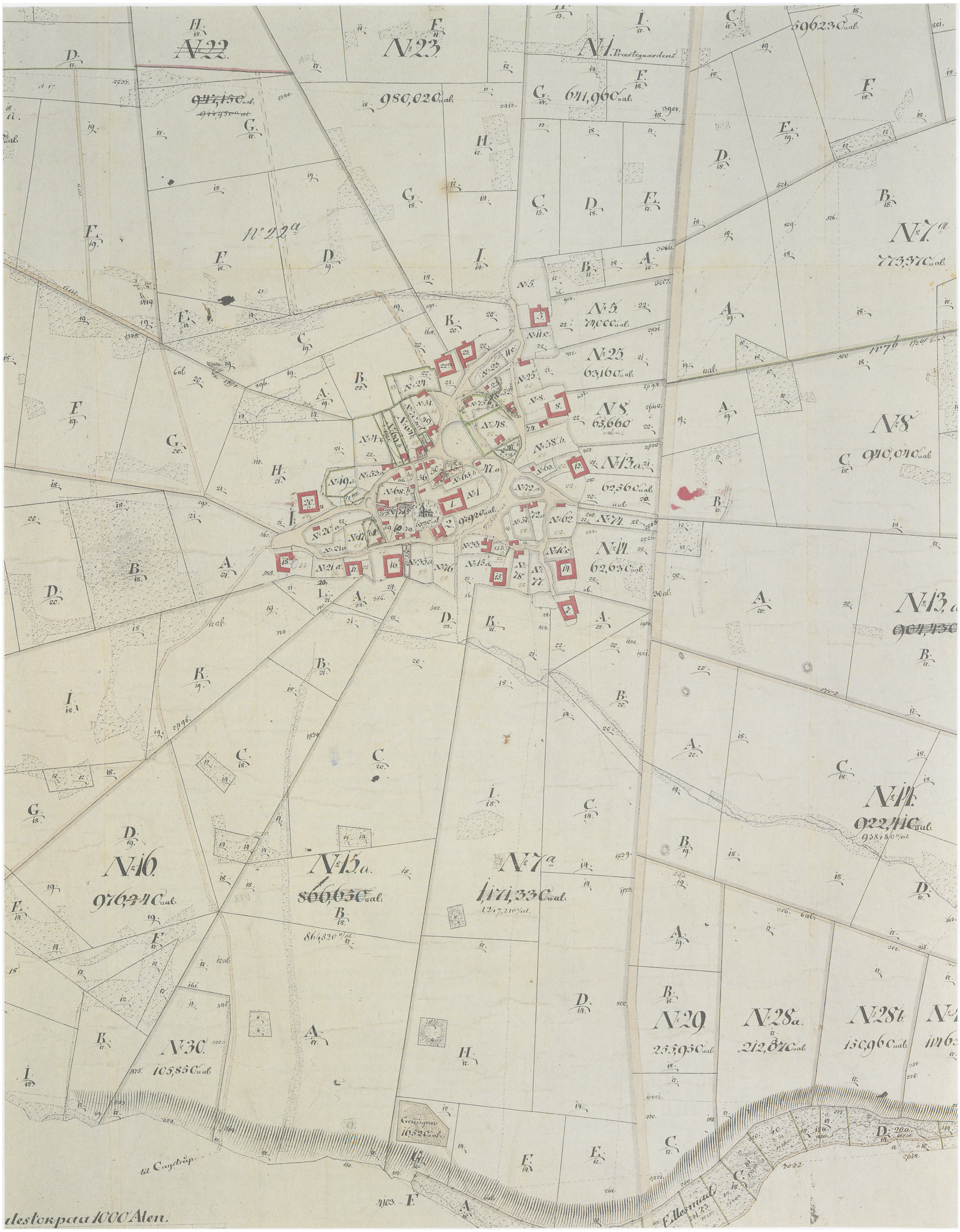


*Fig. 5: The 1844 Danish Land Register. Comparison of average yields (recorded in fold), indicating land values allotted in 1844. (Westermann 1902, Dalsgaard et al. 1976).*

KORT 2a

MAP 2a




1844-boniteringen. Matrikelkort over Karlslunde by. Roskilde Amt. (omtegnet version).

*The Land Register Map of Karlslunde Village. Roskilde County. (source: The Great Danish Land Register of 1844). (revised map version).*

KORT 2b

MAP 2b

1844-boniteringen. Matrikelkort over området umiddelbart øst for Karlslunde by, Roskilde Amt (original version).

*The Land Register Map of the land area lying immediately east of Karlslunde Village, Roskilde County. (source: The Great Danish Land Register of 1844). (original map version).*

*Fig. 2: The 1844 Danish Land Register.*
*Selected reduction maps (Dalsgaard 1989).*
*a) Vosnaesgaard, 20 km. north-east of Aarhus.*
*b) Tolstrup-Tandrup Parish, near Aars, Himmerland, Jutland.*
*c) Himlingsøje, east Zealand*

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KORT 3

MAP 3

Kort over fordelingen af hartkornet i Danmark.

*Map of Denmark showing the Division and Distribution of hartkorn Land Values.*

## The Land Assessment of the Duchies of Schleswig and Holstein, and the Baltic Sea island of Bornholm

Neither in 1664, 1688, nor in 1844, were the Duchies of Schleswig and Holstein included in the National Land Register. The taxation basis was still the ”plough”. The plough tax register was revised in 1652 and formed the basis for land taxation. In the 1770’s, land redistribution had started in Schleswig and served, in some respects, as a model for the rest of the Danish Kingdom. However, the common land of the villages was not assessed, and land redistribution was based on subdivision according to the number of ”ploughs”. Based on the royal decree of 1802, property registration and evaluation were undertaken in the Duchies, but not all land taxes were recorded (Mosbech 1922, Pedersen & Steffensen 1966).

Special royal enclaves within the Duchies, connected to the Kingdom of Denmark, were included in the County Clerks’ Land Register of 1662-64 and in the Great Danish Land Register of 1844, as they belonged to the royal administrative area. These enclaves, called ”mixed districts” by the Royal Exchequer, were to be found on the Frisian islands off the west coast. They comprised the northern half of Sild, all of Amrum, the western part of Føhr, and most of Rømø. Other enclaves in the Duchies were found on the mainland along the west coast stretching well south of the current boundary with Germany (see Figure 6). During the land assessment work of the 1660’s, it was decided that the royal enclaves should be taxed on the basis of ”hartkorn”, whereas Schleswig was to be taxed on the basis of the Plough Tax. The islands of Føhr and Amrum were not included in the Great Danish Land Register of 1844. Surveying and assessment began in these areas in 1838 and terminated in 1841. Objections to the decisions made by the land assessors, meant that the land register did not become law in these districts until 1847 (Stubkjær 1967).

After the defeat by Prussia in 1864, the German border was moved northwards. Much of Schleswig and Holstein became part of Prussia, and the subsequent exchange of territory as part of the peace treaty meant that the former enclaves ceased to exist, either becoming part of Prussia or Denmark. Most of the enclaves became part of Prussia. In compensation, the island of Ærø lying south of Funen, 8 parishes along the east coast south of Kolding, and the enclaves within Ribe County in Jutland, became part of the Kingdom of Denmark. An order issued by the Home Office in 1865 made sure that the land assessment of this part of the country was quickly undertaken in accordance with the procedures outlined in the Great Danish Land Register of 1844 (Heering & Sørensen 1935). Due to changes in the quality of the land, a special land assessment commission reassessed some of the parishes of Funen and Jutland in order to reach the same ”hartkorn” rating in the newly incorporated areas that was valid for the rest of the Kingdom.

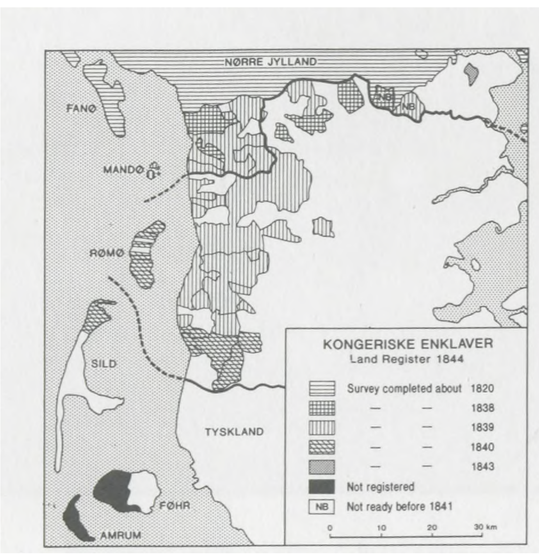



*Fig. 6: The 1844 Danish Land Register. Land value status in the royal enclaves of Schleswig. (Stubkjær 1967)*

### *The German Land Tax System used in Southern Jutland*

After 1864, Schleswig and Holstein were reassessed on the basis of the German Land Tax System. The work was carried out between 1870-78. This land assessment laid the basis for the later decentralised land register offices of southern Jutland which today are under the Danish National Cadastre and Survey.

This land taxation system had its origin in ”La Code Napoleon” originating in France at the beginning of the 19th century. The term ”cadaster” derived from the latin ”capitum registra” stood for land registration records, accompanied by large scale maps. This idea was initiated by Emperor Napoleon I of France, whereby all land parcels were to be recorded in land registers called ”cadastres parcellaires”. The cadaster system was adopted by several western and central European countries, including Germany (Heering 1958).

The measures to be taken during the undertaking of such a register were stipulated by Prussian directives (”Anweisung” of 07.05.1868). The land assessment of the county of South Jutland followed a very different procedure to that of the Great Danish Land Register of 1844. The rateable value was directly based on fixing the estimated net yield for each parcel of land. This method was based on the German ”Reinertrag”, literally meaning the net profit remaining after estimated incurred expenses had been subtracted from the estimated income. The rateable value of the land was wholly based on the expected normal exploitation of the land. In accordance with the basic taxation regulations of Prussia (”Anweisung” of 21.05.1861), all land was to be divided into 7 land-use types; arable, garden allotment, meadow, hill pastures, woodland, water surface areas and wasteland. Each class was again subdivided into 8 subclasses. Based on the classification rate table of the county commission, in which the net yield per unit area was determined for each subclass, the net yield of properties would be calculated and a rateable value fixed for taxation purposes. However, variations in scale could occur within South Jutland. In total, there were 8 regional scales whose rates were different. The best soil of each land-use type was always called ”Class One”, and was used by the county commissions as the basis for fixing preliminary rateable values for exemplary sites within their county. Thorough descriptions of these sites were recorded (Heering 1930, Andresen 1968). Regional variation could be great.

After the First World War, the German border was once again adjusted. By the referendum of 1920, Denmark regained the northern part of Schleswig, now called southern Jutland. The rateable value was adjusted so that 1 t.h. was equal to a unit of 40 Danish ”daler”. During the Land Parcelling Act of 1949, the land tax rate basis, the ”Reinertrag”, was fully converted to the land register tax system of 1844.

### *The Danish Island of Bornholm*

The Danish island of Bornholm, lying to the south of Sweden in the Baltic Sea, has a different land tax history. Having successfully removed the occupying Swedish forces during the 1650’s, the Bornholmers were rewarded by being allowed to retain their lower tax rates. As a result, neither the 1664 Land Register, nor King Christian V’s Great Danish Land Register of 1688, were imposed upon the inhabitants. Rateable values were fixed according to practices based on existing real estate records. Land value assessment based on ”hartkorn” was never introduced at that time. Bornholm became nationally registered for the first time during the compilation of the Great Danish Land Register of 1844 (Knudsen 1931). Through the former specification for the calculation of the ”hartkorn” value, it may be added, that the conversion factor, the ”unitet”, had a lower value i.e. about 2/3 national value.

### *Land Assessment in connection with Land Redistribution and Parcelling Out of Farmland Properties*

As long as land tax was fixed to ”hartkorn”, the value normally remained constant. New properties created by parcelling out processes during land redistribution divided the ”hartkorn” value between themselves, making reference to the soil quality. The Land Parcelling Act of 3.12.1819, based on the Acts of 1810 and 1796, laid down this principle. It was continued in the Act of 1897. This practice was maintained until the next significant period of parcelling out following the Acts of 1906, 1919 and 1925 by which time land assessment had become much less important. The Act of 1925 stated that the local assessment, or even the preceding national land assessment, was sufficient enough as the basis for the division of the ”hartkorn” rateable value of an estate. As a result of the 1949 Land Parcelling Act, both parties could decide whether they desired land assessment or not. Later, even this clause was deleted. This gradual erosion of the importance of land assessment based on soil quality must be seen in the light of the growing importance of property evaluation based on commercial value.

With regard to the land assessment procedure, a circular issued by the Royal Exchequer in Febraury 1820, advised land surveyors to carry out their evaluation using the 24-Point Scale based on the Karlslunde soil. The circular was accompanied by extracts on this ”normal soil” taken from the examination made by the Land Assessment Commission. Based on the instructions related to land assessment methods of the 1925 Land Parcelling Act (Paragraph 28), Heering and Sørensen (1935) refer to the 1820 circular. The same Act (Paragraph 22) stated that the 24-Point Scale had to be the basis for any change in the ”hartkorn” rateable value of a property. Further instructions concerning the land assessment methods to be employed were not mentioned. In relation to the Land Parcelling Act of 1949, Pedersen (1951) referred to certain instructions whereby the following should be recorded:

1) Topsoil Characteristics

2) Topsoil Depth

3) Subsoil Characteristics

The assessment of the soil quality was undertaken by dividing the land parcels into squares (50m. x 50m.), and then taking samples from each comer. Based on the 24-Point Scale, the topsoil value ”T”, the subsoil value ”S”, and the depth of topsoil ”D” were all rated. For depths less than 48 cm, the rate was taken to be half that of the depth, but for depths of topsoil greater than 48 cm, the rate was taken to be 24. The topsoil was rated according to the 24-Point Scale, whereby 24 points represented the best soil. The topsoil and subsoil were both ranked in 7 classes on the basis of content:

Sandy and chalky clay = 24 taxation value

Very sandy or heavy clay = 20 taxation value
Light clay = 16 taxation value
Clayey sand = 12 taxation value
Normal sand = 8 taxation value
Sand and gravel = 4 taxation value
Very ferrous sand and gravel = 0 taxation value

After estimating the rates of the three soil variables, the average value for a soil was found by using the ”Rating Equation”:

$$T = \frac{O + U + D/2}{3}$$

For the lighter, sandy soils, where the boundary between topsoil and subsoil was often unrecognizable, the rate was based on the average for the topsoil and subsoil. Such a soil rarely surpassed a rate of 13-14. Finally, the rateable values were, if necessary, modified so as to relate to the overall pattern for all the squares.

### *The Importance of National Register Land Assessment following the Taxation Reforms of the Early 20th Century*

The Great Danish Land Register of 1844 was used as the basis for real estate taxation for about 60 years. The new taxation legislation of 1903 terminated the use of ”hartkorn” as a taxation basis, replacing it by the commercial, rateable value of property, as it is known today.

One of the reasons for rejecting the continued application of”hartkorn” was the rigidity of the old system, by which the ”hartkorn” value of any given property could not be altered. Furthermore, significant land value disparities had often occurred during the period of land redistribution and parcelling out, whereby the value allotted to previously uncultivated parcels was markedly different to that of adjacent fields whose ”hartkorn” value had been fixed during an earlier phase of national land assessment.

Apart from the rigidity of the ”hartkorn” taxation basis, ”hartkorn” values were no longer accurate due to significant changes in yield potential during the second half of the 19th century. Many clayey areas, that had previously suffered from waterlogging, were now well-drained and were producing higher yields. Grazing areas, that had received a lower ”hartkorn” value, were now more valuable after having been converted to arable land. The yields of sandy soils had proportionally increased even more than those of clayey soils, due to liming, manuring and other forms of fertilization. Thus, the land values fixed at the time of the Danish Land Register of 1844 no longer corresponded to the new productivity of the soils.

However, the ”hartkorn” evaluation method and the former land assessment procedure were still to play a role in the continual administration of parcelling out land or the amalgamation of estates and farm properties. In fact, agricultural regulations stipulated a minimum size for farm properties based on soil quality. There were 4 soil quality classes. The main parcel of land was to have a minimum size determined by soil quality and geometric area. In reality, more attention was paid to the geometric size of properties rather than their assessed value on the basis of soil quality.

After 1958, ”hartkorn” was successively no longer used in the land evaluation of urban areas. In 1962, it was decided to exclude ”hartkorn” from future agricultural legislation. However, its use was still important in the legal identification of properties when referring to land records or cadasters. To a certain extent, property evaluators and building societies retained ”hartkorn” in order to assess potential cultivability. In 1969, it was proclaimed by Act of Parliament that all the ”hartkorn” values recorded throughout the nation (including those subject to the Southern Jutland Land Tax) would be removed from land registers and replaced by National Land Register property specifications (Lense-Møller 1970). However, the comprehensive nature of the work to be undertaken delayed the date of removal until 01.06.1970 (Land Registry Office Circular of 10.06.1970).

## The 1949 Land Assessment Commission

Although property evaluation following the 1903 Tax Reform Act was based on commercial value, there was also a desire to undertake a new national land assessment and renew all the ”hartkorn” values. This was partly because ”hartkorn” was still used in connection with land parcelling up to the 1960’s, and because there was disagreement over the main principle on which to base real property assessment. Hence, from time to time, land surveyors and building societies called for a new national land assessment to be undertaken (Sørensen 1930, Brink 1926, Nielsen 1930, Pedersen 1932). There was also a desire to include an evaluation of the national woodland areas (Pedersen 1926, Heering

1926). On several occasions, as in the period 1940-42, complete proposals were prepared for the undertaking of such a national land assessment, but a bill was never put before Parliament. Steps were not taken until the 1949 Land Parcelling Act, when the Ministry of Agriculture appointed a Land Assessment Commission, whose task it was to lay down the guidelines for trial assessments to be carried out in every local authority. The Commission (Jordboniteringskommission) consisted of agricultural scientists, farmers, land surveyors, chartered surveyors, and representative members of the National Land Register Office who represented the chairmanship (Jordboniteringskommission 1970).

## *The Creation of a New Land Assessment System*

Firstly, the Land Assessment Commission concentrated on preparing a land assessment of arable, meadow and grazing land, whilst woodland was temporarily omitted. To get its bearings, the Commission referred to the details of the preliminary investigations recorded by the Deliberation Commission of 1805 that led to the Great Danish Land Register of 1844. In order to be consistent, the Commission decided to retain the practice of using a numerical scale for land evaluation purposes.

Based on national land assessment directives and the South Jutland and German land assessment procedures, it was concluded that the evaluation would have to be made according to estimations made in the field rather than in the laboratory (Pedersen 1932, Jordboniteringskommission 1970). However, estimates based on theory were insufficient. In practice, soil sampling in the field was based on a description of the external nature of the soil "by the use of one's senses". This work was to be supported by experienced, practising farmers. That is to say, that the procedure of the Great Danish Land Register of 1844 was to be directly followed in principle.

The Land Assessment Commission underlined the importance of updating values on a regular basis so as to maintain their credibility. Certain procedures were made imperative, and their results were irrevocable and binding. At each sampling site, soil values were to be allotted, written descriptions of the topsoil and subsoil made, and the depth of the topsoil was to be recorded. This procedure was to be followed except in the wetland areas. The Land Assessment Commission had considered incorporating other variables such as climate, slope and situation into the overall assessment work, but settled for the fact that these factors would be naturally taken into consideration by the evaluation teams on site.

## *The Land Assessment of Areas with Well-drained Soils*

In well-drained areas, the Land Assessment Commission agreed that the fixing of rates should be based on natural factors as mentioned earlier. The aim of the land assessment was to produce a comprehensive, qualitative picture, restricted to agricultural land-use areas. The different soils of the different parcels of land were to be rated according to their natural characteristics and annual productivity in terms of crop yield per hectare given normal operational conditions. Trial rates on a 100-Point Scale (shown at intervals of 5 points) were then fixed. The scale was to resemble the German "Bodenzahl", so that the value increased linearly with productivity to a maximum of 100 points.

The fixing of the rates was to be partly based on the following soil characteristics, as during the Great Danish Land Register of 1844. The mineral soils were divided into seven classes: 1) Heavy clay 2) Clay 3) Sandy clay 4) Clayey sand 5) Sand 6) Coarse sand 7) Gravelly sand. In special circumstances, the terms "rich in mull" or "poor in mull" were added. These seven classes were fixed for the topsoil, as well as the subsoil. Water retention capacity, soil colour, and the presence of plant roots were also included in the evaluation and rating. By contrast, wetland soils were assessed according to special criteria affecting soil drainage conditions - see next section on "Wetland Soils".

The Land Assessment Commission then fixed the rates for areas for which the total yields of several years' experimental cultivation at national research centres and agricultural association field centres had been recorded. Based on these yield comparisons and the above-mentioned soil evaluations, the following classification scale for mineral soils was made (Table 3).

Table 3. Mineral Soil Classification for Land Assessment.

| (Rating range 100-Point Scale) | | | |
|---|---|---|---|
| soil type | class | topsoil | subsoil |
| Heavy Clay | 1 | 50-90 | 50-80 |
| Light Clay | 2 | 80-100 | 80-100 |
| Sandy Clay | 3 | 70-90 | 70-90 |
| Clayey Sand | 4 | 50-80 | 50-70 |
| Fine Sand | 5 | 15-70 | 30-50 |
| Coarse Sand | 6 | 0-50 | 15-30 |
| Gravelly Sand | 7 | 0-30 | 0-20 |

The next step was to consider the best way of combining the three rates for the topsoil, subsoil, and depth of topsoil to give the final rating value. Initially, it was planned to utilize the Rating Equation of the earlier parcelling out land assessment. However, a simplification in the form of one figure would have led to unrealistic final ratings. Oversimplification through the use of the equation above could have led to false impressions. For example, the same rate could be obtained irrespective of whether a high topsoil rate coexisted with a low subsoil rate, or vice versa. Alternatively, a soil with a relatively low topsoil rate and a relatively high subsoil rate, but with a high topsoil depth rate, risked being rated too high.

Preliminary tests proved that a soil with a topsoil depth greater than 60 cm should be given the highest rate, as the yield was not found to increase significantly once that depth was reached. A topsoil with a depth of 60 cm was to be termed as a "full depth topsoil", so that soils with a topsoil deeper than 60 cm would be given their final rate based on their topsoil rate.

During the practical work in the field, a soil assessment rate table was usual as a practical guide to fixing the rates. All three soil measurements were to be included with the necessary weighting. The Commission found it desirable to introduce a correction factor for the topsoil and subsoil so that the final rate could be obtained by the following equation:

$$R_{cor} = T_{cor} + S_{cor}$$

The correction work was achieved by the use of regression equations, made on the basis of research and tested during the land assessment of a large number of field test areas with the assistance of agricultural advisers. The results reached by the use of the equation above led to the production of the Soil Assessment Rate Table (Table 4). Table 4 shows the rate table for a topsoil (T) rated at 50, showing the possible combinations of topsoil depth (D) and subsoil rate (S). The topsoil depth (D), shown at intervals of 5 cm, ranges from a depth of 5 cm to 60 cm. The subsoil rate (S) is shown at intervals of 5 points.

Table 4. Rate Table valid for a Topsoil of Rate 50 (T).
S = Subsoil Rate (100 point scale)
D = Topsoil Depth (cm.)
(Source: Jordboniteringskommissionen 1970)

| S/D | 60 | 55 | 50 | 45 | 40 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 50 | 55 | 59 | 62 | 65 | 66 | 67 | 68 | 68 | 68 | 68 | 67 | 67 |
| 95 | 50 | 55 | 58 | 61 | 63 | 64 | 65 | 65 | 65 | 65 | 65 | 64 | 64 |
| 90 | 50 | 54 | 57 | 60 | 61 | 62 | 63 | 63 | 63 | 62 | 62 | 61 | 61 |
| 85 | 50 | 54 | 56 | 58 | 59 | 60 | 60 | 60 | 60 | 59 | 59 | 58 | 57 |
| 80 | 50 | 53 | 55 | 57 | 58 | 58 | 58 | 58 | 57 | 56 | 55 | 54 | 54 |
| 75 | 50 | 53 | 54 | 55 | 56 | 56 | 56 | 55 | 55 | 54 | 52 | 51 | 50 |
| 70 | 50 | 52 | 53 | 54 | 54 | 54 | 54 | 53 | 52 | 51 | 49 | 48 | 47 |
| 65 | 50 | 51 | 52 | 53 | 53 | 52 | 51 | 50 | 49 | 48 | 46 | 45 | 44 |
| 60 | 50 | 51 | 51 | 51 | 51 | 50 | 49 | 48 | 46 | 45 | 43 | 42 | 40 |
| 55 | 50 | 50 | 50 | 50 | 49 | 48 | 47 | 45 | 44 | 42 | 40 | 38 | 37 |
| 50 | 50 | 50 | 49 | 49 | 47 | 46 | 45 | 43 | 41 | 39 | 37 | 35 | 34 |
| 45 | 50 | 49 | 48 | 47 | 46 | 44 | 42 | 40 | 38 | 36 | 34 | 32 | 30 |
| 40 | 50 | 49 | 47 | 46 | 44 | 42 | 40 | 38 | 36 | 33 | 31 | 29 | 27 |
| 35 | 50 | 48 | 46 | 44 | 42 | 40 | 38 | 35 | 33 | 30 | 28 | 26 | 24 |
| 30 | 50 | 48 | 45 | 43 | 41 | 38 | 35 | 33 | 30 | 28 | 25 | 22 | 20 |
| 25 | 50 | 47 | 44 | 42 | 39 | 36 | 33 | 30 | 27 | 25 | 22 | 19 | 17 |
| 20 | 50 | 47 | 43 | 40 | 37 | 34 | 31 | 28 | 25 | 22 | 19 | 16 | 13 |
| 15 | 50 | 46 | 42 | 39 | 35 | 32 | 29 | 25 | 22 | 19 | 16 | 13 | 10 |
| 10 | 50 | 45 | 41 | 38 | 34 | 30 | 26 | 23 | 19 | 16 | 13 | 10 | 7 |
| 5 | 50 | 45 | 40 | 36 | 32 | 28 | 24 | 20 | 17 | 13 | 10 | 6 | 2 |
| 0 | 50 | 44 | 39 | 35 | 30 | 26 | 22 | 18 | 14 | 10 | 7 | 3 | 0 |

## *The Land Assessment of the Wetlands*

While defining the assessment rating procedure for areas with well-drained soils, the Land Assessment Commission attempted to outline rules for an evaluation of wetland soils. However, it was difficult to reach a clear and scientifically satisfactory classification. The result was a division of wetland soils into 4 main groups:

a. *Mineral Soils* (clayey meadow, sandy meadow). Including all wetland areas whose topsoil layers consist of mineral soils and are at least 20 cm deep (types 1-7 of the mineral soil classification).

b. *Muddy Soils*
These may be divided into marsh soils, developed in either saltwater marsh or freshwater marsh areas.

c. *Blanket Bog Soils*
These include all soils in which the mineral soils are covered by a pure humus layer to a maximum depth of 30 cm, or by a humus layer topped by mineral soils to a maximum depth of 20 cm.

d. *Bog Soils*
These are mineral soils covered by a pure humus layer to a minimum depth of 30 cm, or by a humus layer topped by a thin layer of mineral soils to a maximum depth of 20 cm. To be included in this category are the high and low moorland and heathland soils.

The four wetland soil groups (a-d) were described in further detail within each wetland group. The mineral soil classification, based originally on 7 soil texture classes, was therefore extended to include wetland soils (texture classes 11-16, see Figure 7 "The Complete Soil Classification Chart").

The degree of wetness was considered so important, that the rates of the wetland soils were modified according to which of 4 drainage categories they belonged. The drainage categories were defined according to the drainage depth, as far as to the level of the water table (Figure 7). Modification was achieved by applying a reduction factor varying from 0.2 to 1.0.

The Land Assessment Commission had many difficulties in applying the Rate Table to the wetland areas. There were problems experienced within each of the four wetland soil groups as well as in their relationship to mineral soils. Establishing the correct relationship between the best mineral soils and the best organic peaty soils was complicated. In fact, it required the advice of horticulturalists specializing in grass cultivation, before the best peatland areas were finally defined as being equal to 2/3 the quality of the best mineral soils (100-Point Scale). The best peatland areas were thereafter rated at 65 points.

Based on their preliminary work, the 1949 Land Assessment Commission laid down the rules for the land assessment to be made. The assessment should be undertaken manually in the field, paying close attention to how the soil affected the senses, especially sight, touch and smell. By this, each soil was classified

| SOIL DESCRIPTION | | | Designation | ASSESSMENT VALUES: Topsoil values with ± correction for the humus content | ASSESSMENT VALUES: Subsoil values |
|---|---|---|---|---|---|
| MINERAL SOILS | CLAYEY SOILS | heavy | 1 | 50 – 90 | 50 – 80 |
| | | light | 2 | 80 – 100 | 80 – 100 |
| | | sandy | 3 | 70 – 90 | 70 – 90 |
| | SANDY SOILS | clayey | 4 | 50 – 80 | 50 – 70 |
| | | fine | 5 | 15 – 70 | 30 – 50 |
| | | coarse | 6 | 0 – 50 | 15 – 30 |
| | | gravelly | 7 | 0 – 30 | 0 – 20 |

| WETLAND SOILS | | | | Values for topsoil deeper than 60 cm | | x) drainage class | Estimated drainage depth, metres | Correction factor |
|---|---|---|---|---|---|---|---|---|
| | MARSH SOILS | light | 11 | 80 – 90 | Values corrected according to drainage conditions (drain. class, cf. x) | 1 | fully drained (above 1 m depth) | 1.0 |
| | | heavy | 12 | 50 – 80 | | | | |
| | MUDDY SOILS | salt water deposits | 13 | 70 – 95 | | 2 | 0.6 – 1.0 | 0.6 – 1.0 |
| | | freshwater deposits | 14 | 65 – 80 | | xx) 3 | 0.2 – 0.6 | 0.2 – 0.6 |
| | BOG SOILS | decomposed partly or non-decomposed | 15 | 45 – 65 | | 4 | morass, no assessment value given | – |
| | | blanket bog | 16 | 30 – 50 | | | | |
| | | raised bog | 17 | 20 – 50 | | | | |
| | FRESHWATER MEADOWS: | described and assessed according to values 1–7 and 11–17. When stratified, the thickness of each topsoil layer is indicated. | With topsoil depths of below 60 cm for soil types 11 – 17, the above assessment scale is used, while the subsoil is described and assessed in the same way as mineral soils. Hence the assessment values related to the topsoil and subsoil are then corrected with respect to drainage conditions, cf x). | | | xx) To this class belong the normally waterlogged, often inundated areas with their characteristic vegetation. | | |
| | SALTWATER MEADOWS: | described and assessed according to the values 1–7 (mineral soils) | | | | | | |

*Fig. 7: The 1949 Land Assessment Commission. Comparison of soil classification and land assessment.*
*(Jordboniteringskommissionen 1970)*

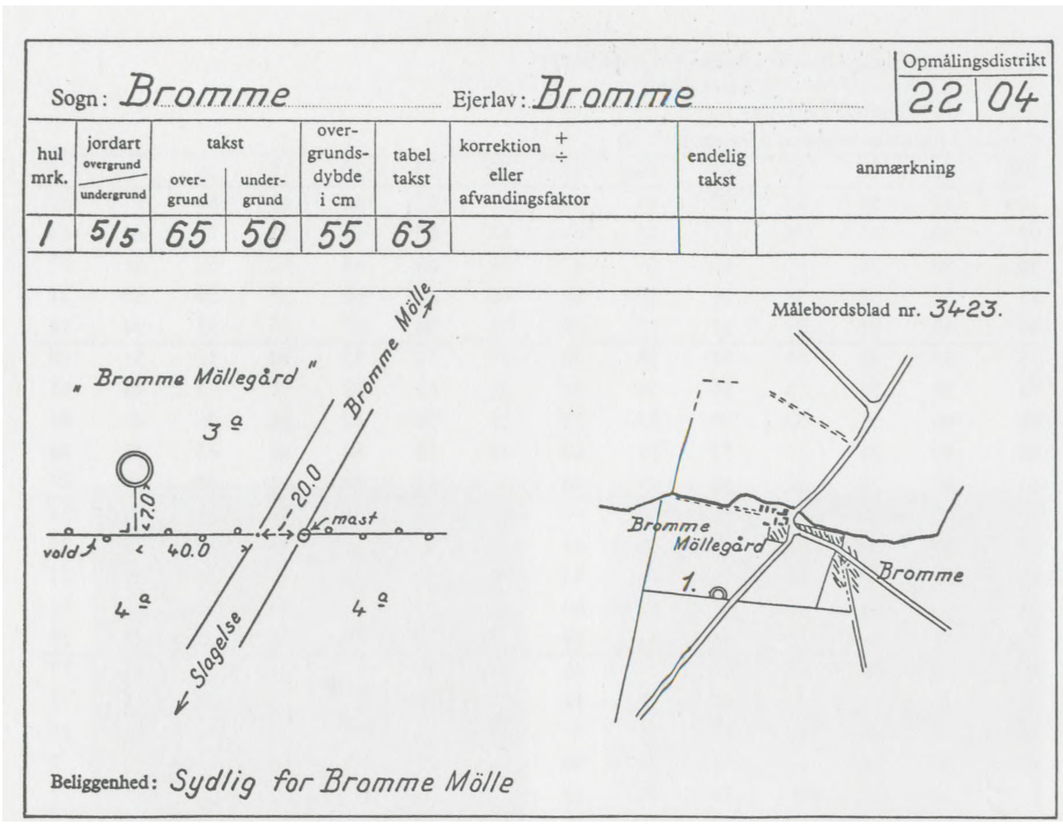



*Fig. 8: The 1949 Land Assessment Commission. Fieldwork sketch taken from the village of Bromme indicating the precise location of a soil sampling site. (Jordboniteringskommission 1970)*

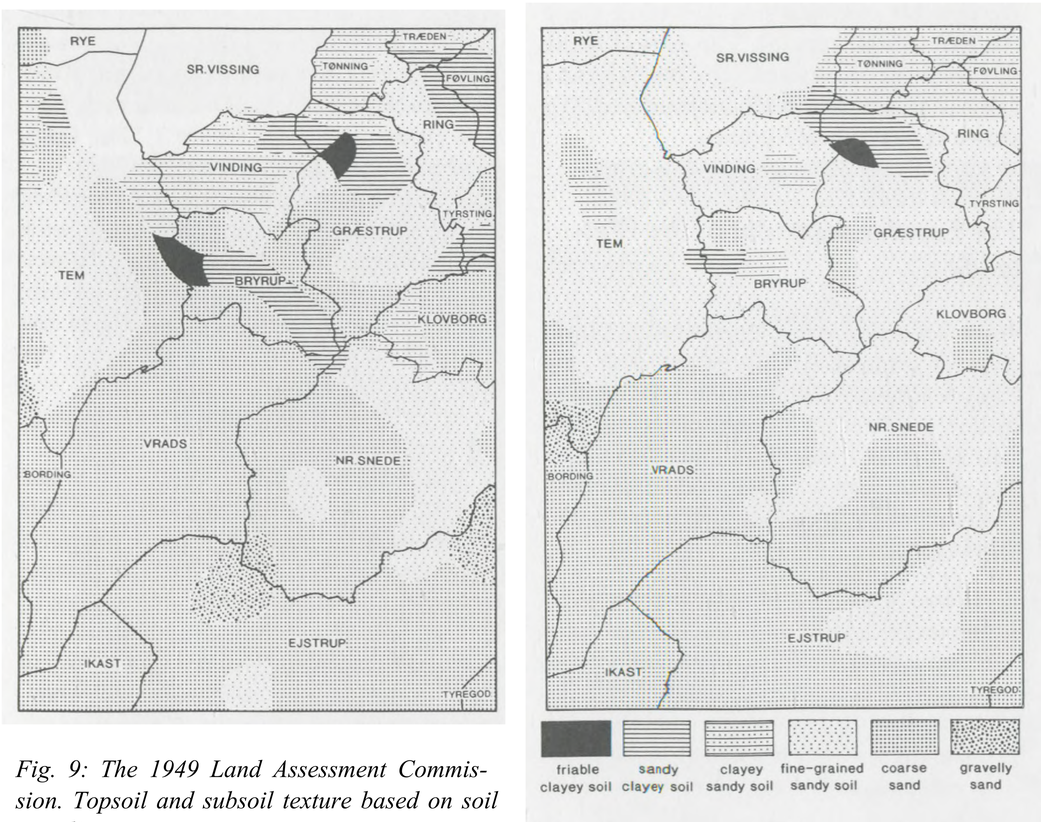



*Fig. 9: The 1949 Land Assessment Commission. Topsoil and subsoil texture based on soil sampling. (Jordboniteringskommission 1970)*

into one of the seven mineral soil classes. For the wetland soils, the drainage factors were the most important, but attention was also paid to colour, and the occurrence and density of worm channels and plant roots etc.

During the land assessment work in the field, the Commission's guideline prescribed the use of maps, either land register maps (scale 1:2,000), or aerial photographs, when registering and measuring the sample sites. The density of the sample sites was proposed to be one per 50 m, although larger distances could be used in the case of homogenous areas, such as outwash plains.

### *Fixing the Trial Land Assessment Values for Local Districts and Parishes*

Prior to forming the procedure and guidelines for the national land assessment, the Land Assessment Commission had already undertaken an enormous amount of preparatory work in the field. This consisted of fixing trial rates in certain parishes. The work was carried out by subcommittees comprising farmers and supervising assessors. The selection of sampling sites in the parishes was based on ordnance survey maps and chartered surveyors' maps showing the local real estate. On average, test rates were fixed for every 250-300 hectares of land. The sample sites for the fixing of rates were marked on the ordnance survey maps. At the same time, site sketches were made to show; precise locations, topsoil texture, subsoil texture, topsoil depth and land assessment values (Figure 8). The site sketch made it possible to relocate the sampling sites at a later date. In less than 10 years, the various subcommittees had undertaken approximately 25,000 sample site ratings across the whole land, with the exception of urban areas. All rates were registered in an easy system. The island of Bornholm presented special problems as the granite bedrock is often found at less than 60 cm from the surface.

The Commission's awareness that not all the rates would be representative of local variations led to the rating being modified according to local property values in certain areas. In the former county of Skanderborg in Jutland, there seemed to be a satisfactory correlation between the rates allotted and the variation in real estate values, whereas the reverse could be said of South Jutland county. General maps showing soil types were made for those areas where such comparisons were to be made (Figure 9). In spite of their limitations in assisting land assessment, the Commission regarded the soil descriptions as being important at a future date, perhaps in connection with national planning, land redistribution on former estates, or even geological mapping etc.

In 1970, the Land Assessment Commission concluded its work and delivered its final report, partly based on a preliminary report from 1962. However, the undertaking of a new, national land assessment based on their recommendations was considered as being too expensive at that time. Furthermore, the accomplishment of such a highly comprehensive work was judged to be too time-consuming. Finally, the agricultural sector was experiencing marketing problems, and its interest in being involved in such a large project had by that time diminished.

## A Short Account of Other Soil Mapping Activities in Denmark

### *Small Scale Mapping*

Bornebusch & Milthers (1935) published a national map at a scale of 1:500,000, that divided the country into the following ten geological areas; clay, diluvial sand, sand dune, saltmarsh, bogland, postglacial marine foreland, meadowland, late glacial marine foreland and bare rock formations. Furthermore, the degree of podzolisation in selected sandy localities was also indicated by four grades; very high, high, average and low.

In 1949, Schou produced a national map at a scale of 1:750,000 based on the National Ordnance Survey wall map (scale 1:250,000). The map shows the distribution of 20 landscape types, of which some are; clayey and sandy moraines from the Saale and Weichsel glaciations, outwash plains, tunnel valleys, eskers, former glacial lake beds, salt marshes, dunes, raised glacial sea beds, littorina and young marine forelands and bedrock outcrops.

In 1978, Per Smed developed on Schou's landscape map, producing a similar map at a scale of 1:360,000. The map also includes 20 landscape types, but the themes are not quite the same.

In connection with the 1:5,000,000 scale "World Soil Map" (FAO-Unesco 1974), Professor K. Rasmussen of the Royal Veterinary and Agricultural University in Copenhagen produced a Pedological Map of Denmark at the same scale. The FAO-Unesco classification system was adopted, which in 1974 included 26 main soil types, subdivided into 106 soil types. Based on this classification, the most common soils in Denmark are podzols and arenosols on well to moderately drained sandy parent materials, and fluvisols and cambisols on well to moderately drained loamy and clayey parent materials. In wetlands, soils such as fluvisols, gleysols and histosols develop.

The mapping consisted of a division of the country into a series of units, each of which possessed a characteristic combination of soil types. A mapping unit consists typically of a main soil type covering normally more than 50% of the total area. Associations cover 20-50% of the total area, and inclusions cover 0-20%. Furthermore, the dominant texture and slope features of each mapping unit are shown. Both are shown graded into 3 classes.

In 1985, a pedological map was produced for the European Community at a scale of 1:1,000,000 (Commission of the European Communities 1985). In principle, the map was based on the FAO-Unesco map of 1974. However, the number of soil types, texture classes and slope classes was increased. The Danish contribution, as with the FAO-Unesco mapwork, was made by Professor K. Rasmussen. The EC soil map was digitized in 1986 by the Bureau of Land Data in Vejle, in conjunction with the CORINE Project, which is currently concerned with the making of an environmental database for the Commission of the European Communities (Platou et al. 1989).

Finally, it should be mentioned that Jacobsen (1984) has also produced a Pedological Map of Denmark, based on the FAO-Unesco classification (see map 4). Furthermore, map 4 shows some typical soil profiles from different Danish regions.

## Map 4

Soil Map of Denmark According to the FAO-Unesco Legend

*1. Regosols(R).*
Dominant soil: Dystric Regosols(Rd) - 1b
Eutric Regosols (Re) - 1b
Inclusions: Dystric Histosols (Od) - a

*2. Fluvisols (J).*
Dominant soil: Eutric Fluvisols (Je) - 2/3a
Associations: Eutric Histosols (Oe) - a
Inclusions: Eutric Fluvisols (Je) - 1a

*3. Gleysol(G).*
Dominant soil: Eutric Gleysols (Ge) - 1a
Associations: Dystric Histosols (Od) - a
Dystric Fluvisols (Jd) - 1a
Inclusions: Eutric Fluvisols (Je) - 2a
Mollic Gleysols (Gm) -1a

*4. Histosol(O).*
Dystric Histosols (Od) - a (Blanket Histosols)
Eutric Histosols (Oe) - a (Basin Histosols)

*5. Valley soils.*
A geomorphic soil unit of Histosols with associations of Fluvisols and Gleysols.

*6. Podzols (P). Inland dunes*
Dominant soil: Orthic Podzols (Po) - 1a
Associations: Gleyic Podzols (Pg) - 1a
Humic Podzols (Ph) 1a
Inclusions: Dystric Histosols (Od) - a

7. Podzols (P). Outwash Plains
Dominant soil: Orthic Podzols (Po) - 1a
Inclusions: Dystric Histosols (Od) - a
Gleyic Podzols (Pg) -1a
Placic Podzols (Pp), sporadically

*8. Podzols (P). Old Moraine*
Dominant soil: Orthic Podzols (Po) - 1a
Associations: Orthic Acrisol (Ao) - 1a
Humic Podzols (Ph) - 1a
Inclusions: Gleyic Luvisols (Lg) - 2a
Gleyic Podzols (Pg) -1a
Dystric Histosols (Od) - a

9. *Podzols (P). Young Moraine*
Dominant soil: Orthic Podzols (Po) - 1b
Luvic Arenosols (Q1 )- 1a
Associations: Orthic Luvisols (Lo) - 2a
Albic Arenosols(Qa)- 1b
Inclusions: Gleyic Luvisols (Lg) - 2a
Dystric Histosols (Od) - a

*10. Arenosols (Q).*
Dominant soil: Cambic Arenosols (Qc) -1a
Associations: Dystric Cambisols (Bd) - 2b
Orthic Luvisols (Lo) - 2b
Orthic Podzols (Po) - 1b
Inclusions: Gleyic Cambisols (Bg) - 2a
Gleyic Luvisols (Lg) - 2a
Dystric Histosols (Od) - a

*11. Acrisols (A).*
*Dominant soil: Orthic Acrisols (Ao) - 1a*
*Associations: Dystric Cambisols (Bd) - 1a*
*Humic Cambisols (Bh) - 1a*
*Inclusions: Gleyic Acrisols (Ag) - 1a*
*Dystric Histosols (Od) - a*

*12. Luvisols(L).*
Dominant soil: Orthic Luvisols (Lo) - 2a
Associations: Eutric Cambisols (Be) - 2a
Inclusions: Orthic Podzols (Po) - 1a
Gleyic Luvisols (Lg) - 2a
Eutric Histosols (Oe) - a

*13. Cambisols (B).*
Dominant soil: Dystric Cambisols (Bd) - 3a
Associations: Gleyic Cambisols (Bg) - 3a
Eutric Histosols (Oe) - a

*14. Soils of the Yoldia Plateau.*
Dominant soil: Dystric Cambisols (Bd) - 1a
Associations: Eutric Gleysols (Ge) - 1a
Gleyic Cambisols (Bg) -1a

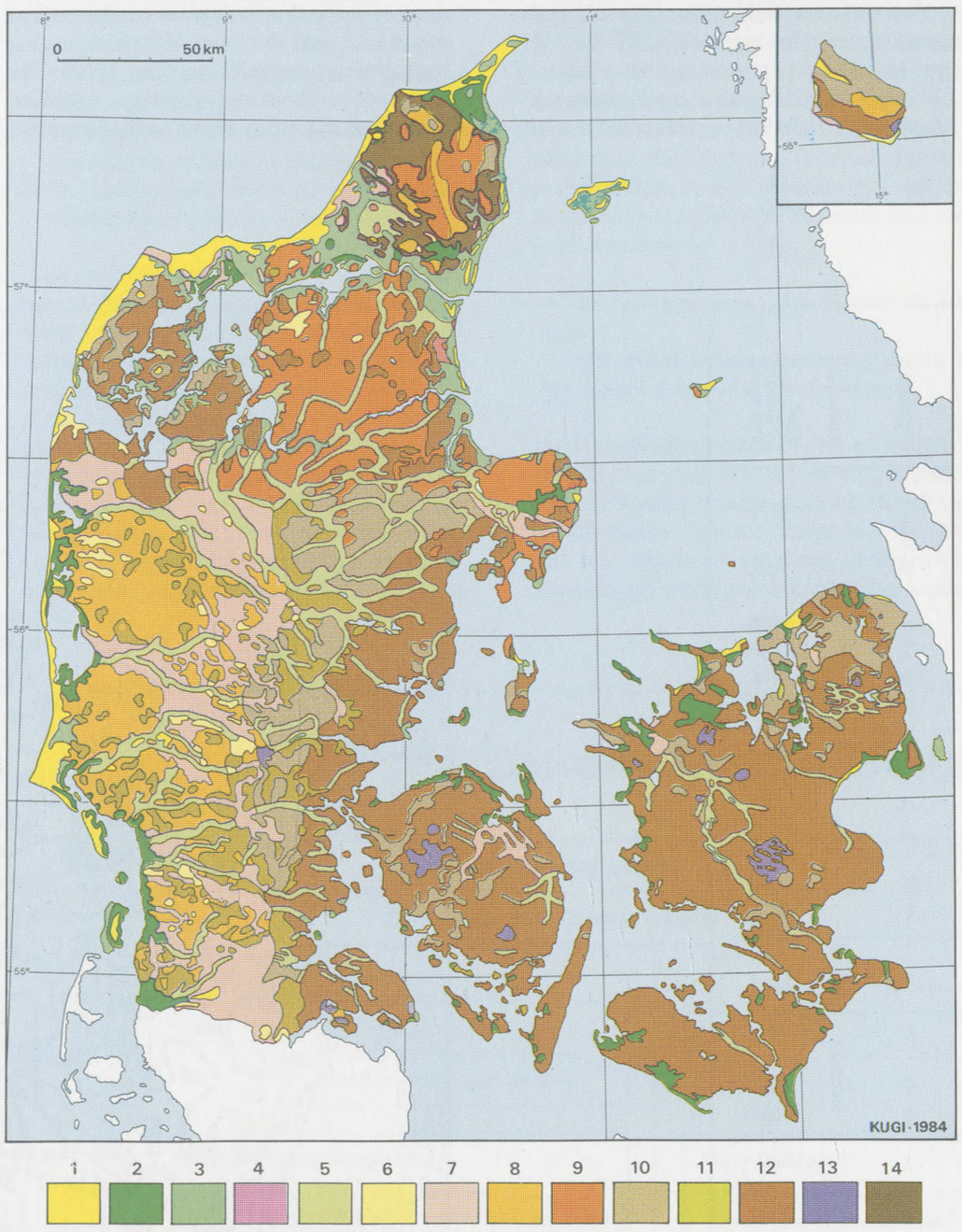
*Textural Classes.*
1. Coarse textured (<18% clay, >65% sand)
2. Medium textured (<35% clay, not class 1)
3. Fine textured (>35% clay)

*Slope classes.*
a. level to gently undulating (dominant slopes ranging between 0 and 8%)
b. rolling to hilly (dominant slopes ranging between 8 and 30%)
c. steeply dissected to mountainous (dominant slopes >30%)

*Associations:*
Covering between 20% and 50% of the area.

*Inclusions:*
Covering < 20% of the area.

SOIL MAP OF DENMARK ACCORDING TO THE FAO-UNESCO LEGEND



## *Mapping the Surface Geology of Denmark*

Mapping the surface geology of Denmark is the responsibility of the Danish Geological Survey (Danmarks Geologiske Undersøgelse, DGU). This important activity started in 1888, and at present, about 80% of the country has been mapped (DGU 1991). Figure 12 shows those parts of the country that were mapped before the middle of the 1970's, when the new Danish Soil Classification began (see Chapter 2). Later, the mapping of the Djursland region of eastern Jutland was carried out and completed in 1991. Special areas in western Jutland were also mapped during the 1980's, such as a large area in the neighbourhood of Ulfborg, as well as a number of smaller areas (DGU 1989).

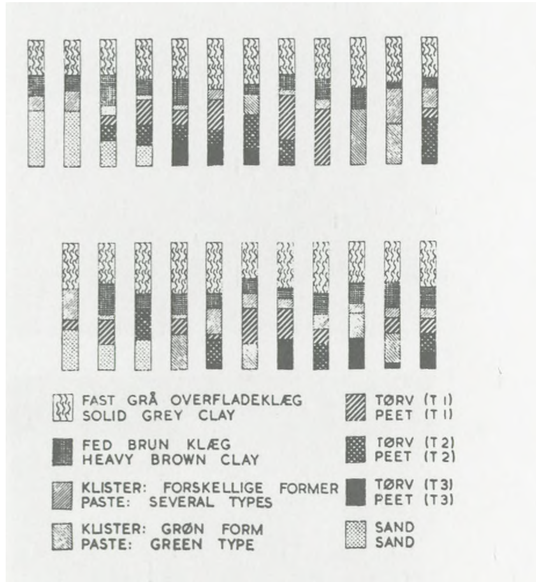
The surface geology mapping was based on borings made with a one-metre auger. Samples are taken at a depth of approximately 80 cm and classified directly in the field. The classification is based on texture, organic content, colour and landscape characteristics. Any abrupt change in the genesis of the soil material taken from the top metre is registered. The density of the borings across the landscape is approximately one sample per 200 metres. Table 5 shows the key to the present classification (DGU 1978). As the compilation work has stretched over more than 100 years, changes to the key have had to be made through time. Formerly, fewer soil types had been identified compared with the 30 types described in the classification today.

National Ordnance Survey maps (scale 1:20,000) were the main reference source for the field investigations. Fieldwork maps used to be only 1/9 size of the Ordnance Survey maps and had to be redrawn to meet the Ordnance Survey format. These former manuscripts, along with the field work records, represent DGU's original mapping material (DGU 1978). However, the subsequent introduction of maps at a scale of 1:25,000 during the 1970's was found to be ideal for fieldwork maps, and since then DGU mapwork has been at this scale.

The redrawn field maps provided the source material for the final "DGU First Series" published in mapsheets at a scale of 1:100,000. Half of the country has been published at this scale. Other parts of the country have been surveyed, but maps have not yet been published. The introduction of scale 1:50,000 has meant that DGU now produces coloured maps at this scale. These are published partly as "Series A" and partly as a map series. For example, the mapsheet 1215 IV VIBORG has been published as "Map Series No. 1, 1986". In 1989, on the basis of surface mapwork and bore data (geological basic data maps), DGU issued a four-part, national, surface geology map at a scale of 1:200,000 (DGU 1989). Figure 10 shows an example of a surface geology map at a scale of 1:25,000. The map shows the upland area of Gislum, near Aars, in North Jutland County.

## *Mapping the Tønder Saltmarsh, South Jutland County*

An example of a very fine, highly-detailed soil map of a local area is that of the coastal marshland near the town of Tønder, on the west coast of Jutland (Jacobsen 1964). The mapwork involved various intensive studies, in particular a study of the likely formation processes of the sedimentary layers forming the marshland. These sediments include peat, gyttja, marine sands and marine basin clay. The investigation involved a close network of borings, many of which reached deep down to the non-marine deposits, known as "the geest".



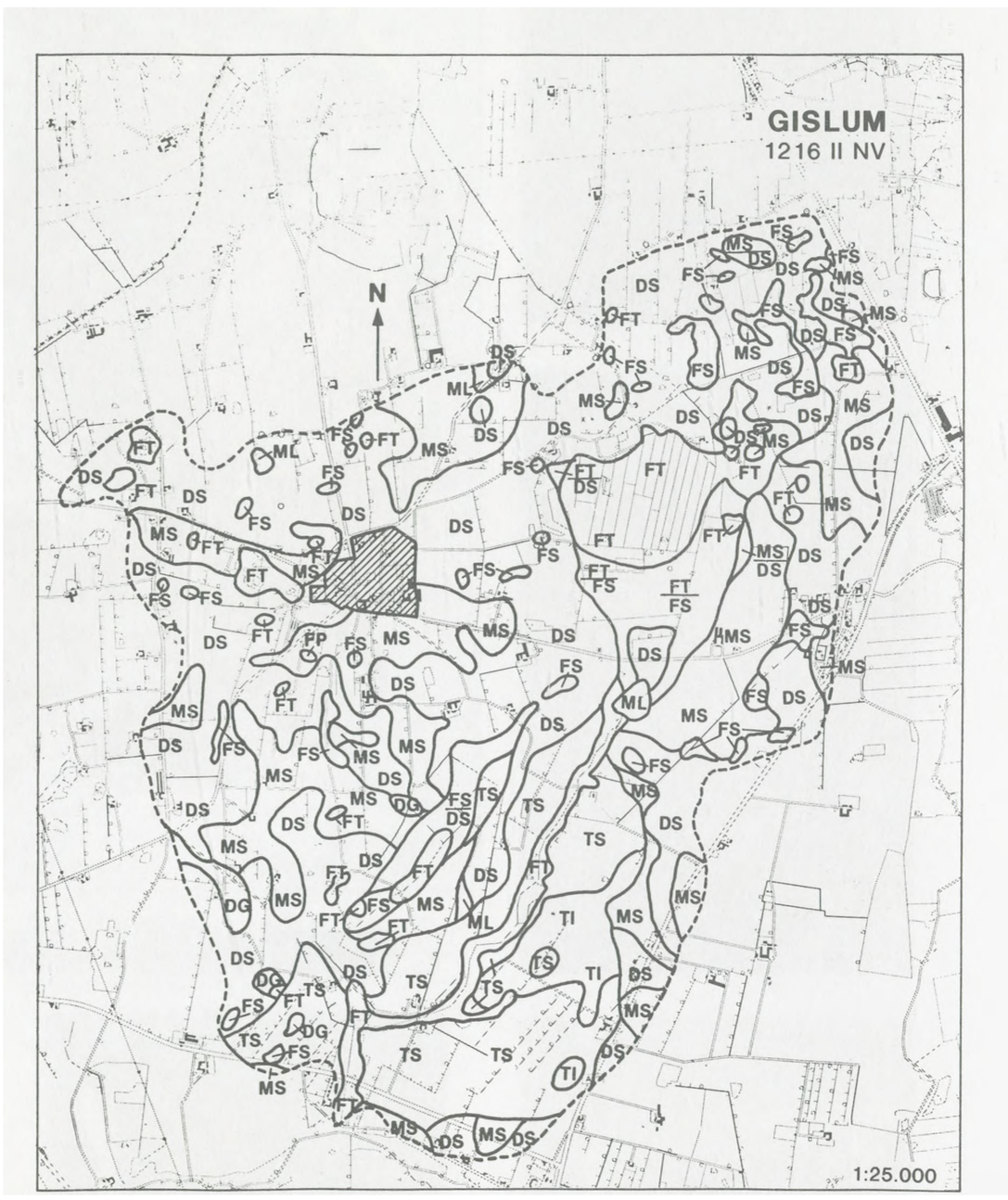




*Fig. 10: Denmarks Geological Survey. Example of a Soil Map (scale 1:25,000)*

| | Geological Survey of Denmark | | letters | symbols | colours | raw material symbols |
|---|---|---|---|---|---|---|
| post-glacial | *Quaternary deposits* | | | | | |
| | freshwater | - peat | FT | ⊥ | green | RTT |
| | | - mud/gyttja | FP | V | | |
| | | - clay | FL | ⩔ | | RLL |
| | | - silt | FI | | | |
| | | - sand | FS | ⩦ | | RSS |
| | | - gravel | FG | ⚲ | | RGG |
| | spring, bog and lake lime | | FK | ⨯ | | RTK |
| | ochre & bog iron | | FJ | ⚷ | | ROO/RYY |
| | salt water | - peat | HT | ℓ | blue | |
| | | - marsh | HV | L | | |
| | | - mud/gyttja | HP | ∧ | | |
| | | - clay | HL | ⩓ | | RLL |
| | | - silt | HI | | | |
| | | - sand | HS | ⩦ | | RSS |
| | | - gravel | HG | ⚲ | | RGG |
| late-glacial | wind-deposited | - clay/silt | EI | | yellow | |
| | | - sand | ES | ∽ ∽ | | RES |
| | freshwater | - clay | TL | ‖ | orange | RLL |
| | | - silt | TI | | | |
| | | - sand | TS | ⫞ | | RSS |
| | | - gravel | TG | ϕ | | RGG |
| | salt water | - clay | YL | Y | violet | RLL |
| | | - silt | YI | | | |
| | | - sand | YS | ·Y | | RSS |
| | | - gravel | YG | ⚳ | | RGG |
| glacial | ice lake | - clay | ZL | ⊟ | red-violet | RLL |
| | | - silt | ZI | | | |
| | | - sand | ZS | ⊟ | | RSS |
| | | - gravel | ZG | ⊟ | | RGG |
| | melt water | - clay | DL | = | red | RLL |
| | | - silt | DI | | | |
| | | - sand | DS | ∴ | | RSS |
| | | - gravel | DG | ∘ | | RGG |
| | till | - clay | ML | △ | brown | |
| | | - silt | MI | | | |
| | | - sand | MS | ⩘ | | RMS |
| | | - gravel | MG | ◊ | | RMG |
| | *Pre-quaternary deposits* | | | | | |
| | quartz sand | | KS | | | RKS |
| | quartz gravel | | KG | | | RKG |
| | micaceous sand | | GS | | | |
| | oligocene sand | | OL | | | |
| | eocene marl | | SL | | | |
| | eocene moler | | ED | | | REL |
| | eocene clay | | LL | | | RXL |
| | paleocene greensand | | PS | | | |
| | paleocene clay | | PL | | | |
| | paleocene lime | | PK | | | |
| | tertiary lignite | | GC | | | RBC |
| | Danian lime | | ZK | | | |
| | senon chalk | | SK | | | RSK |
| | lime, chalk | | K | | | |

Table 5. Classification system used by the Danish Geological Survey for mapping the surface geology of Denmark.

# CHAPTER 2

## The Danish Soil Classification

### Agricultural Soil A Limited Resource

From the end of the 1930's until the 1970's, more than 300,000 hectares of agricultural land were lost to other purposes. A certain amount of this land was converted to new forest plantations. Urbanization was increasing rapidly after the Second World War, and much agricultural land was lost to new housing and industrial estates, new recreational areas such as summer house districts, and the space required for the expansion of the road and motorway network.

In this way, agriculture lost an average of 5,400 hectares per annum between 1946-57, increasing to 13,300 hectares per annum between 1957-60. It was usually the best agricultural land that was lost to urban development. It was normal for such fertile land to be sacrificed to meet the needs of the rapidly expanding, more intensive, land-use forms.

The Regional Planning Act of 1973, and the Local Planning Act of 1975, heralded the start of physical and environmental planning in Denmark. By that time, it had become apparent that agricultural land had to be part of the overall planning process. The future exploitation of all physical and natural resources would have to relate to the needs of Danish society as a whole. In 1975, local and regional planning legislation insisted on the collection of comprehensive information on the extent and distribution of agricultural land and its value.

As a consequence of this development, a few soil maps were made at regional and local level in the first half of the 1970's. One of the first local soil maps covered the district of Grenå in Jutland (Andersen 1974). The land assessment was undertaken by a private planning company in conjunction with local agronomists. The following criteria were examined:

1. The slope characteristics of the land.
2. The soil water content and drainage conditions.
3. The soil texture of the plough layer.

Furthermore comprehensive soil maps were made of the Baltic island of Bornholm and the county of North Jutland (Mathiesen 1974 & 1975). The mapping methods used provided the basis for the later Danish Soil Classification. The aim of the two projects was to map stable soil parameters to aid future physical planning. The analysis involved mapping the open countryside and recording the following characteristics:

1 Topography (especially the slope characteristics)
2 Surface geology (to a depth of one metre)
3 Natural drainage
4 Plough layer texture

Slope analysis was based on topographical maps. The soil sampling involved the collection of samples from the topsoil for texture analysis in the laboratory. The samples were classified according to the humus content and four grain sizes; coarse sand, fine sand, silt and clay.

### The Basis of the Danish Soil Classification

The two above-mentioned, soil classifications at county level uncovered the need for a national soil classification. The idea of making the Danish Soil Classification was conceived in 1974 by the Danish Ministry of Agriculture, which appointed a commission, consisting of 8 members, whose function it was to establish the classification procedure.

The commission consisted of experts who belonged to soil research centres, universities and agricultural organizations. The commission was called upon to determine the procedure for the practical undertaking of the soil classification in accordance with 5 basic requirements:

1. The areas should be classified on the basis of permanent or stable characteristics.
2. There should be a national standard code of reference that would make it possible to classify as uniformly as possible.
3. The results should clearly illustrate the range of fertile and infertile soils.
4. The results should be mapped in such a way that they might be used in future planning at all levels.
5. The classification should be completed within a reasonable time limit (maximum 3 years).

The majority of experts believed that it was best to begin with a classification focusing on a few important soil factors such as; topsoil texture, slope and drainage conditions. Essentially, the work would make use of existing data, supported by texture analysis of the plough layer. In order to benefit from local knowledge on soil conditions, local plant-breeders from agricultural organizations would be consulted. These consultants would be able to advise on the best sites to carry out soil sampling to a depth of 50 cm. The results of the analysis would then form the basis of the Danish Soil Classification.

In December 1975, the Department of Soil Classification (Sekretariat for Jordbundsklassificering, SfJ), was set up in the town of Vejle, in Jutland. It functioned under the Ministry of Agriculture. In 1980, its name was altered to the Bureau of Land Data (Arealdatakontoret), and today it is known as the Department of Land Data (Afdeling for Arealdata og Kortlægning - ADK). Its task was to organize and undertake the work of the Danish Soil Classification. In the same month, work on the Danish Soil Classification began at national level. Prior to this date, the counties of Bornholm and North Jutland had already been classified, and they were initially excluded from further classification. A Data Bank was established at ADK comprising two main departments:

- A Soil Map Department producing the basic data maps.
- A Geographical Database Department storing all the collected data, such as texture analyses.

The classification work led to the collection of entirely new data, stemming in particular from the texture analysis of some 36,000 soil samples taken from the plough layer or subsoil. In addition, the steepness of slopes was determined from topographical maps. Drainage conditions were examined and recorded. Finally, existing surface geology maps by Denmark's Geological Survey, (Danmarks Geologiske Undersøgelse - DGU), were revised in order to meet the requirements of the Danish Soil Classification.

Figure 11 gives a list of the many institutions, organizations and authorities that contributed to the establishment of the Danish Soil Classification. It was financed by the government, apart from county council subsidies which were granted in connection with the basic data mapwork.

The following section describes the methods and procedures of the Danish Soil Classification.

### The Primary Data Collection

The major part of the work at national level was carried out between 1975 and 1980. The resulting maps show the main characteristics of the plough layer; soil texture, organic matter content, and calcium carbonate content. Furthermore, information on slope and drainage conditions, derived from existing topographic maps, is presented in the soil map series, along with details on the surface geology obtained from the DGU soil map at a scale of 1:20,000.

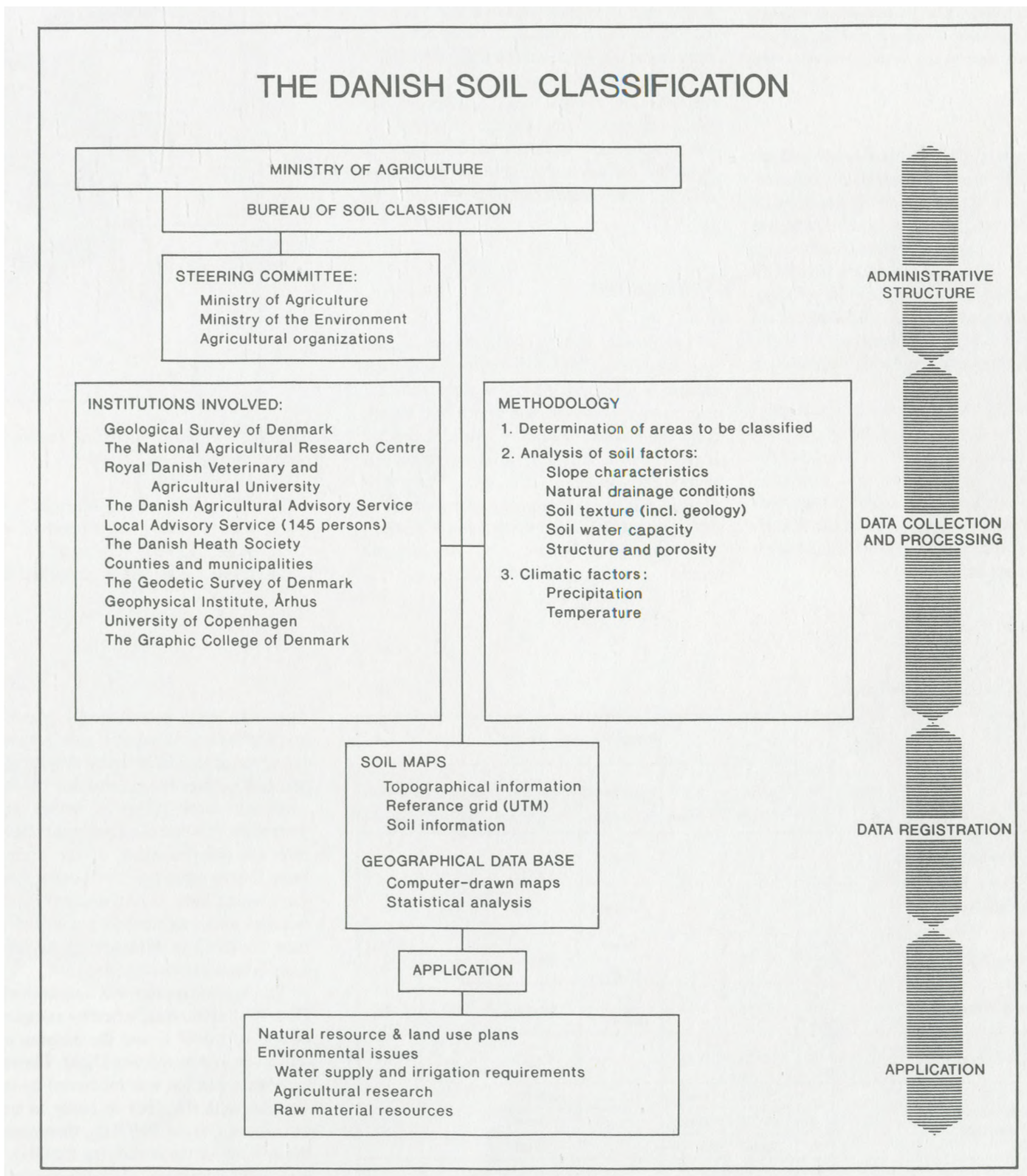



*Fig. 11: Institutions, organizations and authorities which have contributed to the making of the Danish Soil Classification.*

## *Defining the Area to be Classified*

At the start of the classification, it was necessary to divide the country into two broad categories; an area to be classified, and an area that would remain unclassified. These areas are indicated on Map 5.

Generally speaking, the area to be classified comprised the open countryside, representing an area slightly larger than that under agricultural land-use. By contrast, the area to remain unclassified comprised land-use types such as; urban zones, industrial estates, woodland and open water. These areas may be more fully defined as follows:

- Urban areas or summer house areas as defined by the Act of Parliament no. 494 of 19th September 1975, by which the land was divided into urban, summer house and open countryside areas.
- Marginal zones bordering on to urban or summer house areas. These included; housing areas with gardens, transport and communication networks, cemeteries and military areas.
- Large building complexes, industrial plants and factories, fish-farms, open-cast lignite mines and airports.
- Natural woodland and plantations.
- Sand-dune formations, as are typical of the west coast of Jutland.
- All open water surfaces.
- Isolated pockets of agricultural land too small for the practical purposes of classification. These pockets were normally completely surrounded by unclassifiable land and possessed at least one of the following characteristics:

1. They were less than 5 hectares in size.
2. They lay more than 500 metres from the nearest classifiable land and measured between 5 and 25 hectares.
3. They were completely surrounded by water and measuredbetween 5 and 25 hectares.
4. Their boundary with classifiable land was less than 100 metres in length and they measured between 5 and 25 hectares. These pockets of land were typically; woodland clearings, glades, islets, and marginal zones close to open water surfaces or water courses.

The demarcation of the classifiable and the unclassifiable areas was based on information available at the time. Information on urban zones and summer house areas was obtained from county administration maps dating from 1976. The remaining unclassifiable areas were determined by use of topographical maps, at a scale of 1:25,000, except for southern Zealand, Lolland and Falster, where atlas sheets at a scale of 1:40,000 were used.

As a rule, the area to be classified incorporated not only farmland and heathland, but also small rural settlements. At the end of the classification, the classified area measured 34,519 km², while the unclassified area measured 8,479 km². More details on the characteristics of the classified and unclassified areas are given in Table 7.

## *Sampling*

During the period 1975-79, soil samples were examined from approximately 32,000 sites distributed across the whole country, with the exception of Bornholm and North Jutland which had been mapped earlier in 1974-75 using very similar methods (Mathiesen 1974 & 1975). However, during the first half of the 1980s, these two counties were remapped according to the procedure used in the Danish Soil Classification.

At each site (see page 19), soil samples were taken from the plough layer at a depth of 0-20 cm. At selected sites, soil samples were also taken immediately below the plough layer at a depth of 35-55 cm. Exceptionally, soil samples were taken at a depth of 20-40 cm. The frequency of sampling from the plough layer was one sample per 70-90 hectares, compared to one sample per 600 hectares for deep sampling. However, the frequency of sampling was somewhat higher for the counties of Bornholm and North Jutland because of the remapping.

The sampling was carried out by ADK in conjunction with local agronomists. The following procedure was used:

- ADK distributed maps and questionnaires to local agronomists who registered the results of existing texture analyses and other information based on their own previous research.
- The agronomists were encouraged to come forward with their own written recommendations of the most suitable locations for the forthcoming soil sampling.
- ADK then worked on these proposals, at the same time paying attention to other details such as the geological and topographic characteristics of the different local areas. Then the new sampling sites were selected. Local agronomists undertook the sampling activities.

Where possible, each soil sampling site was restricted to a surface area of about 5000m². A 15 mm auger was used. From each site, approximately 25-30 soil samples were taken at evenly spaced intervals in order to produce a satisfactory sample mix. Each sample mix had a volume of some 450 cm. After analysis, the samples were stored in the Soil Archives at ADK, which today contain more than 40,000 preserved soil samples.

## *Soil Analysis*

Texture was determined by the sieving and hydrometric method. After being dried, each sample was passed through a sieve with a 2 mm mesh to separate the gravel and stones from the sand, silt and clay. The hydrometer method was used to determine the texture of grains sizes under 2 µ and 20 µ, while wet-sieving was used on grains larger than 63 µ, 200 µ and 2000 µ. Samples which contained > 10% calcium carbonate, or > 10% organic matter, were not analyzed to determine texture, but were automatically classified as atypical soils and organic soils respectively. However, it should be noted that for all other samples neither the humus nor the calcium carbonate were removed before analysis. Therefore, it is open to debate as to how accurate the determination of the texture has been. On the other hand, removing these contents would have caused many technical difficulties and was therefore opposed due to time limits (The Ministry of Agriculture - Landbrugsministeriet 1976).

The organic matter was determined by an IR-LECO apparatus, whereby samples were heated to 1,600° C and the amount of $CO_2$ was measured by infra-red light. The calcium carbonate content was measured by treating samples with 4N HCl in order to trap the amount of $CO_2$ in $Ba(OH)_2$, then measuring the amount of the remaining $Ba(OH)_2$ by dilute acid titration (Landbrugsministeriet 1976).

After analysis, the topsoil and subsoil samples were classified into 12 soil types, coded JB1 to JB12, as defined in Table 6. On the soil map, these 12 soil types were reduced to the 8 soil classes, named the Map Colour Code 1 to 8. For convenience, throughout this text, these 8 classes will be abbreviated to MCC1, MCC2, MCC3 etc.

The conversion of the JB code to the MCC code may be interpreted as follows: JB1 to JB10, being the equivalent of MCC1 to MCC6, are soils containing less than 10% organic matter or calcium carbonate. The division within MCC1 to MCC6 is then based on the amount of clay, silt and fine sand in the sample. The organic soils, JB11 = MCC 7, have an organic content greater than 10%, irrespective of the calcium carbonate content, while atypical soils, JB12 = MCC8, contain more than 10% calcium carbonate and less than 10% organic matter. Finally, some gyttja soils containing less than 10% calcium carbonate have also been classified and mapped as atypical soils.

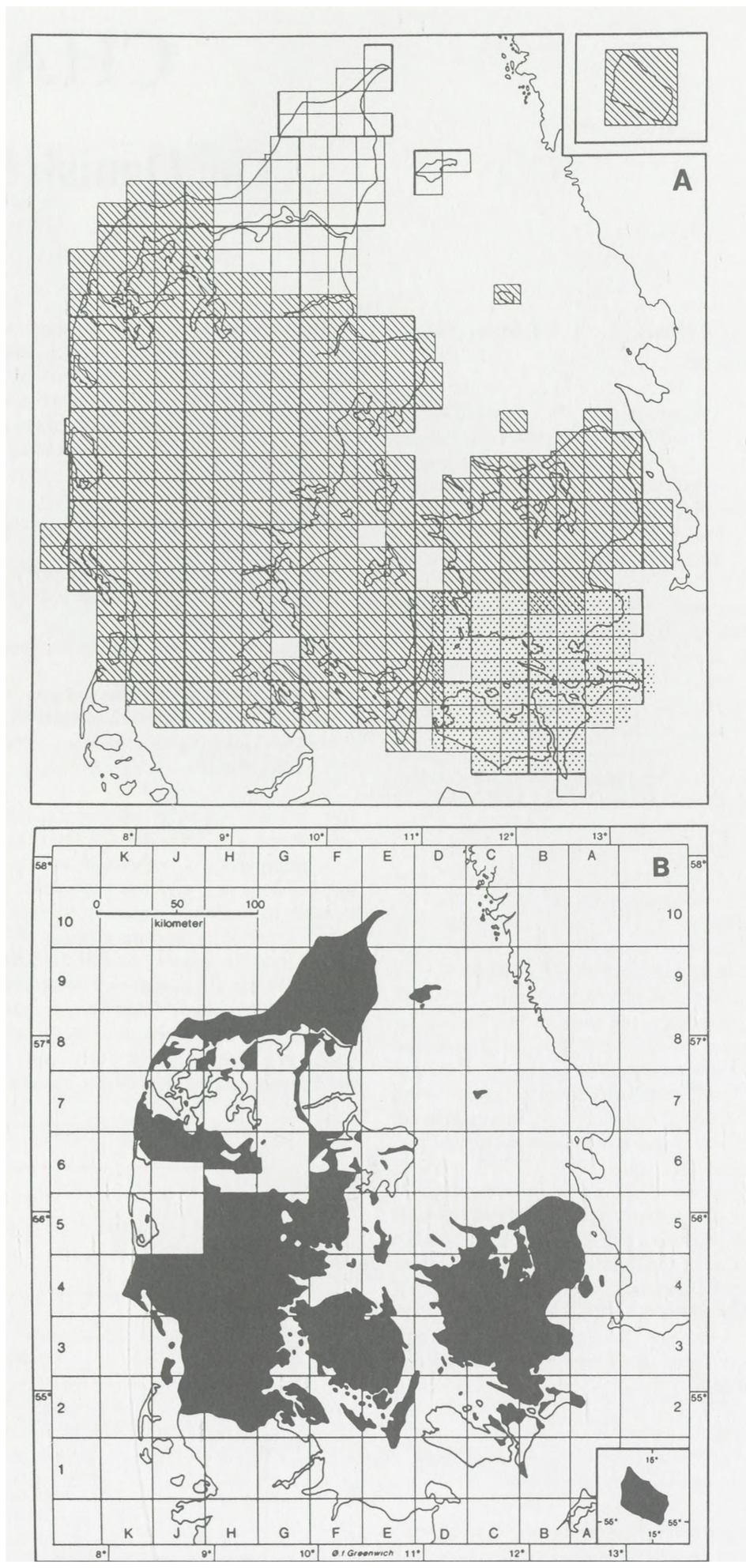


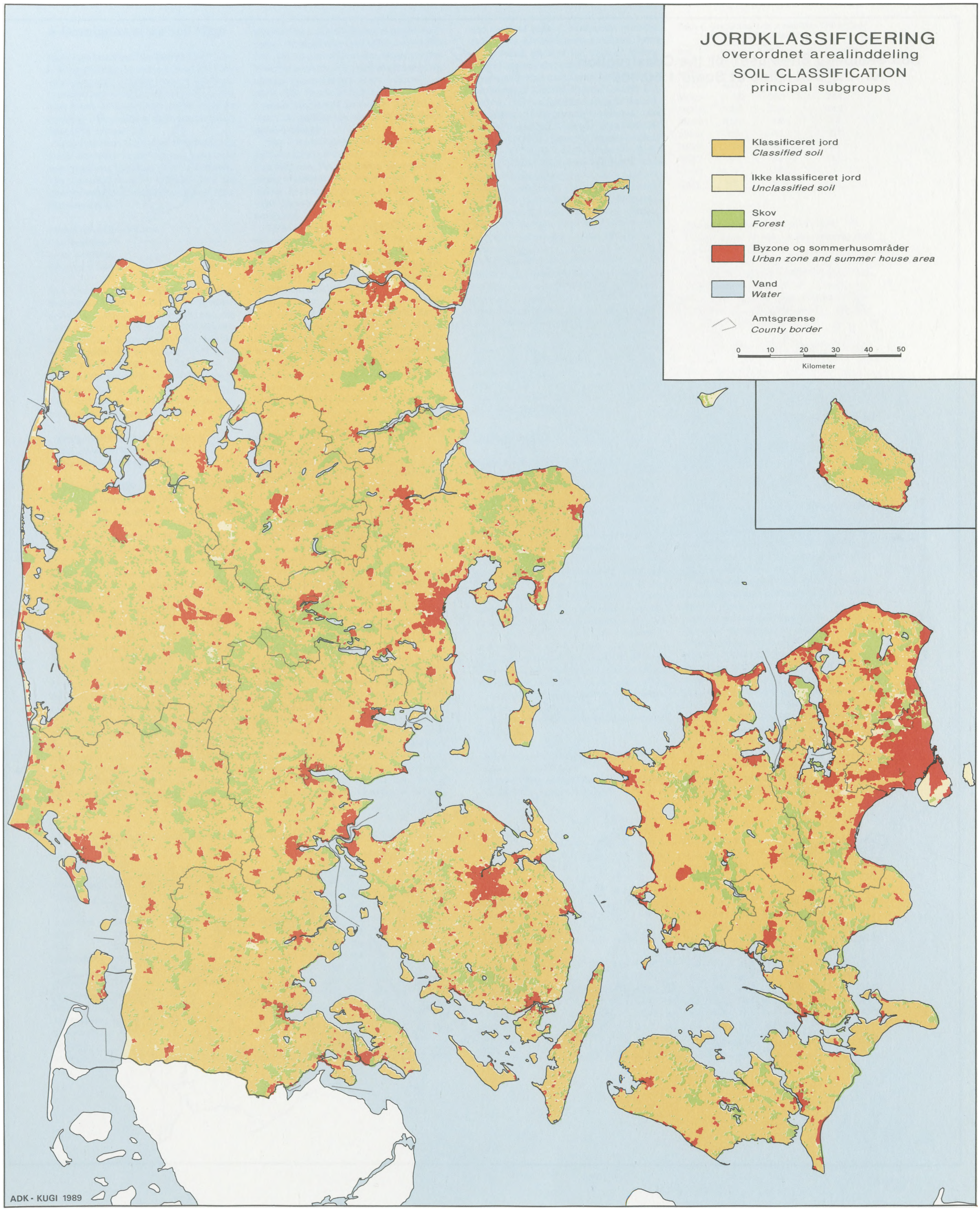

*Fig. 12: Soil maps published and areas with information on surface geology.*
*A: Soil maps published*
*hatching: full colour maps published at scale 1:50,000 on topographic maps at scale 1:25,000 (4CM map),*
*dots: full colour maps published at scale 1:50,000 on topographic maps at scale 1:40,000 (Atlas sheets)*
*white: only computerprint available.*
*B: Surface geology*
*black: Areas mapped prior to 1975 by Denmark's Geological Survey to show the surface geology*

Table 6. The Danish Soil Classification.

| Colour Code | Soil type | JB-nr. | Percentage by weight: Clay < 2 µm | Silt 2-20 µm | Fine Sand 20-200 µm | Total Sand 20-2000 µm | Org.Mat. 58.7 % C | Lime $CaCO_3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Coarse Sandy Soil. | 1 | 0-5 | 0-20 | 0-50 | 75-100 | ≤ 10 | ≤ 10 |
| 2 | Fine Sandy Soil. | 2 | | | 50-100 | | | |
| 3 | Clayey Sandy Soil. | 3 | 5-10 | 0-25 | 0-40 | 65-95 | | |
| | | 4 | | | 40-95 | | | |
| 4 | Sandy Clayey Soil. | 5 | 10-15 | 0-30 | 0-40 | 55-90 | | |
| | | 6 | | | 40-90 | | | |
| 5 | Clayey Soil. | 7 | 15-25 | 0-35 | | 40-85 | | |
| 6 | Heavy Clayey Soil or Silty Soil. | 8 | 25-45 | 0-45 | | 10-75 | | |
| | | 9 | 45-100 | 0-50 | | 0-55 | | |
| | | 10 | 0-50 | 20-100 | | 0-80 | | |
| 7 | Organic Soil. | 11 | | | | | > 10 | 0-90 |
| 8 | Calcareous Soil and atypic Soil. | 12 | | | | | ≤ 10 | > 10 |

KORT 5

MAP 5


JORDKLASSIFICERING
overordnet arealinddeling
SOIL CLASSIFICATION
principal subgroups
Klassificeret jord
Classified soil
Ikke klassificeret jord
Unclassified soil
Skov
Forest
Byzone og sommerhusområder
Urban zone and summer house area
Vand
Water
Amtsgrænse
County border
0 10 20 30 40 50
Kilometer
ADK - KUGI 1989

# The Danish Soil Classification.

## A Description of the Soil Maps

One of the benefits of the Danish Soil Classification has been the production of 320 basic data maps, scale 1:50,000 (Nørr 1980). These coloured maps cover the whole country, apart from North Jutland county whose maps are currently only available as computer prints from ADK (Figure 12).

The basic data maps show the country divided into three broad land-use categories; open countryside, urban areas, woodlands. The soils of the classified area have been categorized according to the following four main characteristics:

- topsoil (plough layer) texture
- surface geology
- slope conditions
- drainage conditions

The texture of the plough layer has been mapped according to the 8 MCC soil classes defined in Table 6. Sampling sites are indicated by either black dots, where samples were restricted to the plough layer, or black squares, where further samples were taken from the depth section 35-55 cm.

Using the experience of operating agricultural machinery in fields, three slope classes, based on gradient, have been mapped. They are indicated on the maps as follows:

- Slope gradient > 12° (double hatching)
- Slope gradient 6-12° (single hatching)
- Slope gradient < 6° (no symbol)

The three slope classes were determined by an analysis of topographical maps at scales of 1:25,000 and 1:40,000. The methodology used is described in detail in Chapter 3.

The surface geology at a depth of 1 metre is also indicated on the soil maps. A 500 m grid has been superimposed on the map, as a black outline, and the surface geology of each 25 hectare square is indicated in the upper right-hand comer. At the time of mapping, such information was only available for approximately 75% of the country, as shown in Fig. 12. The methods used by DGU to map the surface geology at a depth of one metre are described in detail in Chapter 1.

Map 6 shows four examples of soil maps from the Danish Soil Classification (basic data maps). These maps show selected parts of the country. The most westerly of these maps shows the soils of the Ribe area in western Jutland, which is an area of saltmarsh and outwash plains. Another map, showing central Jutland, indicates the soils found just to the west of the Main Terminal Moraine. It includes the Kongeå valley, with its narrow flood plain and former outwash plains, surrounded by a slightly higher moraine landscape. The third map is of south-eastern Jutland, showing the soils of the younger, clayey Weichsel moraine landscape and those of the outwash plains just west of the terminal moraine. The fourth and final map is from Zealand, just west of the town of Roskilde. It shows the soils of the clayey Weichsel moraine landscape.

Map 7 is a soil map of North Jutland. The different map colour codes are shown for the classified area. The unclassified area of urban areas, woodlands and open water is also shown. In contrast to the basic data maps, slope gradients and the surface geology are not shown.

Table 7 shows the soil class distribution for the entire country, as well as for the different counties. The classified area covers 3.45 million hectares, equal to about 80% of the country. Of this amount, 2.8 million hectares are classified as agricultural land.

The mineral soils can be broadly divided into three categories; coarse sands, clayey sands and sandy clays. In the classified area, each category represents about 25% of the total area. The remainder is divided between; fine sands 10%, clays 6%, heavy clays 1%, calcareous soils (atypical soils) 1%, whilst organic soils make up 7%.

Map 8 is a national soil map. It is general compared to maps at a scale of 1:50,000. Woodland and small urban areas have been classified according to the MCC so that only large provincial towns and the capital city remain as part of the unclassified area. Town boundaries are generalized so that small areas of open land or woodland might have been incorporated into the urban zones. Marginal areas, such as the isolated pockets of otherwise classifiable soil under 25 hectares or small strips of organic soils (MCC7) by streams not exceeding 500 metres in width, are not indicated.

Table 8 shows statistics taken from the general national soil map. The classified area has been greatly extended compared to that defined in Table 7 due to the classification of the forest area and minor urban zones. Hence the area of the different MCC groups has increased for all classes, apart from MCC7.

The classification of woodland soils and the soils of small urban areas was carried out on the basis of soil analyses made by the Forest Registry Project (Svendsen & Pedini 1987) and information on Quaternary geology (Bornebusch & Milthers 1935). As the frequency of sampling was normally much lower for woodland areas, the boundaries of these areas must be regarded with greater uncertainty than those of the open countryside.

The sandiest soils (MCCl and MCC2) have their greatest concentration in the west and north of Jutland. Fine sands predominate in the northern part of Jutland, being rarely found south of the town of Viborg. Soils of a greater clay content, the loamy soils, are generally found in eastern Jutland and on the islands of Zealand, Funen, Lolland, Falster etc. Heavy clays often occur in the saltmarsh areas. In the moraine landscapes, there is a predominance of sandy clays (MCC4), while clays (MCC5) are only found as isolated pockets within these areas. Generally, clayey sands (MCC3) and organic soils (MCC7) are evenly distributed throughout the country. It should be noted that a fair amount of clayey sands are found in narrow belts, stretching for many kilometres across parts of the country. These are the relic river beds of meltwater drainage systems that functioned at the end of the last glaciation. These are very distinct surface features in the central part of Zealand, where many former meltwater drainage systems converge near the town of Sorø, while on the island of Funen, two different directions, almost at right-angles, may be detected. However, the fertility of these clayey sands differs markedly from place to place, and depends greatly on the subsoil texture. Calcareous soils or gyttja soils (MCC8) are only found in a few places, mainly in areas of dried-out fjords and lakes, or else where the underlying limestone bedrock lies very close to the surface, as south of Aalborg.

## Data storage

Since the aim of the current Danish Soil Classification is to improve the knowledge of the Danish soils and establish a better basis for planning at all levels, it is of vital importance to be able to combine the soil maps with other maps, as well as data for which grid references have been recorded with the aim of constructing thematic maps. Thematic maps give highly detailed visual accounts of important current issues such as irrigation needs, soil erodibility or drainage requirements. A vector-based, geographical information system has therefore been developed and expanded. Geographical information has been digitized based on the UTM grid reference system in order to realize and faciliate the production of computer-drawn soil maps at different scales based on different combinations of parameters (Platou 1984, Nørr & Platou 1984).

In principle, soil data can be divided into two main types; parametric and linear.

Parametric data may be divided into four main types:

- Information on texture and organic matter from the Danish Soil Classification.
- Detailed profile descriptions, including analytical data from pedological investigations.
- Pedological soil classifications in the field.
- Detailed profile descriptions from augerings that include analytical data.

Linear data are stored at five databases. Four of the databases function at national level, whilst the fifth concentrates on the peninsula of Jutland. The databases contain information on the following:

- The soil boundary lines of the Danish Soil Classification.
- The landscape boundary lines delineated on topographic maps.
- The boundary lines separating clayey and sandy subsoils.
- The boundary lines separating wetlands from other areas.
- The boundary lines separating different classes of potential acidity.

Some of these databases are described in Chapter 3.

The data of the Danish Soil Classification were soon put to use in regional planning as the computerized information was easily accessible. Furthermore, the protection of good farmland had become an integral part of the planning of the open countryside.

The first data to be used were supplied to the county planning departments of Århus and Storstrøm. The data had been converted into computer-drawn maps, scale 1:100,000, showing soil sampling sites and texture. Since 1978, soil maps have been used by planners to protect farmland from urban expansion. They have also been used in irrigation planning, the siting of waste deposits, nature conservation, the identification of areas exposed to wind erosion, and the monitoring of nitrate leaching on farmland etc. (Mathiesen 1978, Landbrugsministeriet 1977, Kierkegaard et al. 1979, Landbrugsministeriet 1982, Miljøstyrelsen 1983).

Examples of the further application of the database in regional planning and for scientific purposes is given in Chapter 4.

Table 8. The Surface area of each Map Colour Code on the Simplified Soil Map.

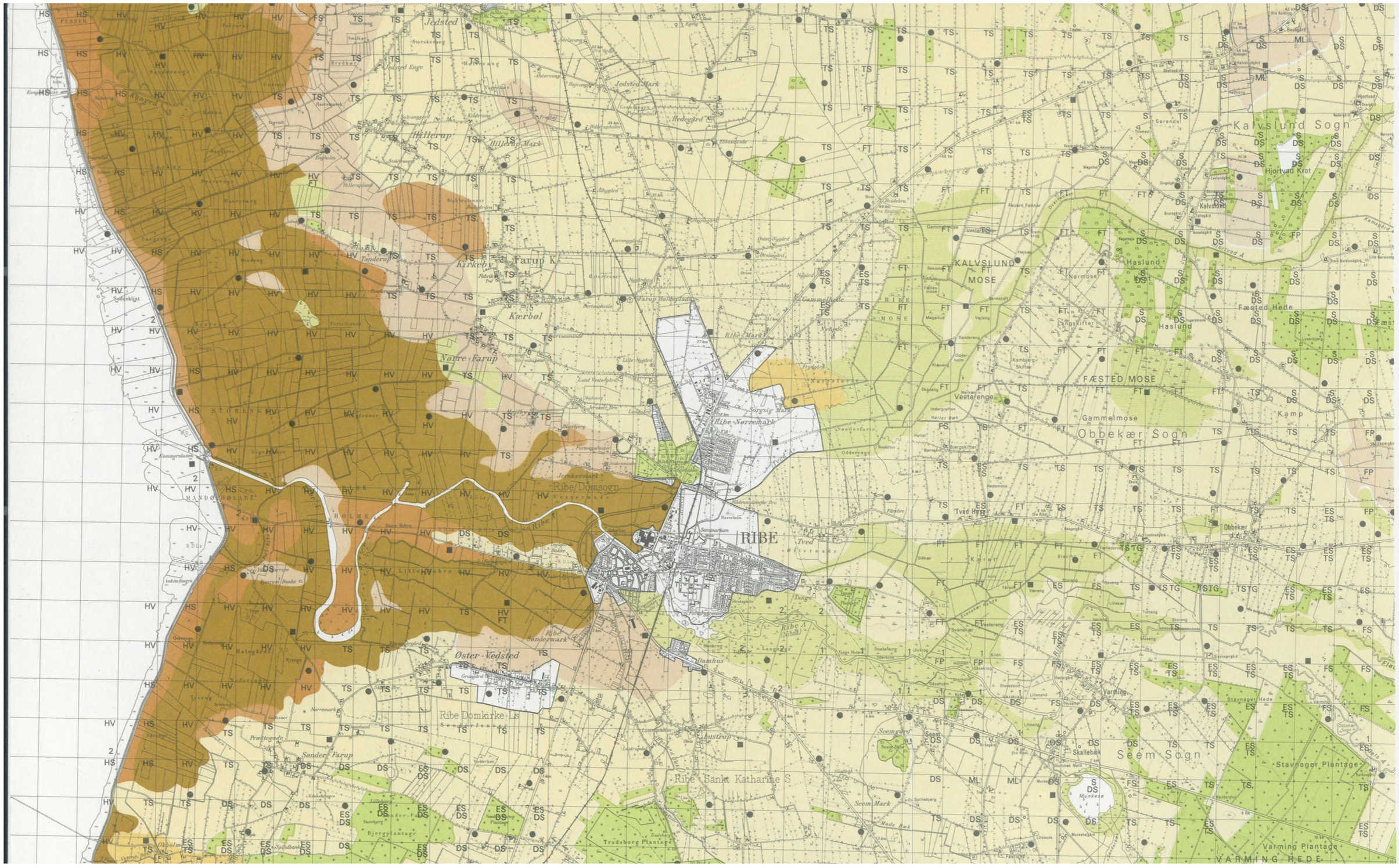
| Soil Class | Area in km² | % of Total Area | % of Classified Area |
|---|---|---|---|
| MCCl | 10,548 | 24.5 | 25.7 |
| MCC2 | 4,233 | 9.8 | 10.3 |
| MCC3 | 11,522 | 26.8 | 28.1 |
| MCC4 | 9,838 | 22.9 | 24.0 |
| MCC5 | 2,389 | 5.6 | 5.8 |
| MCC6 | 303 | 0.7 | 0.7 |
| *MCC7* | 2,091 | 4.9 | 5.1 |
| MCC8 | 86 | 0.2 | 0.2 |
| Towns | 1,703 | 4.0 | - |
| Lakes | 291 | 0.7 | - |

Table 7. The Danish Soil Classification. National and County Statistics for the Classified and Unclassified Areas. Surface area (km²).

| Country | Total Surface | MCCl | MCC2 | MCC3 | MCC4 | MCC5 | MCC6 | MCC7 | MCC8 | Classified Area | Wood | Urban Areas | Fresh Waters | Other Areas | Unclassified Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Jutland | 6,162 | 730 | 2,291 | 1,351 | 125 | 51 | 12 | 590 | 14 | 5,164 | 567 | 365 | 23 | 43 | 998 |
| Viborg | 4,134 | 915 | 442 | 1,277 | 485 | 84 | 12 | 218 | 9 | 3,442 | 426 | 116 | 77 | 72 | 691 |
| Århus | 4,561 | 601 | 137 | 1,534 | 812 | 83 | 22 | 262 | 23 | 3,473 | 649 | 297 | 64 | 78 | 1,088 |
| Ringkjøbing | 4,856 | 2,375 | 304 | 720 | 227 | 40 | 31 | 300 | 0 | 3,997 | 538 | 175 | 27 | 119 | 859 |
| Vejle | 2,997 | 612 | 0 | 697 | 756 | 231 | 3 | 90 | 0 | 2,389 | 379 | 168 | 23 | 39 | 609 |
| Ribe | 3,123 | 1,404 | 61 | 818 | 45 | 10 | 71 | 216 | 0 | 2,625 | 316 | 140 | 7 | 35 | 498 |
| South Jutland | 3,856 | 1,369 | 13 | 657 | 811 | 147 | 88 | 276 | 3 | 3,364 | 294 | 128 | 14 | 56 | 492 |
| Funen | 3,485 | 63 | 47 | 985 | 1,530 | 92 | 11 | 104 | 3 | 2,834 | 317 | 236 | 13 | 85 | 651 |
| Storstrøm | 3,400 | 42 | 44 | 348 | 1,394 | 861 | 24 | 85 | 3 | 2,801 | 383 | 135 | 20 | 61 | 599 |
| West Zealand | 2,975 | 33 | 50 | 581 | 1,361 | 214 | 7 | 132 | 22 | 2,402 | 278 | 213 | 39 | 43 | 573 |
| Roskilde | 893 | 3 | 2 | 81 | 424 | 120 | 0 | 34 | 1 | 665 | 92 | 117 | 4 | 15 | 228 |
| Frederiksborg | 1,349 | 8 | 22 | 538 | 158 | 9 | 1 | 55 | 5 | 797 | 215 | 220 | 70 | 47 | 552 |
| Copenhagen | 618 | 0 | 0 | 26 | 44 | 61 | 0 | 12 | 0 | 143 | 42 | 329 | 14 | 90 | 475 |
| Bornholm | 588 | 9 | 1 | 29 | 264 | 114 | 3 | 2 | 0 | 423 | 121 | 26 | 1 | 17 | 165 |
| Denmark | 42,997 | 8,165 | 3,416 | 9,640 | 8,435 | 2,118 | 286 | 2,377 | 83 | 34,519 | 4,617 | 2,665 | 397 | 800 | 8,478 |

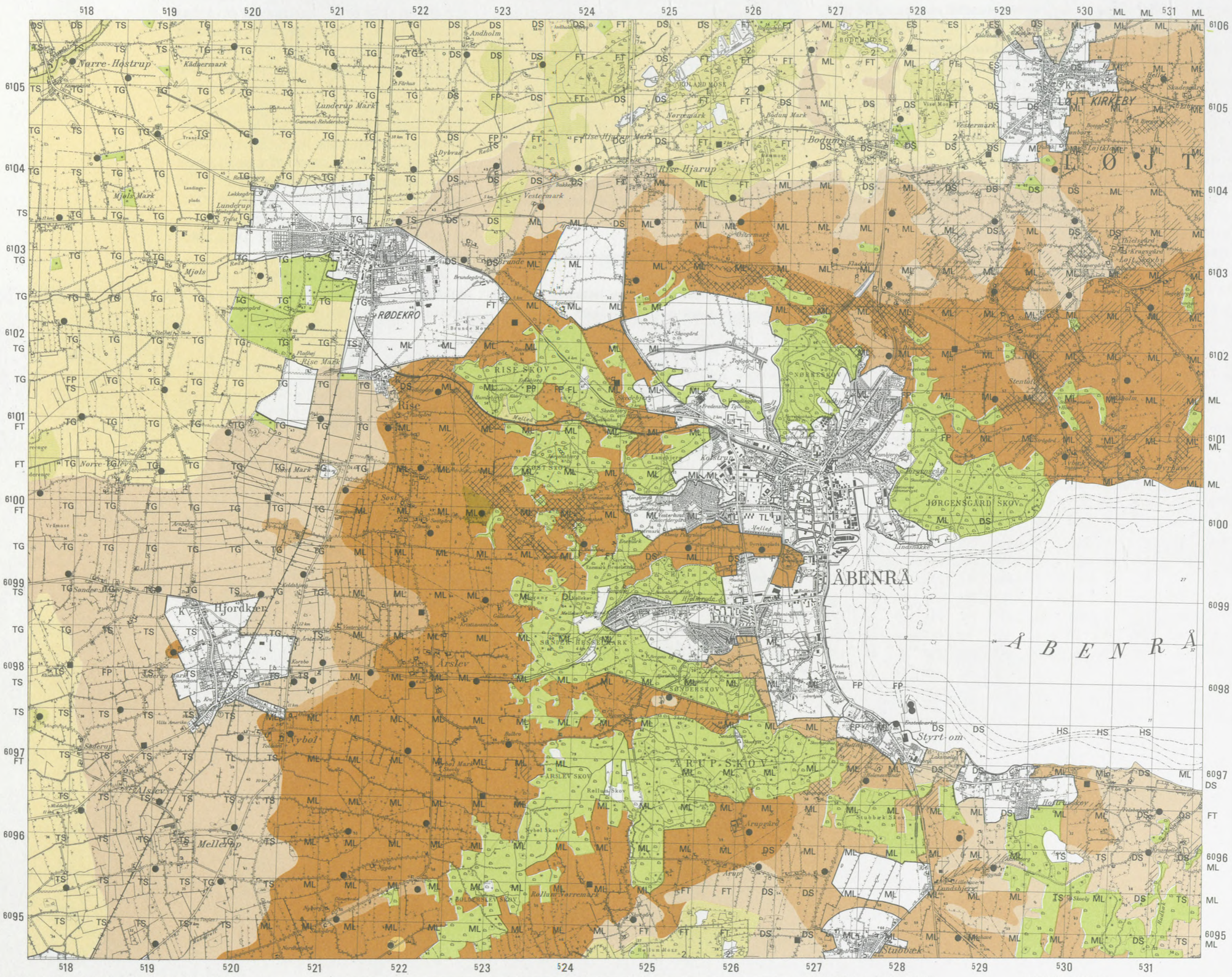
% of Surface Area.

| County | MCCl | MCC2 | MCC3 | MCC4 | MCC5 | MCC6 | MCC7 | MCC8 | Classified Area | Wood | Urban Area | Fresh Waters | Other Areas | Unclassified Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| North Jutland | 11.8 | 37.2 | 21.9 | 2.0 | 0.8 | 0.2 | 9.6 | 0.2 | 83.8 | 9.2 | 5.9 | 0.4 | 0.7 | 16.2 |
| Viborg | 22.1 | 10.7 | 30.9 | 11.7 | 2.0 | 0.3 | 5.3 | 0.2 | 83.3 | 10.3 | 2.8 | 1.9 | 1.7 | 16.7 |
| Århus | 13.2 | 3.0 | 33.6 | 17.8 | 1.8 | 0.5 | 5.7 | 0.5 | 76.1 | 14.3 | 6.5 | 1.4 | 1.7 | 23.9 |
| Ringkjøbing | 48.9 | 6.3 | 14.8 | 4.7 | 0.8 | 0.6 | 6.2 | 0.0 | 82.3 | 11.1 | 3.6 | 0.6 | 2.4 | 17.7 |
| Vejle | 20.4 | 0.0 | 23.3 | 25.2 | 7.7 | 0.1 | 3.0 | 0.0 | 79.7 | 12.6 | 5.6 | 0.8 | 1.3 | 20.3 |
| Ribe | 45.0 | 2.0 | 26.2 | 1.4 | 0.3 | 2.3 | 6.9 | 0.0 | 84.0 | 10.2 | 4.5 | 0.2 | 1.1 | 16.0 |
| South Jutland | 35.5 | 0.3 | 17.0 | 21.0 | 3.8 | 2.3 | 7.1 | 0.1 | 87.2 | 7.6 | 3.3 | 0.4 | 1.5 | 12.8 |
| Funen | 1.8 | 1.3 | 28.3 | 43.9 | 2.6 | 0.3 | 3.0 | 0.1 | 81.3 | 9.2 | 6.7 | 0.4 | 2.4 | 18.7 |
| Storstrøm | 1.2 | 1.3 | 10.2 | 41.0 | 25.3 | 0.7 | 2.5 | 0.1 | 82.4 | 11.3 | 3.9 | 0.6 | 1.8 | 17.6 |
| West Zealand | 1.1 | 1.7 | 19.5 | 45.8 | 7.2 | 0.2 | 4.5 | 0.8 | 80.7 | 9.4 | 7.2 | 1.3 | 1.4 | 19.3 |
| Roskilde | 0.3 | 0.2 | 9.1 | 47.5 | 13.4 | 0.1 | 3.8 | 0.1 | 74.5 | 10.3 | 13.1 | 0.4 | 1.7 | 25.5 |
| Frederiksborg | 0.6 | 1.6 | 39.9 | 11.7 | 0.7 | 0.1 | 4.1 | 0.4 | 59.1 | 15.9 | 16.3 | 5.2 | 3.5 | 40.9 |
| Copenhagen | 0.0 | 0.0 | 5.0 | 8.4 | 11.6 | 0.0 | 2.3 | 0.0 | 23.1 | 6.8 | 53.2 | 2.3 | 14.6 | 76.9 |
| Bornholm | 1.6 | 0.2 | 4.9 | 45.0 | 19.4 | 0.5 | 0.4 | 0.0 | 71.9 | 20.6 | 4.4 | 0.2 | 2.9 | 28.1 |
| Total | 19.0 | 7.9 | 22.4 | 19.6 | 4.9 | 0.7 | 5.5 | 0.2 | 80.3 | 10.7 | 6.2 | 0.9 | 1.9 | 19.7 |




JB 1112 I NV/NØ

# JORDKLASSIFICERING DANMARK — BASISDATAKORT 1:50000 — JB 1212 III SØ




## DOMINERENDE JORDTYPER 0-20 CM DYBDE MED TILHØRENDE FARVEKODE

- 1 Grovsandet jord
- 2 Finsandet jord
- 3 Grov lerblandet sandjord / Fin lerblandet sandjord
- 4 Grov sandblandet lerjord / Fin sandblandet lerjord
- 5 Lerjord
- 6 Svær lerjord / Meget svær lerjord / Siltjord
- 7 Humus
- 8 Speciel jordtype

| FARVE-KODE | TEKSTURDEFINITION FOR JORDTYPE | Symbol | JB-nr. | Vægtprocent: Ler under 2 µm | Silt 2-20 µm | Finsand 20-200 µm | Sand, ialt 20-2000 µm | Humus 58,7 % C |
|---|---|---|---|---|---|---|---|---|
| 1 | Grovsandet jord | GR.S. | 1 | 0-5 | 0-20 | 0-50 | 75-100 | Under 10 |
| 2 | Finsandet jord | F.S. | 2 | | | 50-100 | | |
| 3 | Grov lerblandet sandjord | GR.L.S. | 3 | 5-10 | 0-25 | 0-40 | 65-95 | |
| | Fin lerblandet sandjord | F.L.S. | 4 | | | 40-95 | | |
| 4 | Grov sandblandet lerjord | GR.S.L. | 5 | 10-15 | 0-30 | 0-40 | 55-90 | |
| | Fin sandblandet lerjord | F.S.L. | 6 | | | 40-90 | | |
| 5 | Lerjord | L. | 7 | 15-25 | 0-35 | | 40-85 | |
| 6 | Svær lerjord | SV.L. | 8 | 25-45 | 0-45 | | 10-75 | |
| | Meget svær lerjord | M.SV.L. | 9 | 45-100 | 0-50 | | 0-55 | |
| | Siltjord | SI. | 10 | 0-50 | 20-100 | | 0-80 | |
| 7 | Humus | HU. | 11 | | | | | Over 10 |
| 8 | Speciel jordtype | SPEC. | 12 | | | | | |

TEKSTURDATA - JORDPRØVER

- ● Jordprøve: 0-20 cm dybde
- ■ Jordprøve: 0-20 cm og 35-55 eller 20-40 cm dybde. (Enkelte kun i 20-40 cm dybde).

Alle teksturdata lagres i JB-DATABANK med reference til udtagningsstedets UTM-zonekoordinater.

JB-DATABANK

Data for jordens tekstur, herunder geologi, vand-kapacitetsundersøgelser, m.m., samt øvrige jordfaktorer lagres af SfJ i en JB-DATABANK.

Klimadata, nedbør og temperatur, gældende for basisdatakortets dækningsområde lagres endvidere i JB-DATABANKEN.

TERRÆNHÆLDNING

- Større arealer, 6°-12° hældning
- Større arealer, over 12° hældning

IKKE KLASSIFICERET

- Større skove og plantager
- Byzone/sommerhusområde i henhold til Lov om by- og landzoner - generaliseret ved supplement med mindre båndlagte arealer i landzone.

Uden markeret sort grænse: større båndlagte arealer i landzone - samt vandarealer, m.m.

## GEOLOGI DOMINERENDE JORDARTER 1 M DYBDE

Opdelt efter tid, aflejring og sedimenttyper (kornstørrelser). Registreringen er foretaget med grundlag i den af Danmarks Geologiske Undersøgelse udførte kartering.

Sort to-bogstavsymbol i NØ-hjørne af UTM 25 ha-felt markerer den dominerende jordart i cirka 1 m dybde i feltets klassificerede areal.

Symbol for UTM 25 ha-felt ved kortrammen gælder for hele feltets klassificerede areal.

Overlejring er angivet som ovenfor ved symboler - ne for: øverste/nederste dominerende jordart.

| KVARTÆRE JORDARTER - SYMBOLER | | | |
|---|---|---|---|
| Moræneler | ML | Morænegrus | MG |
| Smeltevandsler | DL | Smeltevandsgrus | DG |
| Issøler | ZL | Issøgrus | ZG |
| Ferskvandsler | TL | Ferskvandsgrus | TG |
| Yoldialer | YL | Yoldiagrus | YG |
| Saltvandsler | HL | Saltvandsgrus | HG |
| Ferskvandsler (postglacialt) | FL | Ferskvandsgrus (postglacialt) | FG |
| Morænesand | MS | Saltvandstørv | HT |
| Smeltevandssand | DS | Ferskvandstørv | FT |
| Issøsand | ZS | Saltvandsdynd | HP |
| Ferskvandssand | TS | Ferskvandsdynd | FP |
| Yoldiasand | YS | Marsk | HV |
| Flyvesand | ES | | |
| Saltvandssand | HS | Kildekalk, mose- og søkalk | FK |
| Ferskvandssand (postglacialt) | FS | Okker, myremalm | FJ |
| PRÆKVARTÆRE JORDARTER - SYMBOLER | | | |
| Skrivekridt | SK | Eocænt moler | ED |
| Danien-kalk | ZK | Eocæn mergel | SL |
| Brunkul | GC | Oligocænt ler | OL |
| Paleocæn kalk | PK | Glimmerler | GL |
| Paleocænt ler | PL | Glimmersand | GS |
| Paleocænt grønsand | PS | Kvartsgrus | KG |
| Eocænt ler | LL | Kvartssand | KS |

NATURLIG AFVANDINGSTILSTAND

Opdelt i tilstandsgrupperne:
1: Eng- og mosearealer, herunder sivarealer.
2: Arealer med sid bund eller marsk.

Sort tal i SØ-hjørne af UTM 25 ha-felt markerer den tilstandsgruppe feltets klassificerede areal tilhører.

For øvrigt klassificeret areal er der ikke foretaget markering.

UTM ZONE 32 NET

Inddelt i ½ km-kvadrater (25 ha-felter).
Sorte tal i kortrammen angiver zonekoordinater (Easting-Northing) i km til 1 km-netlinierne.

STAMOPLYSNINGER

Grundmaterialet er Geodætisk Instituts 4 cm kort 1:25000 i speciel udgave nedfotograferet til 1:50000.

Basisdatakortet omfatter hele grundkortet og benævnes med JB og dettes nummer.

Supplerende tematisk information hvad jordklassificeringen angår er udarbejdet og påført af Landbrugsministeriet, Sekretariatet for Jordbundsklassificering (SfJ) i samarbejde med landbrugets forsknings- og forsøgsvirksomhed, landbrugets konsulenttjeneste, Det danske Hedeselskab, amtskommunerne, Hovedstadsrådet og Danmarks Geologiske Undersøgelse.

Udgivet af SfJ med Geodætisk Instituts tilladelse (A. 830/77).
SfJ og GI COPYRIGHT.

Reproduceret ved Geodætisk Institut.
Trykt 1979 ved Aalborg Offset.

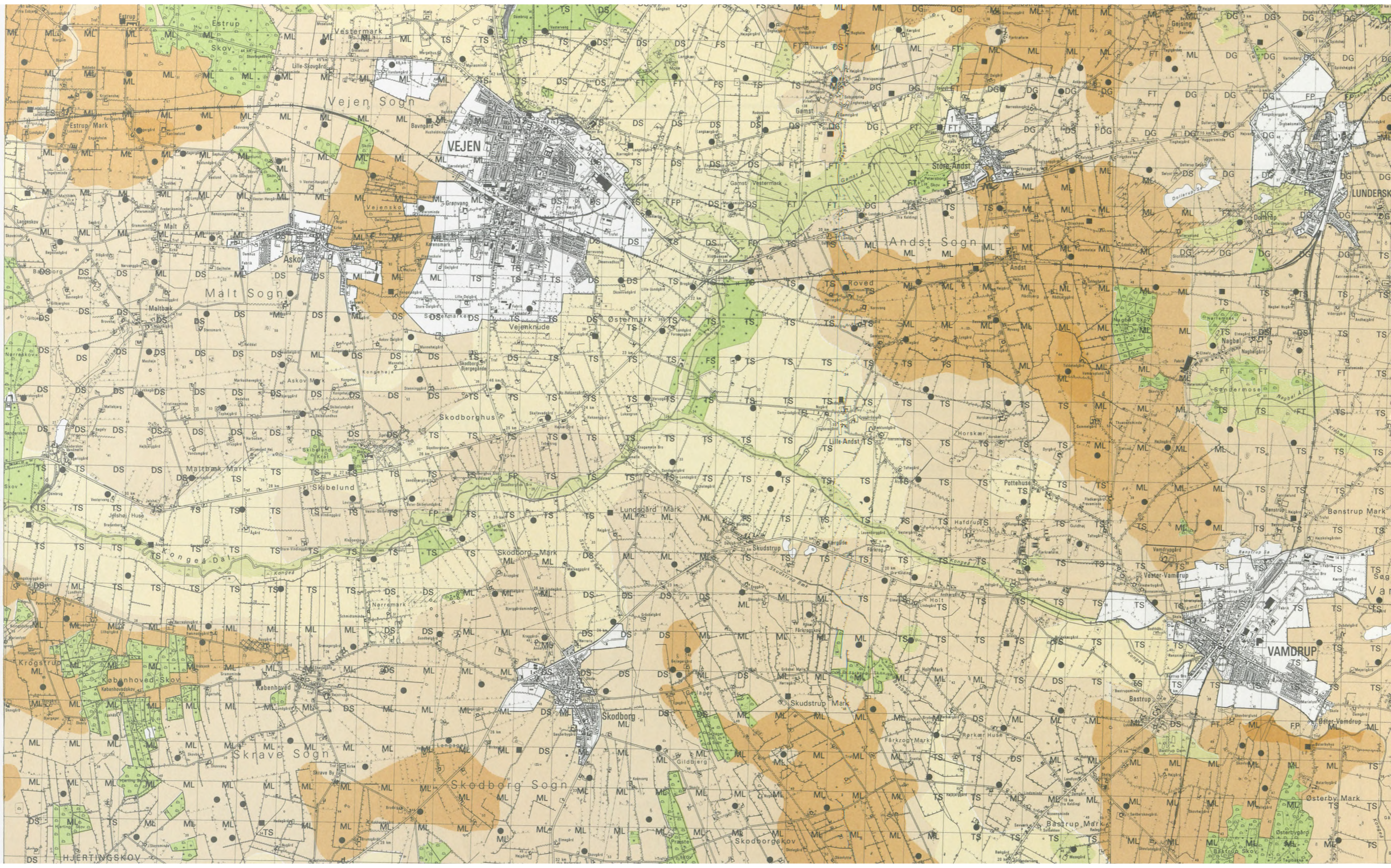
Grundmaterialets trykkeår og udgavekode:
1972 -1.1.1.

ANVENDELSE I OFFENTLIG PLANLÆGNING

Jordklassificeringen omfatter en oversigtlig registrering af en række egenskaber - BASISDATA - hos den faste jordskorpes øverste, cirka 1 m tykke, løse lag.

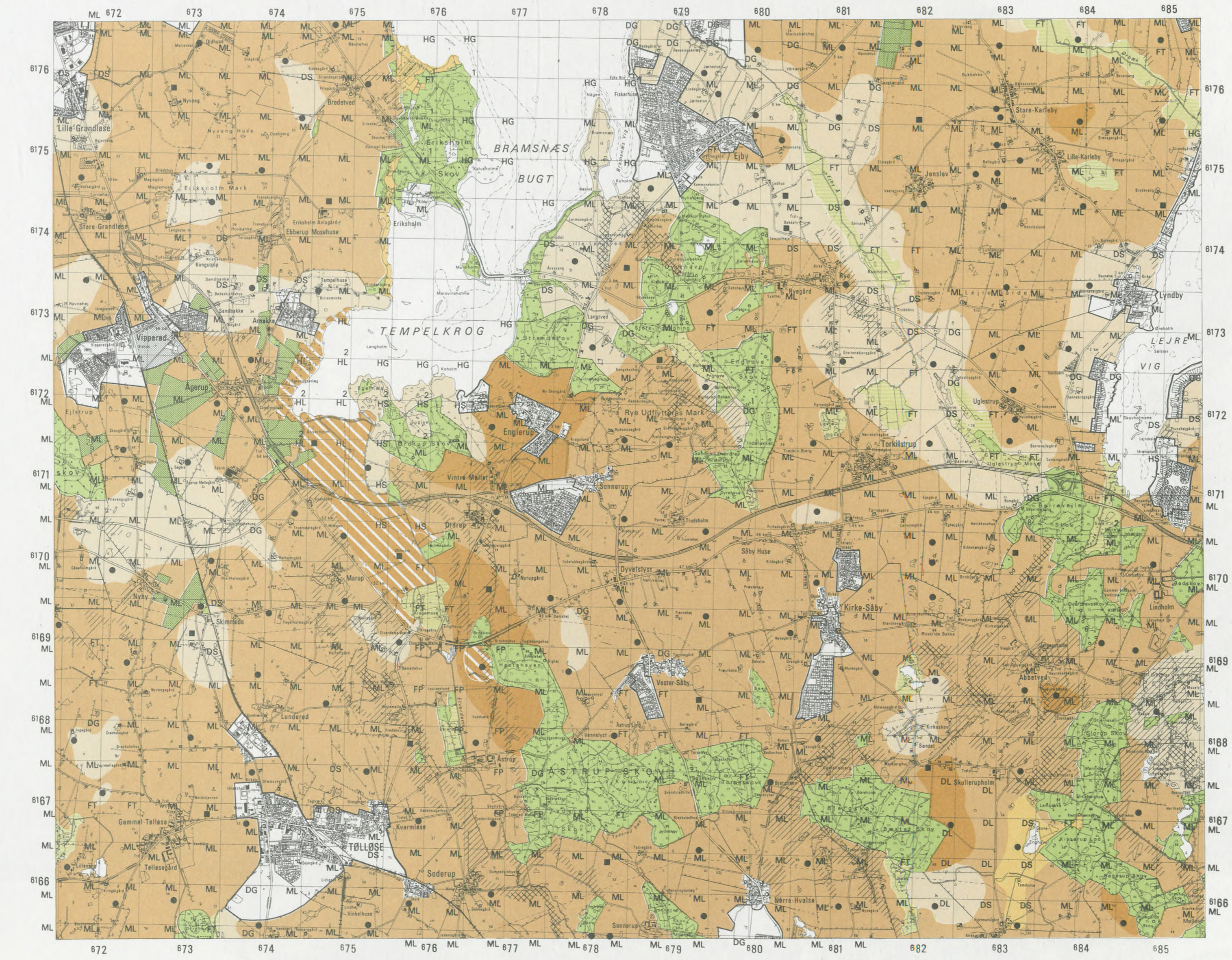
Basisdatakortet er primært udformet til brug ved den generelle arealplanlægning.

Basisdatakortet er endvidere udformet til brug som oversigtskort ved de nødvendige suppleren - de detailundersøgelser i forbindelse med lokal - planlægningen.




JB 1213 III SV SØ

JORDKLASSIFICERING DANMARK BASISDATAKORT 1:50000 JB 1513 IV SV



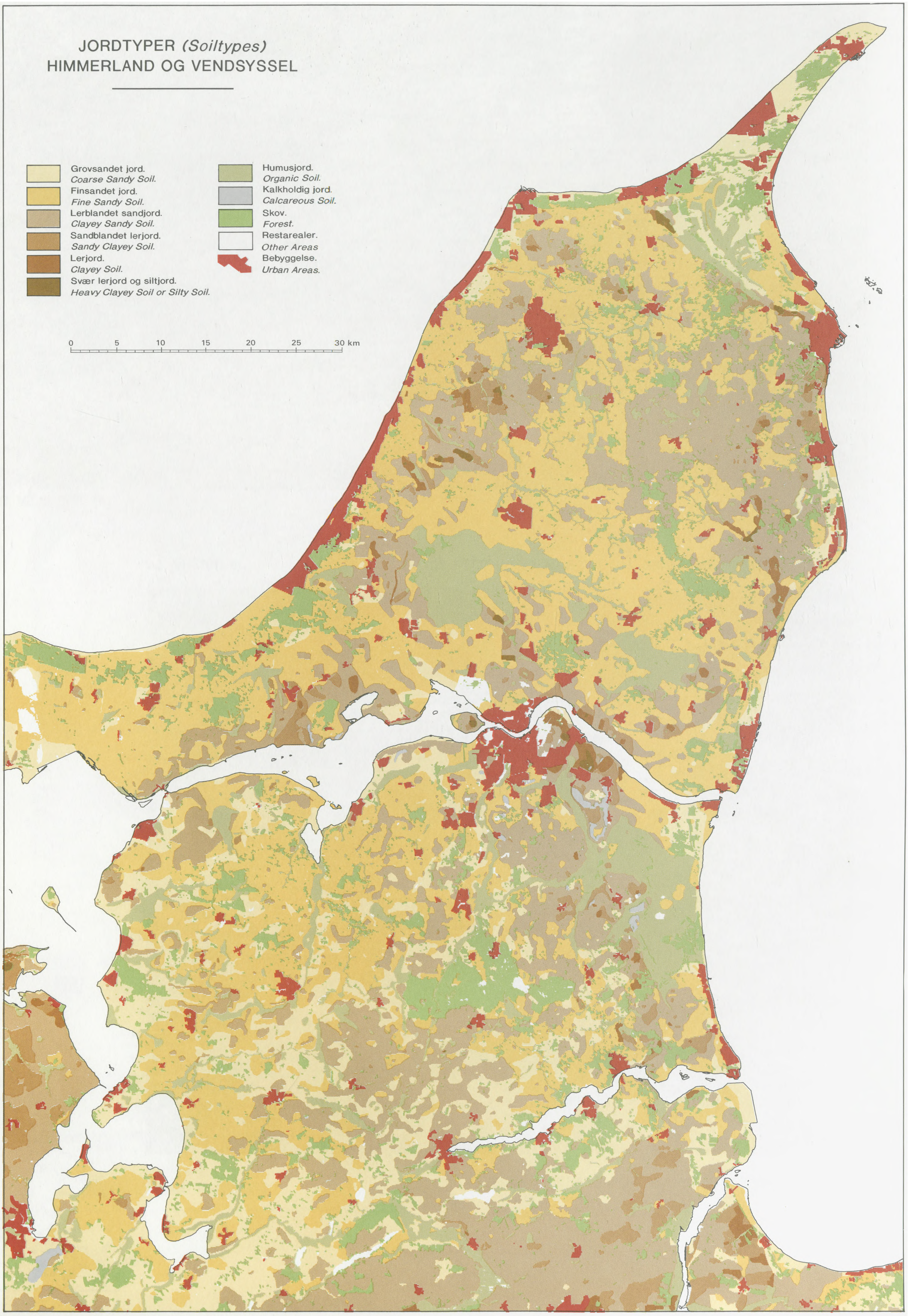

SOIL MAPS FROM THE DANISH SOIL CLASSIFICATION

KORT 6

MAP 6

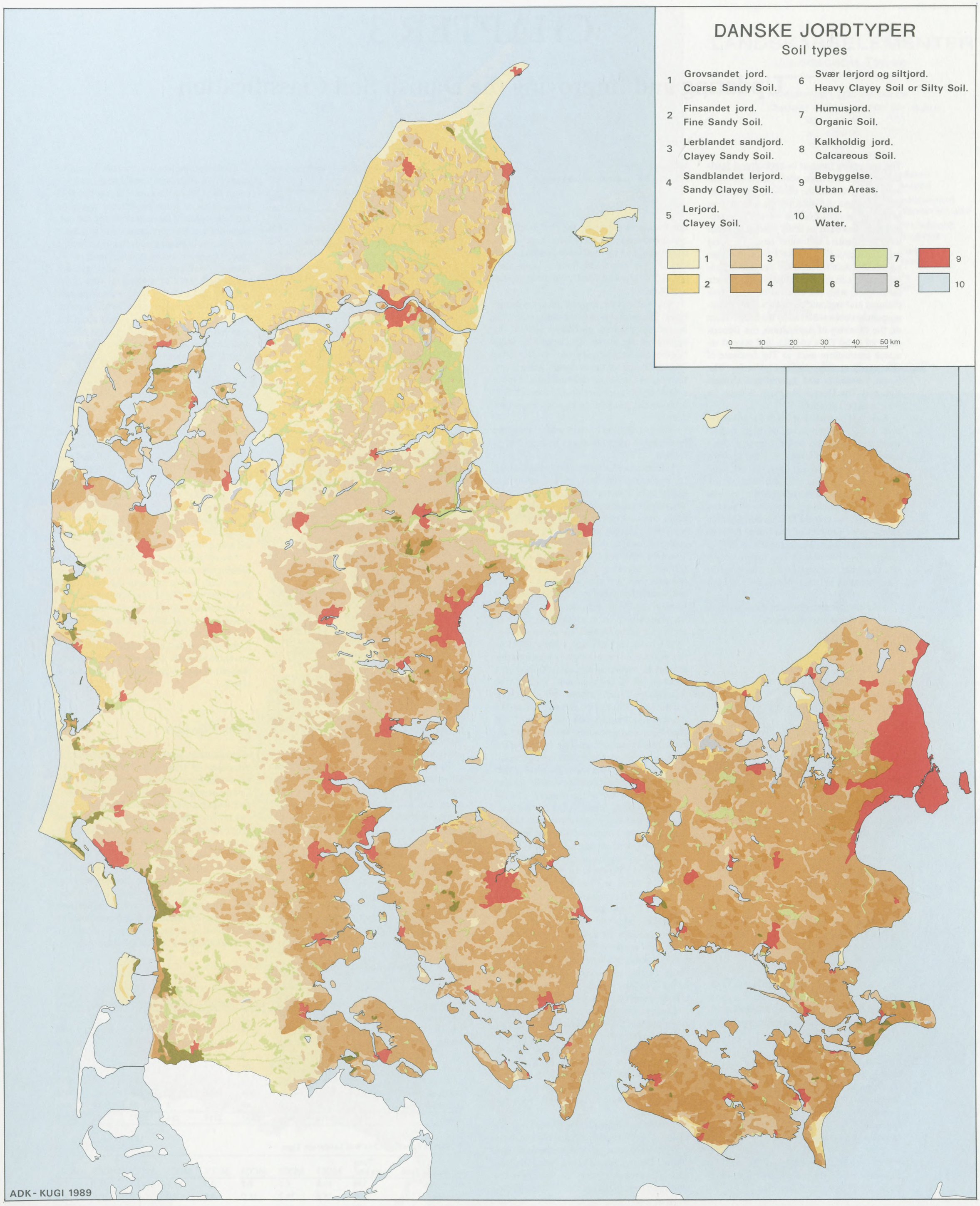
KORT 7

MAP 7


JORDTYPER (Soiltypes)
HIMMERLAND OG VENDSYSSEL
Grovsandet jord.
Coarse Sandy Soil.
Finsandet jord.
Fine Sandy Soil.
Lerblandet sandjord.
Clayey Sandy Soil.
Sandblandet lerjord.
Sandy Clayey Soil.
Lerjord.
Clayey Soil.
Svær lerjord og siltjord.
Heavy Clayey Soil or Silty Soil.
Humusjord.
Organic Soil.
Kalkholdig jord.
Calcareous Soil.
Skov.
Forest.
Restarealer.
Other Areas
Bebyggelse.
Urban Areas.
0 5 10 15 20 25 30 km

KORT 8

MAP 8


DANSKE JORDTYPER
Soil types
1 Grovsandet jord. Coarse Sandy Soil.
2 Finsandet jord. Fine Sandy Soil.
3 Lerblandet sandjord. Clayey Sandy Soil.
4 Sandblandet lerjord. Sandy Clayey Soil.
5 Lerjord. Clayey Soil.
6 Svær lerjord og siltjord. Heavy Clayey Soil or Silty Soil.
7 Humusjord. Organic Soil.
8 Kalkholdig jord. Calcareous Soil.
9 Bebyggelse. Urban Areas.
10 Vand. Water.
1 2 3 4 5 6 7 8 9 10
0 10 20 30 40 50 km
ADK - KUGI 1989

# CHAPTER 3

## Updating and Improving the Danish Soil Classification

The increasing interest in agricultural land-use practices and their effect on the environment has increased the necessity of continually updating and expanding the information of the initial classification work. For example, there has been an acute need at regional level to calculate soil water balances, plant nutrient recyclings and plant nutrient losses e.g. nitrate. As a result, there has been a definite increase in the accumulation of soil data since 1981, with the establishment of both national and regional databases. This development has been achieved by the cooperation of; the Ministry of Agriculture, the Department of Land Data (ADK), and several research institutions such as The Institute of Geography at Copenhagen University, The Royal Veterinary and Agricultural University, and The Danish Research Service for Plant and Soil Science.

Constant progress has led to the construction of supplementary detailed maps, such as the ones showing the major landscape types, subsoil texture, wetlands, and areas showing potential acidity. Furthermore, in 1981, a soil profile database was initiated to store soil profile descriptions and related chemical and physical soil analyses. Hence, it can be concluded that the current Danish Soil Classification is the product of; the initial national classification work which started in 1975, a series of supplementary maps, and the results of soil profile investigations determining the chemical and physical properties of soil horizons.

This chapter describes the establishment of the supplementary databases.

### Maps

#### *Landscape Types*

The major Danish landscape types have been delimited and digitized so that this information can be used in conjunction with the soil maps. The delineation has been based on the following material:

Contour Maps, 1:100,000 (The Geodetic Survey of Denmark)
A Map of the Danish Landscapes, 1:360,000 (Smed 1979)
An Atlas of Denmark, 1:750,000 (Schou 1949)
A Soil Map of Denmark, 1:500,000 (Bornebusch & Milthers 1935) Geology Maps of Denmark, 1:100,000 (Denmarks Geological Surveys existing range of maps).

The delineation of the major Danish landscape types has been carried out on a topographic map at a scale of 1:100,000. The following major Danish landscape types have been identified:

Saltmarsh
Littorina Yoldia plain Sand-dune
Saale Moraine
Outwash plain
Weichsel Moraine
Reclaimed areas
Exposed Bedrock (Bornholm only).

Where it was not possible to identify distinct landscape types, the following ”mixed landscape” types have been identified:

Dune and outwash plain
Saale Moraine and dune
Dune, littorina and younger marine forelands
Littorina and Weichsel moraine
Outwash plain and Weichsel moraine
Weichsel Moraine and dune
Yoldia and dune
Littorina, Weichsel moraine and Yoldia

For statistical purposes, the first landscape type mentioned in a ”mixed landscape” name has determined its final landscape classification. For example, the ”mixed landscape” group, ”Yoldia and dune”, will be classified as Yoldia.

Map 9 shows the major Danish landscape types. The map also indicates areas with soils containing calcium carbonate within the uppermost two metres. The latter were identified on the basis of soil profile studies in the 7 km grid used for the national nitrate investigation on Danish agricultural soils. A more comprehensive description of these soil characteristics is given in the section on soil profiles.

The distribution of the 9 major landscape types shown on the map can be described as follows.

Saltmarsh sediments occur in tidal areas. In Denmark, the deposits are not found higher than 3 metres above mean sea level. They consist mainly of two materials; marine basin clay and marine foreland clay (Jacobsen 1964). Marine basin clay is a heavy clay sediment, whilst marine foreland clay is a stratified sediment of clay, silt and sand. The saltmarsh areas are mainly concentrated in the south-western part of Jutland, running northwards from the German border as far as Ringkøbing Fjord. Saltmarsh covers 42,000 hectares, which is equivalent to approximately 1% of the Danish land surface.

The Littorina landscape, being a combination of littorina deposits and younger marine sediments, measures about 300,000 hectares, equal to 7% of the total land surface. The deposits are found between 0-13 m above sea-level. The littorina transgressions responsible for these deposits took place about 7,000 years ago, corresponding to a warmer climatic phase when a large-scale melting of the polar ice occurred. Since then, isostatic uplift has raised the deposits above sea-level so that the former littorina coastline now lies inland in the northern half of the country. The deposits are mainly found in the northern regions of Jutland: Thy, Vendsyssel, and Himmerland. They attain their highest altitude, 13 m above mean sea-level, in Vendsyssel.

The Yoldia deposits are almost entirely confined to Vendsyssel, covering some 99,000 hectares, or 2% of the total land surface. The Yoldia transgression took place at the end of the last glaciation (the Weichsel). Since then, isostatic uplift has raised the Yoldia deposits 40 m above current mean sea-level in northern Vendsyssel, from where they dip gently southwards, being eventually covered by the more recent littorina deposits in the Limfjord region. Yoldia deposits can also be found on the island of Bornholm.

Dune landforms cover 164,000 hectares, or about 4% of the total land surface. They are a common feature of the Danish west coast as well as several inland districts of Jutland. Their ages differ according to the particular period during which they were formed. However, all were formed after the last glaciation, and some are still in the process of being formed today.

The Saale moraine landscape consists basically of landforms which were formed more than 100,000 years ago during the Saale glaciation. During the following Weichsel glaciation, this area was free of ice, as it lay to the south and west of the ice cap. Today, the old, isolated, Saale moraine hills, known in Danish as ”bakkeøer”, (literally ”hill islands”), are surrounded by large, low-lying areas of meltwater deposits created during the Weichsel glaciation. The Saale moraine landscape covers about 473,000 hectares, or 11% of the total land surface.

Table 9. The Surface Area of the Major Landscape Types.

| | Landscape Type | Area km² |
|---|---|---|
| 21 | Saltmarsh | 419 |
| 22 | Littorina/Younger marine forelands | 2,994 |
| 23 | Yoldia Plain (older marine deposits) | 992 |
| 24 | Sand dune areas | 1,641 |
| 25 | Saale moraine landscape | 4,794 |
| 26 | Outwash Plain | 4,827 |
| 27 | Weichsel moraine landscape | 26,006 |
| 28 | Reclaimed land | 482 |
| | Combination of 24 and 26 | 164 |
| | Combination of 24 and 25 | 201 |
| | Combination of 24 and 22 | 108 |
| | Combination of 22 and 27 | 2 |
| | Combination of 26 and 27 | 111 |
| | Combination of 24 and 27 | 90 |
| | Combination of 24 and 23 | 8 |
| | Combination of 22 and 23 | 8 |
| | Unclassified areas | 163 |
| | Total | 43,010 |

The outwash plain is a product of the last glaciation, the Weichsel. This landscape consists of an almost continuous belt of outwash plains and fans covering much of western and central Jutland lying west of the main terminal moraine. Elsewhere, outwashed sands have often been deposited in meltwater channels, which appear as sharply-defined linear landforms in the landscape. Being similar in their areal extent to the Saale deposits, the Weichsel outwash plain deposits occupy 483,000 hectares, about 11% of the total land surface.

The younger Weichsel moraine landscape, created by the last glaciation, has produced some of the most naturally fertile soils to be found in Denmark. These are generally located in the eastern part of the country. The Weichsel moraine landscape covers 2.6 million hectares, being equal to as much as 60% of the total land surface.

Table 9 gives a statistical account of the major landscape types, while Table 10 shows the relationship between the landscape and soil types.

Heavy clays dominate the soil types of the saltmarsh landscape, accounting for about half of its area. Fine sands and peats make up more than half of the littorina and younger marine foreland deposits, while clays and heavy clays are almost absent. Similarly, more than half of the Yoldia landscape contains fine sandy soils, and few of them have a clay content of more than 15% in the plough layer. The dune landscape consists almost entirely of coarse and fine, sandy soils. Coarse sandy soils dominate the Saale moraine landscape. Clayey sands (MCC3) are occasionally found, while more clayey soils (MCC4 and MCC5) are very rare.

The outwash plain is dominated by coarse sands (70% of the area), while peaty soils account for 15% of the area. Clays are almost absent. Due to some uncertainty regarding the delineation of the saltmarsh and the outwash plain, a few clay areas may have been classified as belonging to the latter landscape type. The most common soils found in the younger Weichsel moraine landscape are sandy clays (MCC4), making up 40% of the area. Clayey sands (MCC3) are also common and these two soil types cover 75% of the total surface area. The reclaimed land areas are dominated by sandy soils. Fine and coarse-grained sandy soils are almost equally represented. Furthermore, calcareous soils constitute 10% of the soils.

Based on their total amount, calcareous soils (MCC8) are distributed as follows. The reclaimed land accounts for 65%, the young Weichsel moraines 20%, and the littorina 10%. Peats (MCC7) are most common in the littorina deposits and the outwash plains. They are seldom found in the Weichsel moraine landscape. Heavy clays (MCC6) are only significant in the saltmarsh areas, where they dominate. Clay (MCC5) occurs chiefly in the saltmarsh areas and Weichsel moraines. Sandy clay (MCC4) is dominant in the Weichsel moraines and is frequently found in the soils of the reclaimed land areas.

Clayey sand (MCC3) seems to be evenly distributed throughout all the landscape types, with the exception of the dune areas. Fine sand (MCC2) is very commom in the Yoldia areas, and rather common in the littorina deposits, dune areas, and reclaimed areas. Coarse sands (MCC1) are most commonly found in the dune areas, Saale moraines and the outwash plain. They are rarely found in the soils of the Yoldia plain or Weichsel moraines.

#### *Subsoil texture*

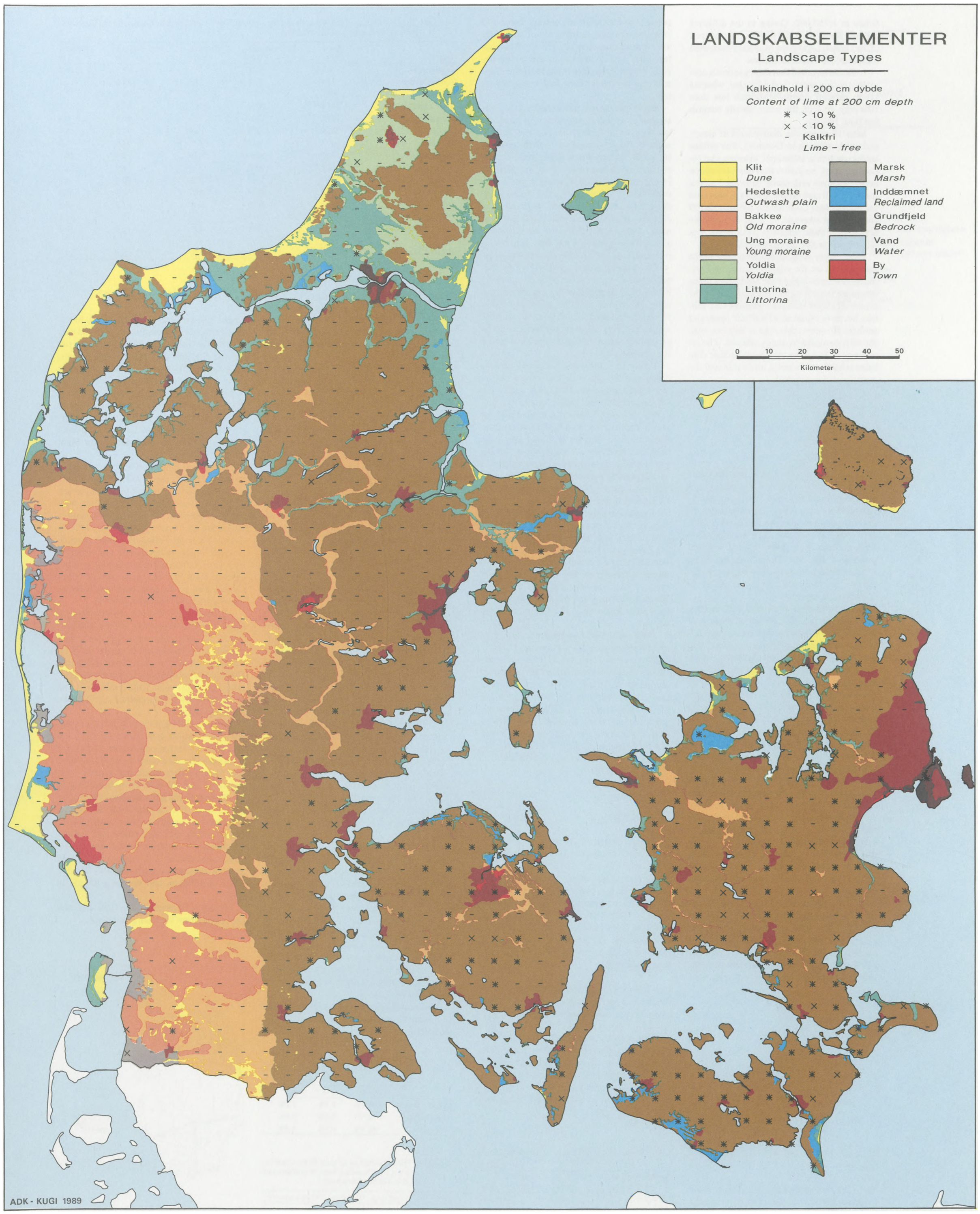
Subsoil texture greatly influences the root development of crops and hereby determines the available water content in the soil profile. Consequently, it affects root zone capacity and irrigation requirements (Madsen 1979, 1983a). Investigations have shown that a high clay content in the subsoil causes low, hydraulic conductivity and increases the need for drainage. Hence, a map has been made to show the distribution of clayey and sandy subsoils for the following landscape types; Yoldia, Saale, Weichsel, outwash plain and dune. This has been compiled on the basis of; a soil map by Milthers and Bornebusch at 1:500,000, a landscape map by Smed at 1:360,000, and a geomorphology map by

Table 10. Relationship between Landscape Type & Soil Type (MCC).
a: Surface Area (km²).

| Landscape Type | MCC1 | MCC2 | MCC3 | MCC4 | MCC5 | MCC6 | MCC7 | MCC8 | Total Area |
|---|---|---|---|---|---|---|---|---|---|
| saltmarsh | 42 | 22 | 31 | 13 | 40 | 162 | 48 | 0 | 358 |
| Littorina | 469 | 704 | 448 | 121 | 49 | 21 | 673 | 9 | 2495 |
| Yoldia | 23 | 500 | 253 | 31 | 10 | 3 | 86 | 0 | 906 |
| Dune | 785 | 213 | 17 | 2 | 0 | 2 | 51 | 0 | 1070 |
| Saale | 2275 | 211 | 1491 | 95 | 4 | 6 | 249 | 0 | 4331 |
| Outwash Plain | 2743 | 102 | 502 | 51 | 7 | 5 | 583 | 3 | 3996 |
| Weichsel | 1733 | 1565 | 6818 | 8074 | 1986 | 85 | 660 | 17 | 20938 |
| Reclaimed land | 94 | 99 | 80 | 48 | 22 | 2 | 27 | 54 | 426 |
| Total | 8164 | 3416 | 9640 | 8435 | 2118 | 286 | 2377 | 83 | 34519 |

b: Topsoil Type (MCC) as % of Landscape Type.

| Landscape Type | Total Area km² | MCC1 | MCC2 | MCC3 | MCC4 | MCC5 | MCC6 | MCC7 | MCC8 |
|---|---|---|---|---|---|---|---|---|---|
| Saltmarsh | 358 | 11.8 | 6.1 | 8.7 | 3.7 | 11.1 | 45.3 | 13.4 | 0.0 |
| Littorina | 2495 | 18.8 | 28.2 | 18.0 | 4.9 | 2.0 | 0.9 | 27.0 | 0.4 |
| Yoldia | 906 | 2.5 | 55.3 | 27.9 | 3.4 | 1.1 | 0.3 | 9.4 | 0.0 |
| Dune | 1070 | 73.5 | 19.9 | 1.6 | 0.2 | 0.0 | 0.1 | 4.7 | 0.0 |
| Saale | 4331 | 52.5 | 4.9 | 34.4 | 2.2 | 0.0 | 0.1 | 5.8 | 0.0 |
| Outwash Plain | 3996 | 68.7 | 2.6 | 12.6 | 1.3 | 0.2 | 0.1 | 14.6 | 0.0 |
| Weichsel | 20938 | 8.3 | 7.5 | 32.6 | 38.6 | 9.5 | 0.4 | 3.2 | 0.0 |
| Reclaimed land | 426 | 22.1 | 23.2 | 18.9 | 11.3 | 5.1 | 0.5 | 6.3 | 12.6 |


LANDSKABSELEMENTER
Landscape Types
Kalkindhold i 200 cm dybde
Content of lime at 200 cm depth
* > 10 %
× < 10 %
- Kalkfri
Lime - free
Klit
Dune
Hedeslette
Outwash plain
Bakkeø
Old moraine
Ung moraine
Young moraine
Yoldia
Yoldia
Littorina
Littorina
Marsk
Marsh
Inddæmnet
Reclaimed land
Grundfjeld
Bedrock
Vand
Water
By
Town
0 10 20 30 40 50
Kilometer
ADK - KUGI 1989

Schou at 1:750,000. Owing to the different scales of these maps, the digitized boundaries of the Danish Landscape Map have been used to demarcate the subsoil zones.

It should be noted that clayey subsoils normally contain more than 15% clay, whereas sandy subsoils normally contain less than 10% clay. In fact, the latter usually contain less than 5% clay.

Map 10 shows the distribution of clayey and sandy subsoils in Denmark. For certain landscape types; saltmarsh, littorina and reclaimed land, no distinction has been made between clayey and sandy subsoils. Profiles from the national nitrate grid have provided the Map Colour Code for the subsoil (75-100 cm) at 7 km intervals. A more detailed description of these results is given in the section on soil profile investigations.

Most clayey subsoils are found in eastern Jutland and on the islands of eastern Denmark, corresponding to the landscapes dominated by the young Weichsel moraine. The area with clayey subsoils measures 1.81 million hectares, equal to 42% of the total land surface. However, this area is still less than the 48% occupied by sandy subsoils. The remaining 10% of the total land surface contains subsoils of littorina and saltmarsh deposits or reclaimed land.

### *Wetlands*

Wetland soils often lie low in relation to the nearest recipient, so that the water-table is almost permanently high. The soils usually have humus-rich, peaty, upper horizons, or else an anaerobic layer near the surface. Wetland soils may also be found at some distance from the nearest recipient in areas with impermeable subsoils. These soils are often characterized by long-term, waterlogged conditions. In Denmark, they are typical of "dead-ice" landscapes.

The distribution of wetland soils in Denmark has been greatly affected by the scale of artificial, drainage activities. Several years after the initiation of a drainage programme, an area might lose its wetland character and become classified as a relatively well-drained area. As a result of much drainage activity, the total wetland area has been greatly reduced during the past 200 years. This fact is clearly illustrated in Figure 13, which shows the change in the distribution of wetland and marl pits during the past 150 years for the Bjergsø Housing Association District, in western Zealand. The wetlands have been defined on the basis of the boundaries and symbols shown on old topographical maps. The maps show that the extent of the wetlands used to be far greater, particularly during the first half of the 19th century. The digging of drainage ditches and the introduction of tile drainage greatly reduced the wetlands during the second half of the last century. The wetland area has continued to decline during this century.

As can be seen from Figure 13, the total wetland area has been constantly changing. However, its estimated size depends on when a particular map is made. Seasonal factors may play a role as to whether an area is classified as wetland or not. Wetlands seem smaller in summer and early autumn, compared to winter and early spring, due to the lower water-table. A sequence of unusually wet years or unusually dry years will also affect their extent. Moreover, much will depend on the subjective opinion of the mapmaker as to how far these factors are important.

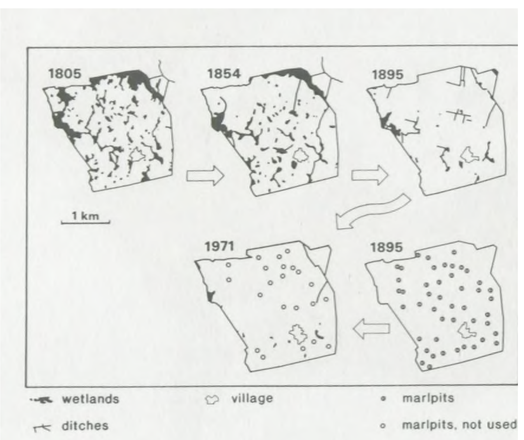



*Fig. 13: Changes in the areal extent of the wetlands and the number of marl pits in the Bjergesø Housing Association District for the period 1805-1971. (Danish Nature Conservancy) (Fredningsstyrelsen 1983).*

While making the map of Jutland showing areas of potentially acid sulfate soils, the Danish Ministry of Agriculture and the Department of the Environment (Landbrugsministeriet & Miljøstyrelsen 1984) limited their research to regions marked as wetlands on former maps, such as 1:20,000 topographic maps from the first half of this century. On these maps, the wetlands are symbolized as meadow, moorland and marshland. Furthermore, landscape types such as reclaimed areas, littorina deposits and the younger marine forelands are also classified as wetlands.

The wetlands are expected to have a potential drainage requirement. Most of their soils have a considerable capillary rise in the root zone during most of the growing season. Hence, calculating the root zone capacity would not give an accurate picture of the amount of water available to plants during the growing season.

Today, the wetlands of Denmark cover a much smaller area than that shown on the old, topographical maps. This is due to the subsequent drainage activities and the fact that some of the originally classified wetland area of the littorina plain lies so high that it is doubtful as to whether it should ever have been classified as wetland. However, for the purpose of these landscapes, it is not possible to distinguish between wetlands and non-wetland areas solely on the basis of information stored in the ADK database.

The greater part of the wetlands which has been drained during the past 60 to 80 years could presumably be recreated by terminating drainage activities. On the other hand, it will probably be impossible to recreate the former wetlands of the heaths and moorlands, which are dependent on a mature, spodic horizon. Many of these spodic horizons were destroyed by the onset of drainage activity.

The Danish wetlands have been digitized and their distribution is shown on Map 11. Table 11 reveals that the wetland areas on the islands of eastern Denmark are much smaller than those in Jutland. This is certainly true of the islands of Bornholm and Funen, as well as of Roskilde County on Zealand. These regions contrast markedly with North Jutland County which has the largest area of wetland of all the Danish counties. This is partly due to the presence of old marine forelands.

### *Slope factors*

An integral part of the Danish Soil Classification was the analysis of slope conditions. In 1974, the National Committee for Farm Buildings and Machinery carried out a series of experiments to discover the effect of slope gradient on the operation of agricultural machinery. These tests were made in the hilly district of Ugelbølle-Rønde, in Jutland. Table 12 shows the results. Three slope classes, based on gradient, were defined for the purpose of the map.

Class 1: 0° to 6° - Good working conditions.
Class 2: 6° to 12° - Acceptable working conditions.
Class 3: > 12° - Impossible working conditions.

According to the experiments, the effect of slope on the operation of farm machinery may be described as follows. In Slope Class 1, no physical restriction is caused by the prevailing slope conditions on the use of agricultural machinery. In Slope Class 2, the gradient is steep enough to hinder the optimal use of agricultural machinery, especially during the cultivation of root crops. In Slope Class 3, the gradient creates almost impossible conditions for the effective operation of agricultural machinery.

However, soil texture also plays a role, as it is possible to operate machinery on steeper gradients on clayey soils than on sandy soils. Moreover, soil erosion may affect all 3 slope classes. In Class 1, it may already occur on a slope as slight as 2° to 3° and then increase as the gradient increases. Besides hindering sowing, spraying, weeding and harvesting, steep slopes will also present a problem for irrigation by limiting those areas on which watering vehicles can manoeuvre.

The Raisz-Henry method (Monkhouse & Wilkinson 1970) was used for the slope analysis. The method involves the use of contour lines on a topographic map in order to divide areas into slope categories. For the Danish Soil Classification, the aforesaid three slope classes were chosen. Where possible, standard topographic maps were used at a scale of 1:25,000. However, they were not yet available at that scale for the regions of southern Zealand, Lolland, Falster and Møn. The latter were analyzed using atlas sheets at a scale of 1:40,000. The method bases the estimation of slope gradients on the intensity of contour lines. Given the scale of the map, it is possible to calculate a gradient by the intensity of equidistantly-spaced contour lines, provided that they occur across a sufficiently large surface area. This surface area was judged to be a minimum of 2 to 3 hectares. Furthermore, the strips of land had to be 50 m wide.

During the slope investigations, only the classified area was studied. Woodland and forestry plantations were omitted. To compensate for this omission, a mapping of the slope conditions in the unclassified area was carried out in 1988 based on the same principles.

Map 12 shows the slope classes for the whole country. Table 13 shows the percentage share of the three slope classes of the classified area, plus woodland. The results reveal that only 3% of the country is steeper than 6°, and only a little more than 1% is steeper than 12°. Furthermore, Table 13 shows that woodland is more common than arable land on undulating terrain. Table 14 shows similar facts. Approximately half of the land steeper than 12° is used as woodland or forest plantations, whilst this is only true of 10% of the land in Slope Class 1.

On the soil map, Slope Class 3 is indicated by double hatching and Slope Class 2 by single hatching.

Table 11 : The Distribution of the Wetlands and the Areas of Well-drained Soil, by County, for the Classified Area of the Danish Soil Classification.

| County | Total Area | Well-drained km² | Wetland km² | Well-drained % | Wetland % |
|---|---|---|---|---|---|
| Copenhagen | 143 | 128 | 15 | 89.8 | 10.2 |
| Frederiksborg | 797 | 684 | 113 | 85.9 | 14.1 |
| Roskilde | 665 | 617 | 48 | 92.7 | 7.3 |
| West Zealand | 2403 | 2099 | 305 | 87.3 | 12.7 |
| Storstrøm | 2813 | 2544 | 270 | 90.4 | 9.6 |
| Funen | 2834 | 2590 | 244 | 91.4 | 8.6 |
| Bornholm | 423 | 415 | 9 | 98.0 | 2.0 |
| South Jutland | 3362 | 2686 | 676 | 79.9 | 20.1 |
| Ribe | 2623 | 2063 | 560 | 78.7 | 21.3 |
| Vejle | 2389 | 2168 | 222 | 90.7 | 9.3 |
| Ringkjøbing | 3997 | 3134 | 863 | 78.4 | 21.6 |
| Århus | 3474 | 2835 | 638 | 81.6 | 18.4 |
| Viborg | 3443 | 2717 | 725 | 78.9 | 21.1 |
| North Jutland | 5162 | 3171 | 1991 | 61.4 | 38.6 |
| Whole Country | 34529 | 27851 | 6678 | 80.7 | 19.3 |

Table 12: Slope Gradient and its Effect on the Effective Operation of Farm Machinery.

| Operational Use of Farm Machinery | Slope Gradient cm/m (%) | degree of slope |
|---|---|---|
| Unusable | over 25.0 | over 14° |
| Difficult | 17.6 to 25.0 | 10° to 14° |
| Average | 10.5 to 17.6 | 6° to 10° |
| Very Good | under 10.5 | under 6° |

Table 13: The Distribution of the 3 Slope Classes in Denmark.

| | 0°-6° | 6°-12° | >12° |
|---|---|---|---|
| Whole Country | 96.1% | 2.7% | 1.3% |
| Classified area | 96.9% | 2.3% | 0.8% |
| Woodland | 88.1% | 6.5% | 5.4% |

Table 14: The Distribution of each Slope Class between the Classified Area, Woodland and other Forms of Land-use.

| | Classified Area | Woodland | Other Land-use |
|---|---|---|---|
| 0-6° | 81.0% | 9.9% | 9.1% |
| 6-12° | 68.7% | 26.1% | 5.2% |
| > 12° | 50.9% | 45.5% | 3.6% |

## Soil Profile Investigations

Since 1980, a long series of pedological investigations has been made in order to build up a national database on the physical characteristics and chemical properties of Danish soils. This research has been made possible due to the close cooperation between the following bodies; The Institute of Geography at Copenhagen University, the Chemistry Institute at the Royal Veterinary & Agricultural University, the Department of Land Data (ADK) and the Danish Research Service for Plant and Soil Science.

In 1980, a pilot project was carried out in Himmerland (Madsen 1983). Between 1981 and 1985, most of the soil profile investigations were undertaken in conjunction with the construction of the main natural gas pipeline being laid across Denmark by DONG (Dansk Olie og Naturgas). Three pipeline stretches were investigated; one pipeline from the German border to Egtved, another pipeline from the west coast right across to Copenhagen on the east coast, and a shorter pipeline east of Herning (Figure 14).

Approximately 900 soil profiles were examined during this period. Some 8,500 pedological classifications resulted from the field examinations carried out at regular 25 m intervals along sections of the pipeline (Madsen 1983b). At the same time, soil profile descriptions were made in the Tønder saltmarsh, and in the new polder, "Margrethe Kog" (Madsen & Jensen 1985).

Between 1987 and 1989, detailed soil profile investigations were based on the 7 km grid used for the national nitrate study being undertaken by the Danish Agricultural Advisory Service. This meant that exactly 7 km separated each site to be investigated, Figure 14. This produced 835 sampling sites: 672 on arable land, 116 on woodland, and 47 on heathland or meadows. The investigations began at 275 sites on Lolland and Falster, continuing in northern, eastern and central Jutland in 1987. In 1988, western Jutland and most of Zealand were investigated. The last areas were Funen and southern Jutland in 1989.

Hence, a comprehensive, national, soil profile database has been established.

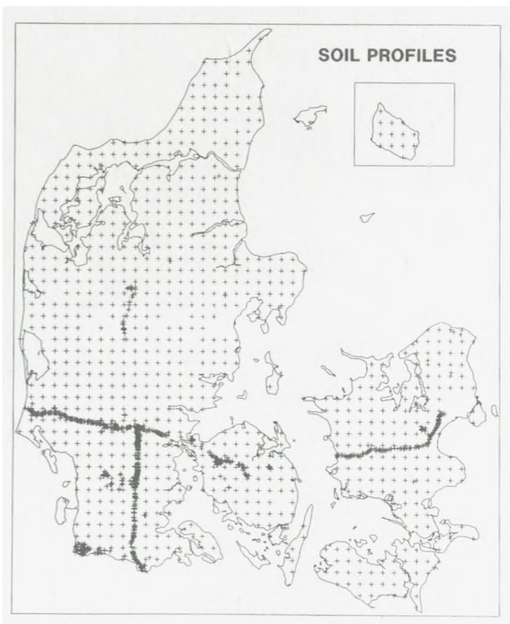
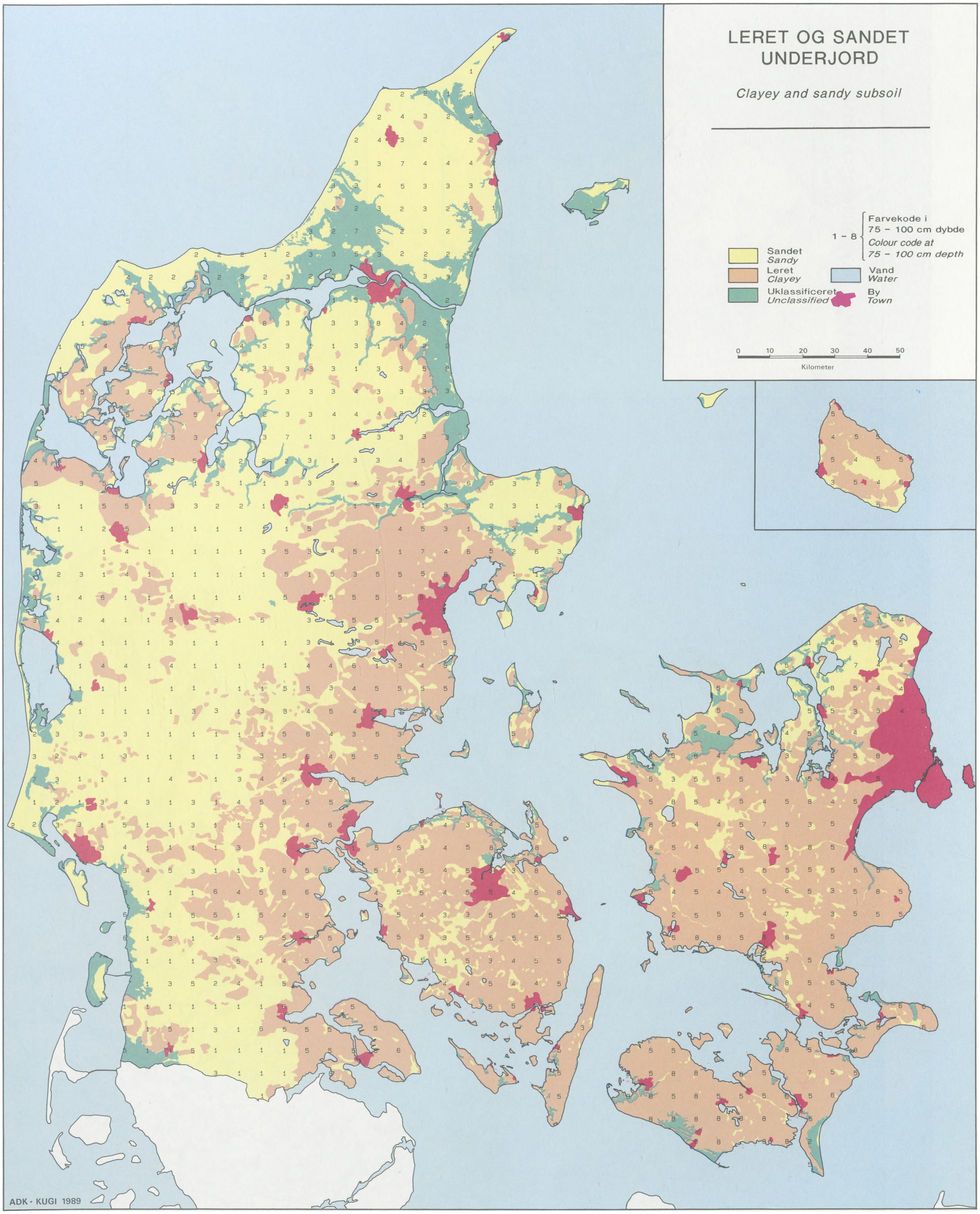



*Fig. 14: Soil profiles from the DONG natural gas pipeline trenches (1981-85) and the national nitrate grid (1987-89).*


LERET OG SANDET UNDERJORD
Clayey and sandy subsoil
1 - 8
Farvekode i 75 - 100 cm dybde
Colour code at 75 - 100 cm depth
Sandet
Sandy
Leret
Clayey
Uklassificeret
Unclassified
Vand
Water
By
Town
0 10 20 30 40 50
Kilometer
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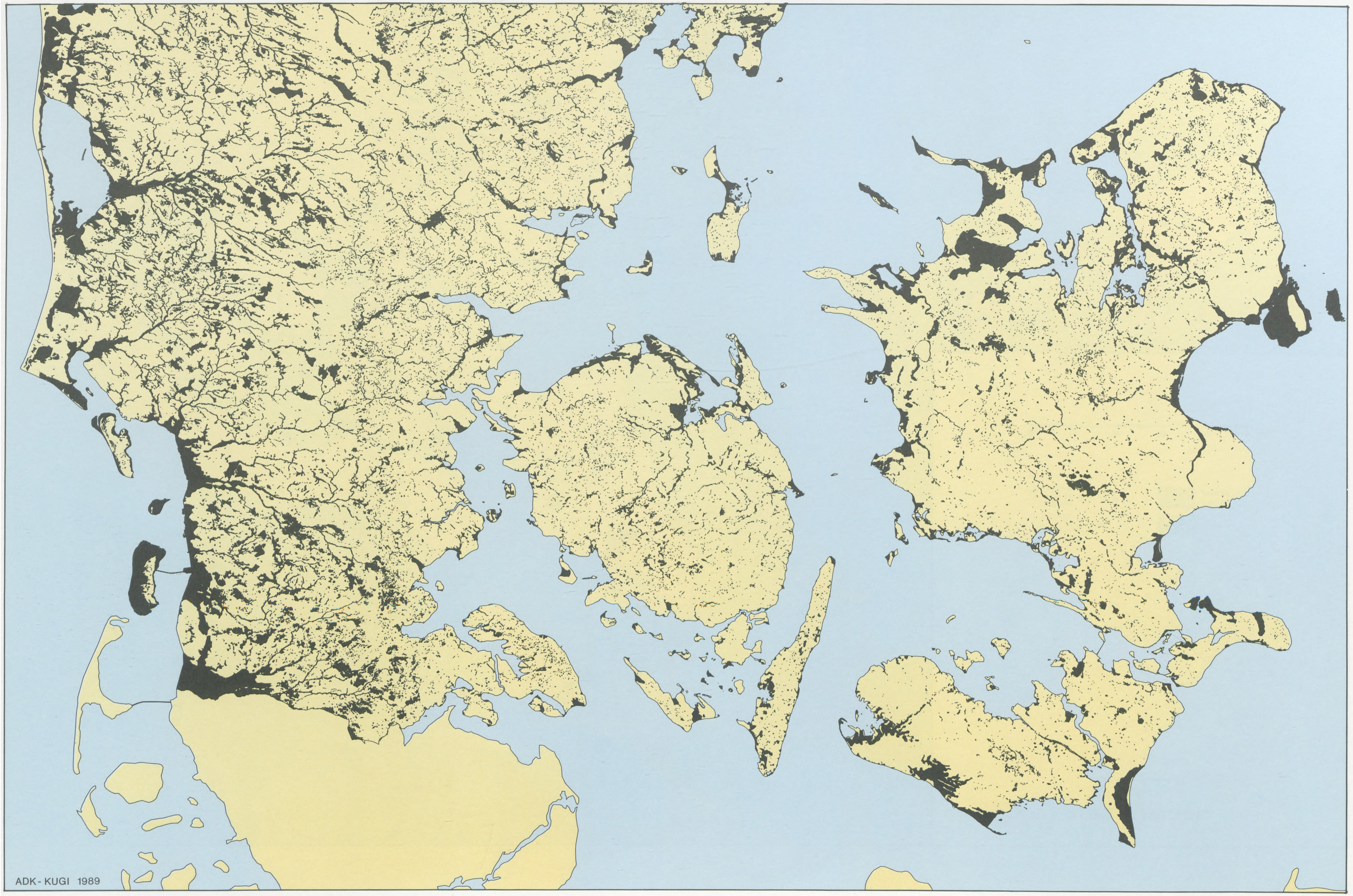
KORT 11

MAP 11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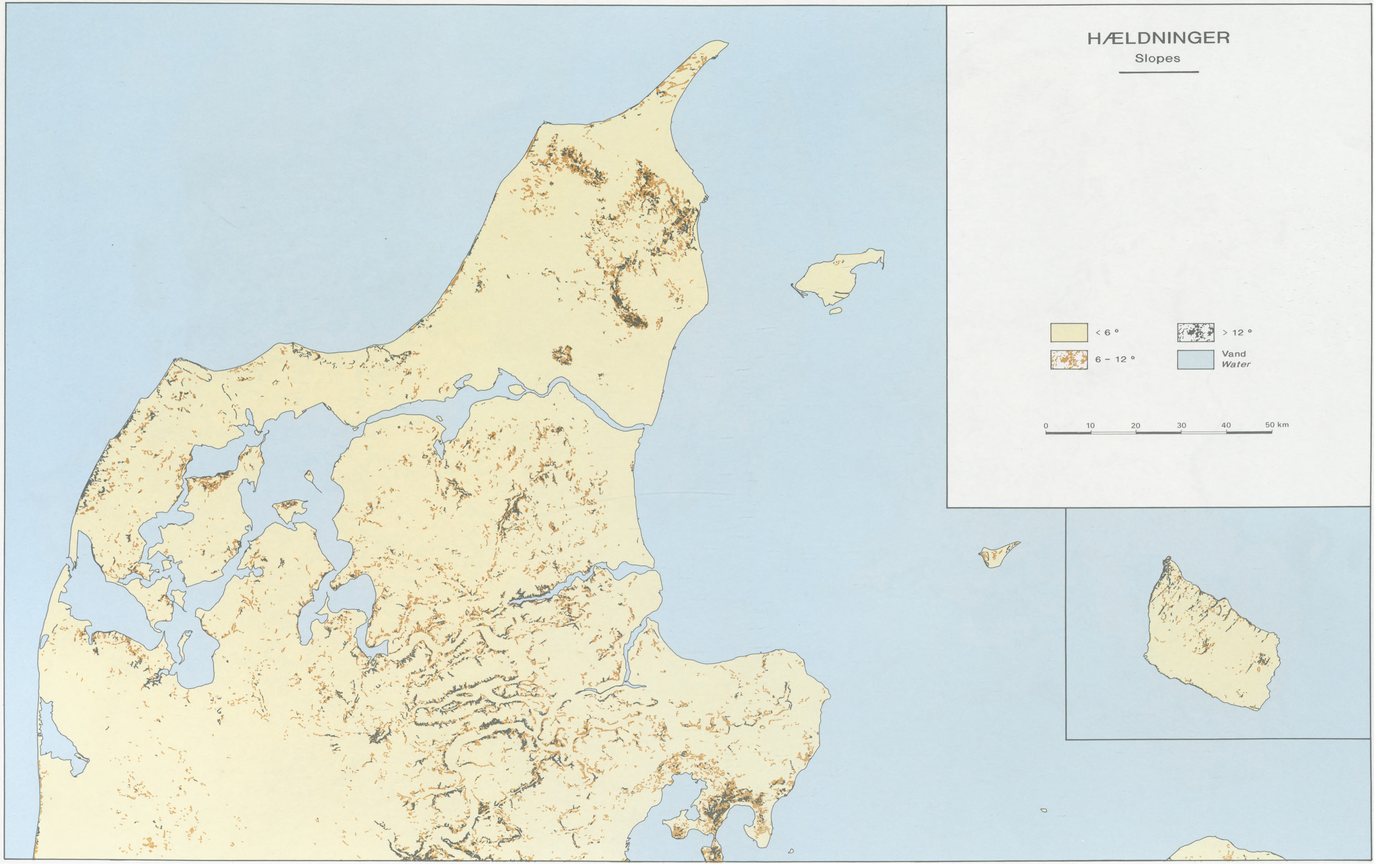
KORT 12




MAP 12

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## *Fieldwork and Analysis*

The soil profile investigation began by a profile being dug to a depth of 1.5 to 1.8 metres, or only down to the water-table where this lay higher than 1.8 metres from the surface. Then the profile was photographed and the photographs stored in a photographic library. The profile was then divided into soil horizons and described according to "A Key to Soil Profile Description" (Madsen & Jensen 1988), which is a variation of FAO's "Guidelines For Soil Profile Description" adapted to conditions prevailing in Denmark and designed to be compatible with computer data storage and retrieval. According to the key, the following details of the soil profile were recorded:

- Horizon sequence
- Horizon depth
- Horizon colour and related characteristics (mottling, gleys)
- Parent material
- Horizon texture, and organic/chalk/stone content
- Horizon structure and consistency
- Macropore characteristics and root density
- Nodules, cementations, pans and cutans

Further details included; the date of the profile sampling, the name of the researcher, profile registration code, UTM grid reference, nature of the terrain, topographical features of note, slope gradient, profile depth, water-table depth, drainage class, vegetation type etc. Figure 15 shows the standard form that was to be completed during the field profile description.

Samples were taken from each horizon in order to determine the physical characteristics and the chemical properties of the soil. In most of the analyses, disturbed samples were used. Approximately 500 cm of soil was collected from each horizon. In order to determine soil water retention, samples were collected in tubes in order to retain the natural in situ layering. The volume of each tube was about 100 cm. 3 tubes were extracted from each horizon. To determine the soil water content at pF 4.2, sub-samples were taken from the disturbed samples. Normally, samples were taken at 4 to 6 different depths. The inorganic horizons were analyzed for; texture, humus, calcium carbonate content and pH. Many samples were analyzed for; total nitrogene, phosphorus, dithionite-citrate and pyrophosphate-soluble iron and aluminium, cation exchange capacity, and soil water retention. For certain profiles, information was obtained on; the mineralogy, citric acid-soluble phosphorous, KCl-soluble A1 and H, and root density (Madsen & Jensen 1985). In total, some 10,000 soil profile samples have been stored in the Soil Archives at ADK.

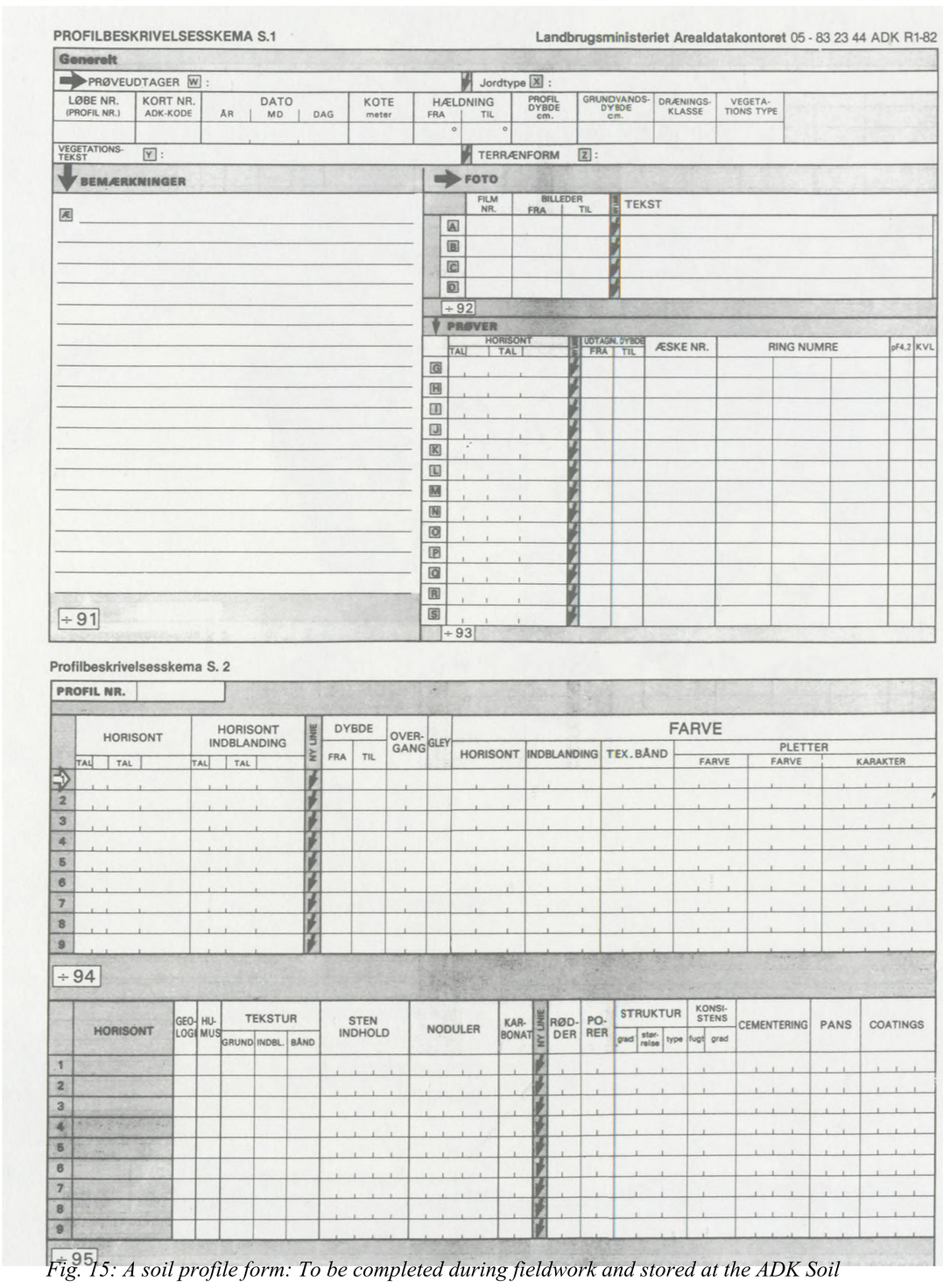



*Fig. 15: A soil profile form: To be completed during fieldwork and stored at the ADK Soil Profile Database.*

## *Data Storage and Results*

All fieldwork data and the results of soil analysis have been stored in databases at ADK. Data files exist on the following:

a) Soil profile descriptions
b) Pedological classifications from the pipeline trench
c) Texture, humus, pH ($CaCl_2$), pH ($H_20$), calcium carbonate content.
d) CEC, exchangeable bases, acid ions
e) Iron and aluminium soluble in dithionite-citrate and pyrophosphate, as well as electric conductivity.
f) Total nitrogen, total and organic phosphorous
g) KCl-soluble aluminium and citric acid-soluble phosphorous
h) Soil water retention
i) Mineralogical measurements of sand, silt and clay fractions
j) Root density, pH($CaCl_2$), bulk density

Nearly all the data are stored numerically, including the profile descriptions and classifications, hence it is easy to obtain computer prints on specific characteristics of the soil profile. To aid the user, the numerical data can be converted into a comprehensive, written description.

Map 9 indicates where calcareous soils are located, based on the soil information from the national nitrate grid. Most of the soils containing chalk or limestone in the uppermost two metres are to be found in the young moraine landscapes of Zealand, Lolland, Falster, and Funen. These are the areas in Denmark where pre-Quaternary, calcareous, sed imentary parent material, lying close to the surface, was eroded by the Baltic ice during the last glaciation and incorporated into the till.

Map 10, shows the MCC for soil samples taken at a depth between 75-100 cm. These samples also stem from the national nitrate grid. In the young moraine landscape, there is a definite tendency for this lower layer to be more clayey or more calcareous than the topsoil. This is due to clay illuviation and the leaching of calcium carbonate.

Map 13 is a local soil map showing the area east of the town of Ribe in Jutland. It combines several elements of the Danish Soil Classification; the MCC, landscape details, wetland areas and the Quaternary geology (Balstrøm 1990).

Based on the results from the soil profile investigations in the 7 km grid, the pedological development of the soils in Denmark is shown in figure 16.

The pedological development of soils is a function of the soil forming factors; climate, vegetation, parent material, slope, human activity and time. Before discussing the pedological development of Danish soils demonstrated in figure 16, a short presentation of the soil forming factors relevant to Denmark will be given.

Denmark has a temperate, Atlantic climate with a winter mean of about 0°C and a summer mean of about 17°C. The mean annual precipitation ranges from about 800 mm in central Jutland to below 500 mm in the Great Belt region. The annual potential eva potranspiration is about 550 mm, the annual actual evapotranspiration being about 380 mm.

In spring and early summer, the potential evapotranspiration exceeds precipitation, and the vegetation utilizes water stored in the root zone, causing depletion of soil water. In late summer and early autumn, the soil water reserves are replenished due to a precipitation surplus. In late autumn, winter and early spring, leaching takes place. In central Jutland, the annual percolation exceeds 400 mm. In the Great Belt region it is about 150 mm (Aslyng 1978).

The natural vegetation is deciduous forest, the climax vegetation being beechwood. Today, about two-thirds of the country is agricultural land that is manured, limed and, to some extent, drained. Only about 10% is under forest, and a large part of this is spruce plantations.

The origin and texture of the parent material are shown in map 8, 9, and 10, and map 12 shows the slope conditions at national scale. The major part of the country consists of Weichsel glacial deposits, mainly tills. In western Jutland, old relic Saale glacial deposits and the younger Weichsel outwash plain deposits dominate, while in northern Jutland marine deposits cover large areas. Along the west coast of Jutland, sand dune and saltmarsh deposits are dominant. The Danish landscape is generally flat or slightly undulating. About only 1% of the country has slopes with gradients exceeding 12°.

Figure 16 A shows the soil profiles in the 7 km grid classified according to the FAO-Unesco Soil Classification system (1974).

The soils have been grouped into eight classes according to the classification system. The classes reflect the dominant soil forming processes.

1) podzolized sandy soils
   FAO: podzols
2) non-podzolized sandy soils
   FAO: arenosols, regosols
3) acid loamy and clayey soils with clay illuviation
   FAO: acrisols, podzoluvisols
4) neutral or slighly acid loamy or clayey soils with clay illuviation
   FAO: luvisols, luvic and most gleyey phaeozems
5) loamy or clayey soils without clay illuviation
   FAO: cambisols, phaeozems except luvic and some gleyey ones
6) wetland soils showing gley formation
   FAO: gleysols, fluvisols
7) wetland soils showing deep peat formation
   FAO: histosols
8) soils on limestone
   FAO: rendzinas

The sandy soils are mainly regosols, arenosols or podzols, while the more clayey soils are cambisols, phaeozems, luvisols, acrisols or podzoluvisols. The wetland soils are mainly gleysols, fluvisols or histosols. This means that the overall soil forming processes on well-drained sites reflecting the soil forming factors are; acidification due to the leaching of calcium carbonate and exchangeable bases, weathering of the different minerals, migration of clay particles on loamy or clayey soils, and podzolization of sandy soils involving translocation of humus, iron and aluminium (hydr)oxides from the A to the B horizon. In wetlands, gleys and peats will form.

Because the sampling has been carried out in a fixed grid, it is possible statistically, to make some simple estimations on the occurrence of different soils found within different geographical regions. Table 15 shows the number and percentage share of the different soils in relation to the landscapes shown in Map 9. The landscape types reclaimed land and salt marsh have been excluded as the number of soils investigated in these areas was very small. However, most of the soils of these two landscapes are fluvisols or gleysols. Areas with mixed landscape types where the soils cannot be related to a definite landscape have been excluded.

In the littorina areas, wet soils dominate: 56% are gleysols or fluvisols, while 9% are histosols. On the more elevated parts, arenosols are most common while podzols are rare. On the Yoldia plateau, well-drained, non-podzolized, sandy soils dominate, while loamy soils are rare. The wetlands are mainly situated in deep narrow valleys. In these valleys, histosols dominate. The dune landscapes have arenosols (regosols) and podzols on the well-drained parts, while the wetlands are characterized by gleysols, some of which have thin histic epipedons. In the Saale glacial landscape and on the Weichsel glacial outwash plains, podzols dominate, accounting for about two-thirds of the profiles investigated, while arenosols cover less than 20% of the area. Among the loamy soils, no specific soil type dominates. The wetland soils, mainly gleysols and fluvisols, cover about 10% of the area. Only 1% are histosols. In the Weichsel glacial landscape, luvisols are the dominant soil type, accounting for 40% of the investigated profiles. Cambisols cover 15% of the area, while acrisols cover only 5%. Among the sandy soils, arenosols seem to be a little more common than podzols. The wetland soils account for 11% of the investigated profiles, 9% were gleysols/fluvisols and 2% were histosols. The three rendzinas, mentioned earlier, were also found in these areas.

In the country as a whole podzols and luvisols are the most common soils. Each covers 26% of the investigated area. Arenosols,

Table 15: Soil Types in Relation to Landscapes based on the Soil Profile Investigations in the 7 km Grid.

| | Number of Profiles | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | P | QR | AD | LH | CH | GJ | o | E |
| Saltmarsh | 6 | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 0 |
| Littorina | 41 | 1 | 9 | 0 | 0 | 2 | 25 | 4 | 0 |
| Yoldia | 24 | 4 | 11 | 2 | 1 | 2 | 0 | 4 | 0 |
| Dune | 23 | 9 | 10 | 0 | 0 | 0 | 4 | 0 | 0 |
| Saale | 90 | 52 | 10 | 8 | 5 | 7 | 7 | 1 | 0 |
| Outwash Plain | 93 | 64 | 17 | 0 | 0 | 2 | 9 | 1 | 0 |
| Weichsel | 487 | 60 | 76 | 26 | 194 | 76 | 44 | 8 | 3 |
| Other | 19 | 9 | 2 | 1 | 0 | 0 | 7 | 0 | 0 |
| Total | 783 | 200 | 135 | 37 | 200 | 89 | 100 | 19 | 3 |

P = podzol, QR = arenosol/regosol, AD = acrisol/podzoluvisol,LH = luvisol/phaeozem with Bt, CH = cambisol/phaeozem without Bt,GJ = gleysol/fluvisol, O = histosol, E = rendzina.

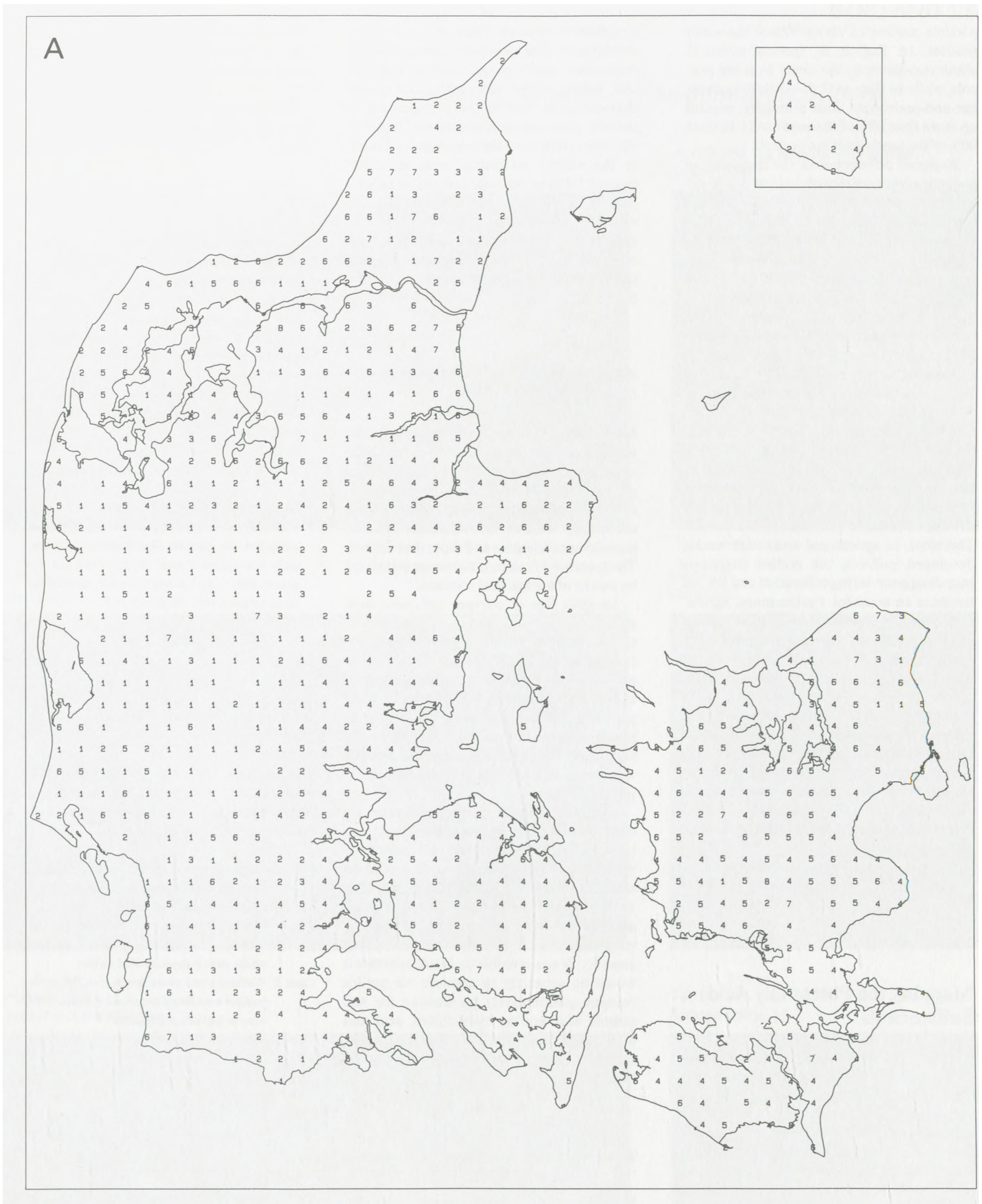
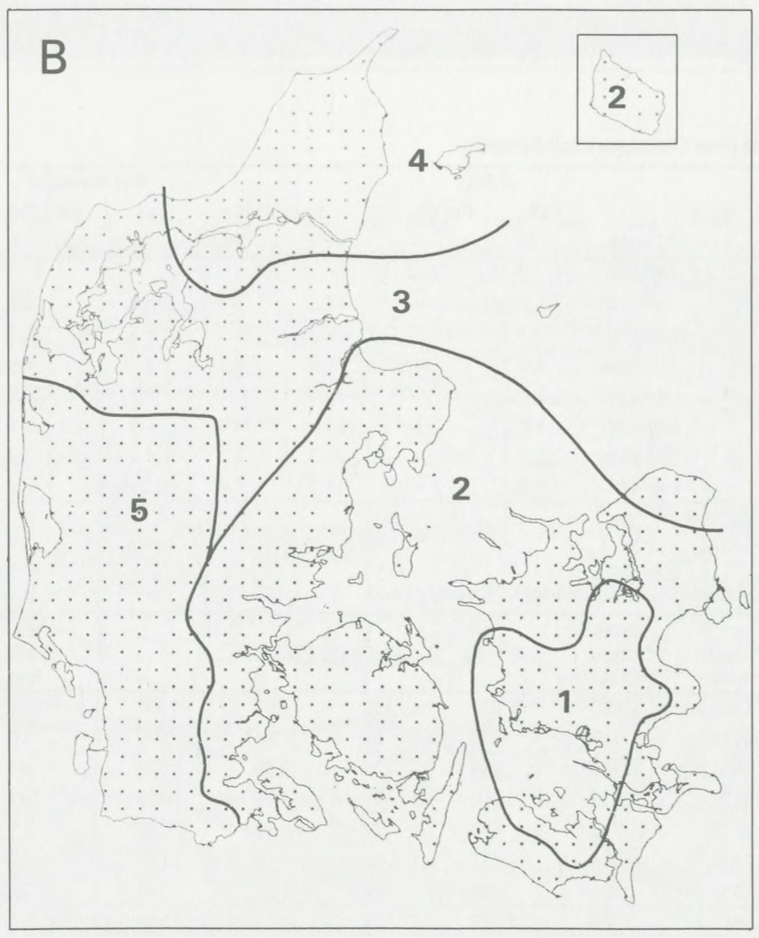



*Fig. 16: The pedological development of Danish soils based on the results from the soil profile investigations within the 7 km grid.*

*Fig. 16A: Denmark - Major soil groupings according to the 1974 FAO-Unesco Soil Classification system that are found within the 7 km grid.*

*1) podzol*
*2) arenosol, regosol*
*3) acrisol, podzoluvisol*
*4) luvisol, phaeozem with Bt*
*5) cambisol, phaeozem without Bt*
*6) gleysol, fluvisol*
*7) histosol*
*8) rendzina*



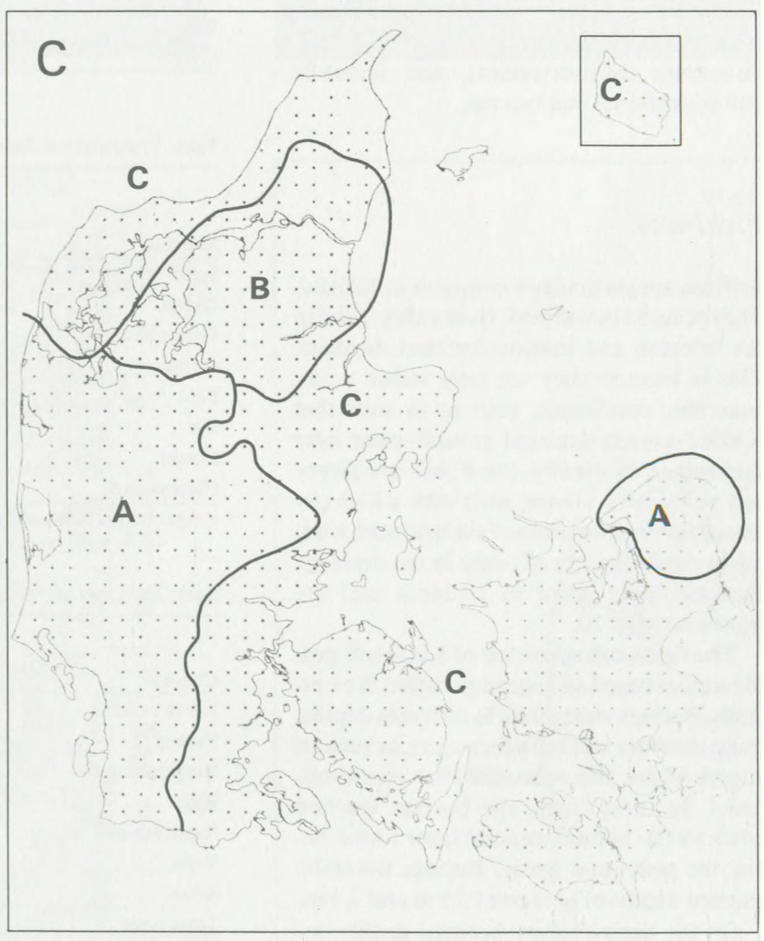




*Fig. 16B: Denmark - Soil regions based on the pedological development of soils on loamy or clayey parent materials.*

*1: cambisol > luvisol; acrisol absent*
*2: luvisol » cambisol; acrisol nearly absent*
*3: luvisol > acrisol = cambisol*
*4: acrisol » luvisol = cambisol*
*5: acrisol = cambisol > luvisol*

*Ratio: » higher than 3, > 1.5 to 3, = less than 1.5.*

*Fig. 16C: Denmark - Soil regions based on the pedological development of soils on sandy parent material.*
*A: podzols » arenosols*
*B: podzols > arenosols*
*C: arenosols » podzols*
*Ratio: » higher than 3, > 1.5 to 3, = less than 1.5.*

cambisols and gleysols each cover 10% to 20% of the investigated area, while acrisols, histosols and rendzinas are rare, covering 5%, 2% and less than 1%, respectively. The rather well-drained soils cover 86% of the area, and the wetland soils 14%.

Figure 16B shows the dominant soils, and hence the dominant soil forming processes, for well-drained loamy and clayey soils in different parts of the country. Five major regions have been identified. Two major geomorphological features can be recognized on the map; the Main Terminal Moraine and the East Jutland Terminal Moraine.

Region 1 (cambisol>luvisol) includes the southwestern part of Zealand and the northern part of Lolland. The parent material in this region is mainly loamy calcareous till. The dominant soil forming processes are weathering and structure formation. The soils are classified as cambisols. Clay illuviation leading to the formation of luvisols was only apparent in one-quarter of the profiles. Acid soils with clay illuviation are not found in the region.

Region 2 (luvisol»cambisol) covers almost the entire remaining area east of the East Jutland Terminal Moraine. In this region, about 80% of the soil profiles are luvisols. These are neutral or slighly acid soils with clay illuviation. Only about 20% of the soils are cambisols, and acrisols are nearly absent.

Region 3 (luvisol>acrisol=cambisol) has a ratio of soils with and without clay illuviation similar to that found in Region 2, but acid soils with clay illuviation are more common, making up about one-quarter of the soils investigated. Luvisols are still dominant, covering more than half of the area.

Region 4 (acrisol>>luvisol=cambisol) covers Vendsyssel and the northern part of Himmerland. The area is mainly sandy and only 14 soil profiles have developed on loamy or clayey parent material. Among these, acrisols dominate, making up about 70% of the profiles. The loamy and clayey soils in the northern part are more acid than in the south, but soils with a loamy and clayey texture are rare in this region.

Region 5 (acrisol=cambisol>luvisol) includes the loamy and clayey parts of the Saale glacial landscape. None of the three types dominate in this region. There is more or less the same areal extent of acrisols and cambisols (about 40% each), while luvisols cover about 20% of the area.

Overall, luvisols are dominant on well-drained loamy and clayey deposits, and they constitute about two-thirds of the profiles. Cambisols, which are dominant in Region 1, account for about one-quarter of the investigated soil profiles, while acrisols make up one-eighth. This means that clay illuviation is the dominant soil forming process in loamy and clayey soils, and the large majority of the soils are only slightly leached (acidified).

The regional variation in soil types is probably mainly due to differences in the physical and chemical properties of the parent material and the time factor. In Regions 1 and 2, the Baltic ice deposited a loamy till with a clay content of about 25%. East of the Great Belt and in the eastern part of Funen, the till was often calcareous when deposited, and in many places it still contains calcium carbonate within a depth of two metres. The parent material has therefore been very resistant to acidification, and acid, clay-illuviated soils are rare in these regions. The tills in Regions 3 and 4 are not so clayey, containing 10 to 15% clay, and they are not so calcareous. Resistance to acidification is low, and acid soils with clay illuviation are more common. No soils in the regions mentioned above are older than about 15,000 years, the time when the Weichsel Glaciation terminated in Denmark. By contrast, the parent materials in Region 5 might be much older because the tills were deposited during the Saale Glaciation. This has caused a severe leaching of the soil bases and thereby the formation of acid soils.

Figure 16C shows Denmark divided into three regions according to the frequency of podzolized sandy soils. Region A, (podzol» arenosol), covers the area west of the Main Terminal Moraine of central Jutland and some parts of central eastern Jutland. Furthermore, northeastern Zealand belongs to this soil group. There is a clear dominance of podzols making up about 90% of the sandy profiles. In Region B, (podzol>arenosol), about two-thirds of the sandy soils are podzols, while in Region C, (arenosol» podzol), the non-podzolized soils dominate, making up more than 80% of the sandy soils. In total, 60% of the sandy soils are podzols.

Regional differences in the frequency of podzolization are probably mainly due to differences in parent material, land-use, natural vegetation and time. In the west, mainly in Regions A and B, heather vegetation (Calluna Vulgaris) has covered the land for centuries, generating a strong and deep podzolization of the soils. Podzolization is also common in soils in areas afforested with spruce, but not in soils under oak forest (Muller 1884, Larsen 1971). Oakmay even destroy an existing podzol profile (Nielsen et al. 1987ab). Sandy materials, low in iron and aluminium hydroxides, are also more vulnerable to podzolization than more iron and aluminium-rich soils (Petersen 1976, Madsen 1983a). A strongly developed podzol soil will not lose its characteristic subsurface horizons when subjected to ploughing, but this may occur in weakly developed podzols with shallow B-horizons. Therefore, in agricultural areas with weakly developed podzols, the podzol characters may disappear during cultivation and the soil becomes an arenosol. Furthermore, agricultural practices prevent podzolization because of liming, manuring, and the conversion of mor into mull. The time factor is especially important in the sand dune areas of Denmark. The deposits in these regions may be so young that the degree of podzolization will be very low. Regional variation in relation to the Danish climate, especially its influence on the amount of percolation, does not seem to play an important role, as podzols can be found in all climatic zones even in the dry areas of the Great Belt, such as those found on the island of Langeland, at Røsnæs, and in the coastal cliff of Knudshoved Odde.

## Mapping the Potentially Acid Sulfate Soils

Between 1981-84, Jutland was mapped to indicate potentially acid sulfate soils, which means those areas which contain sulfide in such large quantities, that they would become extremely acid, due to the production of sulfuric acid, if drained. Apart from other detrimental effects, this may lead to an increased ochre burden for the recipients in the vicinity such as ditches, streams and lakes. The investigation was carried out in accordance with the Act of Parliament of 18th February 1981, paragraph 57, endorsing the mapping of all sulfide-rich areas in Jutland with a potential for ochre formation. The survey was carried out by ADK and conducted by representatives from the Ministry of Agriculture (Landbrugsministeriet), the Department of the Environment (Miljøstyrelsen), and scientific and educational institutions.

### *Fieldwork*

Sulfides are particularly common in Jutland. They occur in marshland, river valleys, and in the littorina and marine foreland deposits. This is because they are only stable under anaerobic conditions, such as in soils that contain oxygen-depleted ground-water near the surface. Normally, these soils are gleyey and peaty soils. Hence, soils with a high potential for the formation of sulfuric acid, leading to the formation of ochre in the drainage channels, only occur in wetlands and are shown on Map 10.

The fieldwork consisted of 8,000 soil profile studies based on augerings within the wetlands. Borings were made to different depths, using chamber and cylinder augers, or suction augers where the sediment was unconsolidated. In most cases, the borings reached down to the natural mineral layer found below the peats and gyttja. Borings normally reached depths of between 1.25 m and 2.5 m.

On the basis of these borings, profile descriptions were made. The horizons were described according to; texture, colour, calcium carbonate content, pungency of the $H_2S$ content, height of the water-table, and special characteristics such as the precipitation of jarosite, plant remains, concretions and ores etc. Information on the occurrence of ochre in the nearby recipients, such as watercourses, lakes or drainage hollows, or in local drainage pipes was also recorded. All samples were taken from below the water-table. The discovery of any distinctive stratification necessitated the taking of more than one sample. On average, two samples were taken from each profile.

### *Analytical Methods and Classification*

More than 14,000 samples were taken. On the very day of sampling, the pH-value of each sample was measured by the insertion of a glass electrode. Soil colour was determined by use of the Munsell Soil Color Charts. Then the samples were divided into those containing calcium carbonate and those that did not. The presence of calcium carbonate was tested by means of a weak acid solution.

Samples free of calcium carbonate were treated with a few drops of acid drainage water taken from a pyrites-rich soil. Afterwards, they were oxidized for up to 16 weeks. The pH-values were measured by the insertion of a glass electrode after 2, 8 and 16 weeks. If the pH-value fell below 3 after the second or eighth week of oxidization, or if there was no significant fall in the pH-value, the analysis was terminated before the 16 weeks had expired.

Samples containing calcium carbonate were tested for their pyrites content by a semi-quantitative X-ray method. The capacity of the soil samples to neutralise acids was determined as m.eq. Ca + Mg/100 g soil, after having shaken the samples in hydrochloric acid. By comparing the semi-quantitative pyrites measurement with the acid neutralising capacity, it was possible to decide whether it would be necessary to measure the pyrites content quantitatively by treating the soil sample with boiling hydrochloric acid and nitric acid. The quantitative analysis was undertaken by the Danish Heath Society in Viborg, Jutland.

Tables 16 and 17 show respectively the analytical results for those samples that contained calcium carbonate and those that did not.

Each sample was classified according to its degree of acidity on the basis of the following criteria:

1. Samples not containing calcium carbonate:

a) Where the pH-value fell to below 3, after 2, 8 or 16 weeks of oxidization, the sample was classified as being potentially acid sulfate.
b) Where the pH-value fell to between 3 and 4, and gave a value of more than 1 unit lower than the pH-value at the time of sampling, the sample was classified as being slightly potentially acid sulfate.
c) All other samples were regarded as containing an insignificant amount of pyrites, if any, and were therefore classified as not being potentially acid sulfate.

2. Samples containing calcium carbonate

Based on the assumption that for every 100 g. soil each 1% of pyrites produces 34 m.eq. $H_2SO_4$ on oxidation, the samples were classified as potentially acid sulfate if m.eq. $H_2SO_4$/100 g soil was greater than m.eq. Ca+Mg/100 g soil, determined by an infusion with 100 ml 4N HCl.

### *Regional divisions and the Area Report*

The wetlands were divided into potential acidity classes, based on the frequency of profiles containing potentially acid sulfate soils. Four classes were defined:

Class 1: Wetland areas where more than 50% of the profiles were found to contain samples which were potentially acid sulfate.
Class 2: Wetland areas where between 20% and 50% of the profiles were found to contain samples which were potentially acid sulfate.
Class 3: Wetland areas where fewer than 20% of the profiles were found to contain samples which were potentially acid sulfate.
Class 4: Wetland areas where no profiles were found to contain samples which were potentially acid sulfate.

Table 16: Analytical Results from Non-calcareous Soil Samples.

| | | pH-Value | | | |
|---|---|---|---|---|---|
| Material | Depth | At Sampling | 2 weeks | 8 weeks | 16 weeks |
| Sand | 140-150 | 5.9 | 4.2 | 3.8 | - |
| Sand | 145-155 | 6.4 | 6.1 | 5.4 | - |
| Sand | 115-125 | 6.2 | 5.8 | 6.6 | - |
| Sand | 125-135 | 6.4 | 3.8 | 3.3 | 2.9 |
| Sand | 140-160 | 5.8 | 4.6 | 3.4 | 3.6 |
| Gyttja | 60- 80 | 6.2 | 2.8 | - | - |
| Peat | 130-150 | 4.8 | 4.0 | 3.9 | - |
| Peat | 110-125 | 5.8 | 3.6 | 2.5 | - |
| Gyttja | 180-205 | 4.9 | 3.0 | 2.5 | - |

Table 17:Analytical Results from Calcareous Soil Samples.

| | | X-Ray | | | | Wet chemical | |
|---|---|---|---|---|---|---|---|
| | | $FeS_2$ | $FeCO_3$ | m.eq./100g. | | $FeS_2$ | HCl(Fe) |
| Material | Depth | % | - | Ca | Mg | % | % |
| Sand | 140-150 | 0 | (+) | - | - | - | - |
| Gyttja | 60- 70 | 1.8 | + | 15.5 | 2.5 | 0.47 | 4.3 |
| Gyttja | 130-150 | 3.3 | + | 11.5 | 26.7 | 3.2 | 3.7 |
| Gyttja | 110-120 | 4.9 | + | 21.0 | 4.2 | 8.1 | 4.8 |
| Peat | 90-110 | 3.1 | + | 42.0 | 1.7 | 1.9 | 23.0 |
| Silt | 120-130 | 2.2 | + | 353.0 | 61.7 | 1.3 | 2.3 |
| Gyttja | 80-110 | 2.0 | + | 24.5 | 1.7 | 1.1 | 2.3 |
| Clayey sand | 140-150 | 1.7 | + | 84.5 | 15.8 | 0.35 | 1.1 |

+ signifies presence of $FeC0_3$

Table 18: Areas of Potential Acidity in the Counties of Jutland ($km^2$).

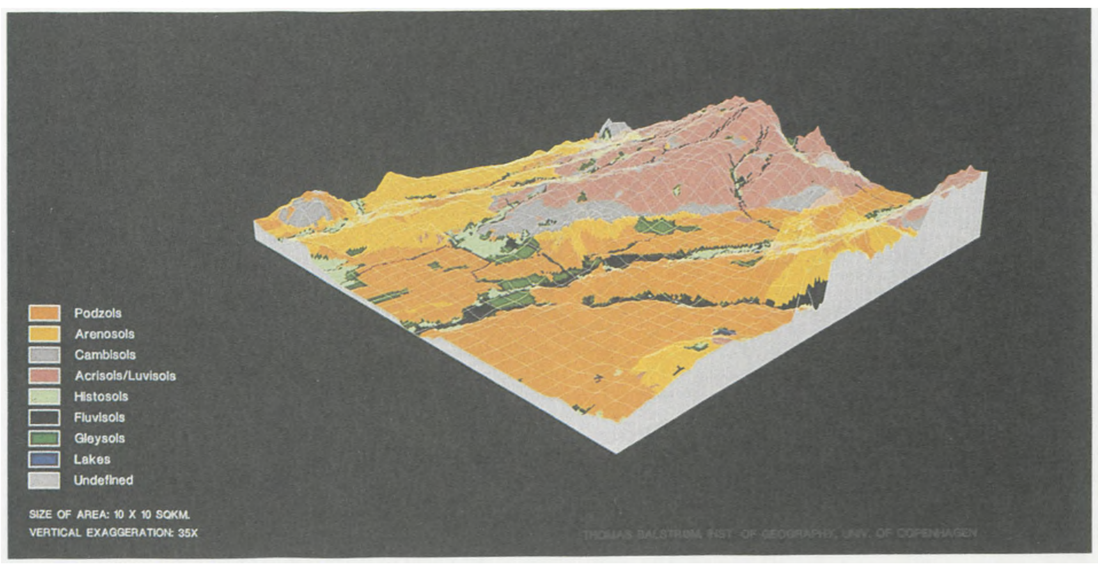
| | | | Drainage Class | | | | |
|---|---|---|---|---|---|---|---|
| County | Total Area | Wet-land Area | 1 | 2 | 3 | 4 | Un-classi-fied |
| North Jutland | 6160 | 2133 | 257 | 172 | 361 | 1208 | 135 |
| Viborg | 4110 | 713 | 258 | 62 | 84 | 299 | 10 |
| Ringkjøbing | 4861 | 860 | 354 | 121 | 124 | 198 | 63 |
| Ribe | 3121 | 537 | 160 | 69 | 72 | 203 | 33 |
| South Jutland | 3856 | 722 | 279 | 84 | 93 | 259 | 7 |
| Vejle | 2997 | 254 | 71 | 19 | 5 | 137 | 22 |
| Århus | 4561 | 691 | 138 | 62 | 122 | 345 | 24 |
| Total Area | 29667 | 5910 | 1517 | 589 | 861 | 2649 | 294 |

# JORD- OG AREALKLASSIFICATION

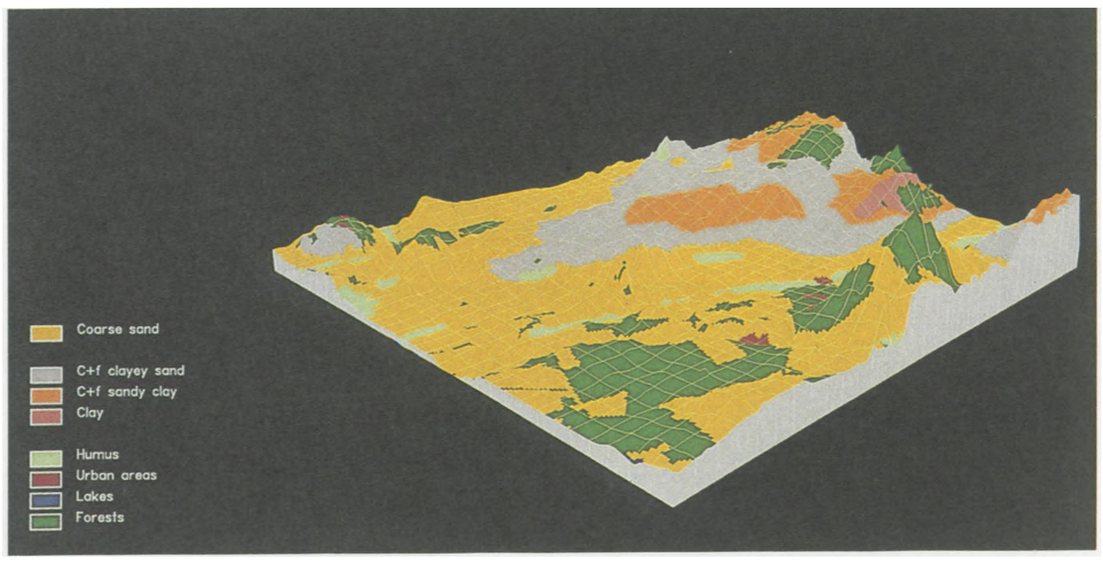
# SOIL AND LAND CLASSIFICATION

## Hygum, Ribe Å. — *Hygum area, Ribe Å.*

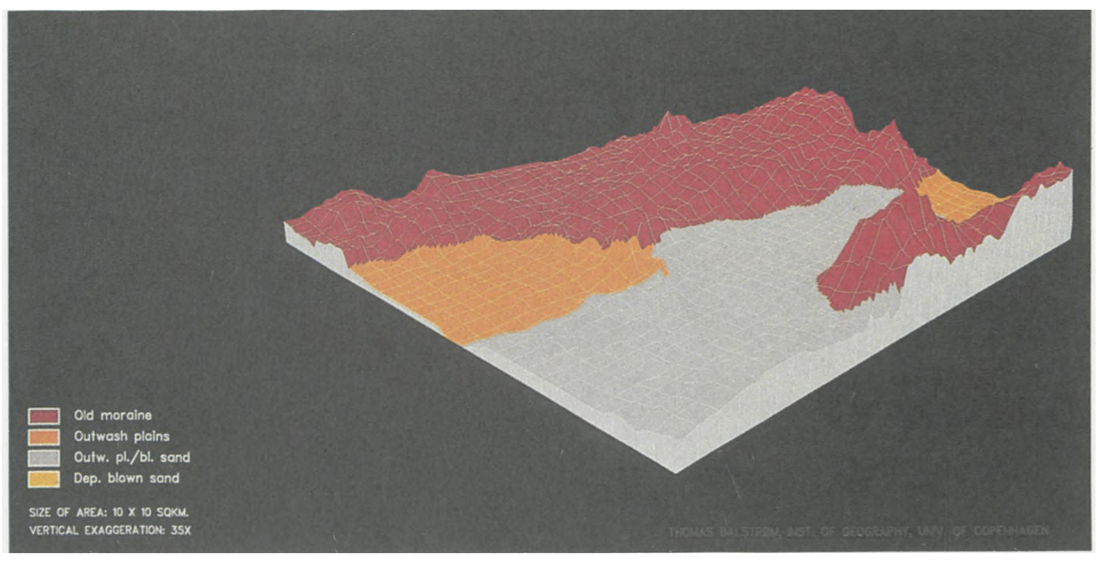
Jordbundstyper.
*Soil map (FAO )*



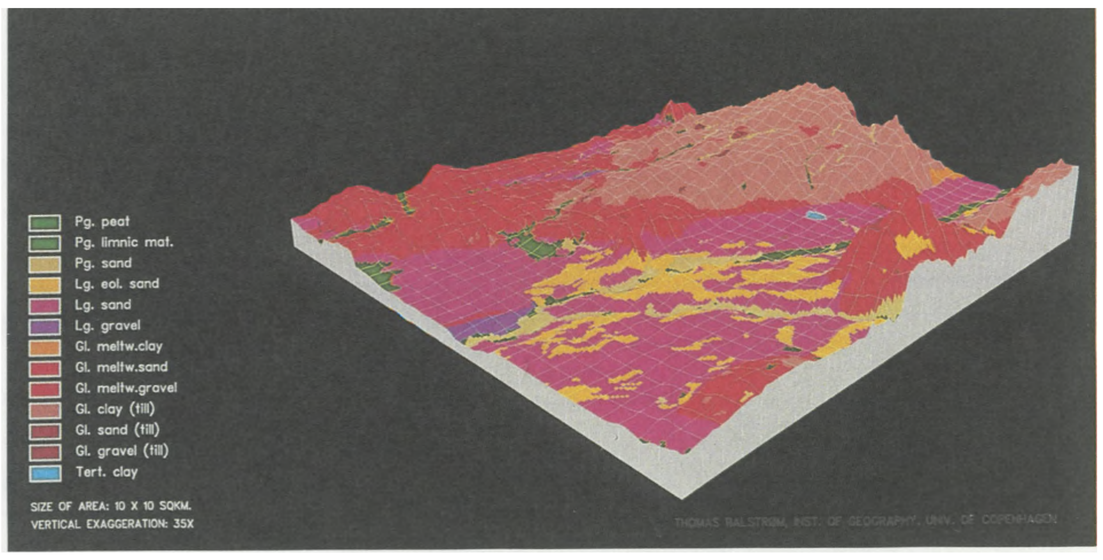

Jordbund og arealanvendelse.
*Soil types.*



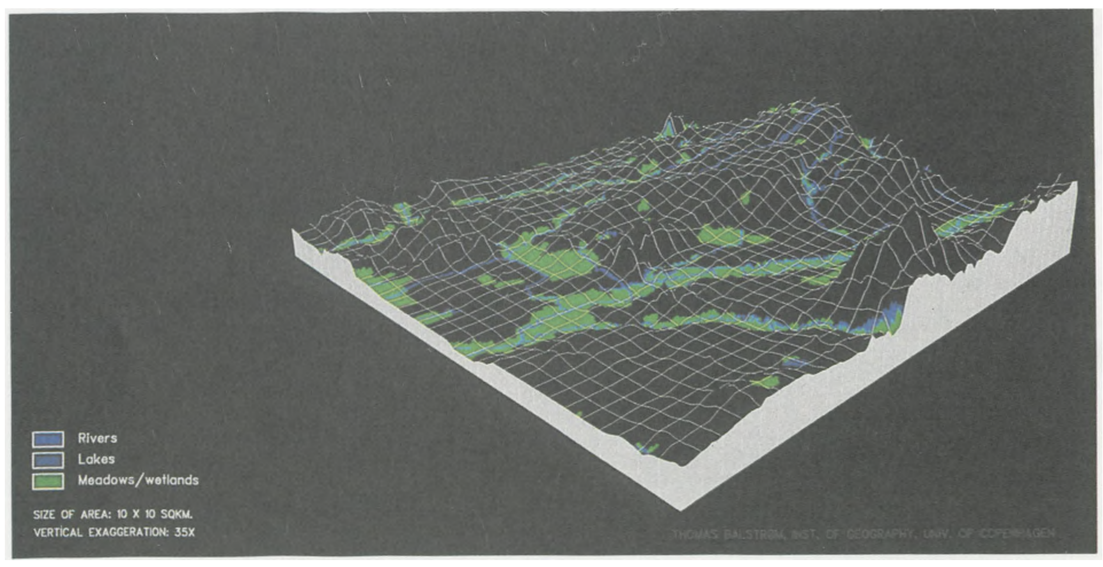

Geomorfologi.
*Geomorphology.*



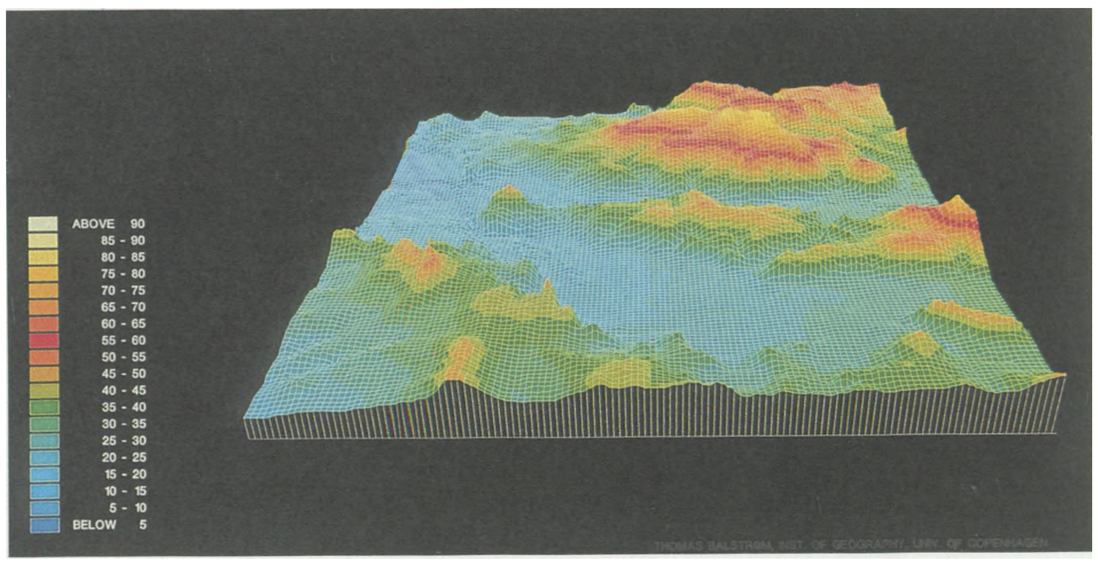

Geologi.
*Geology.*

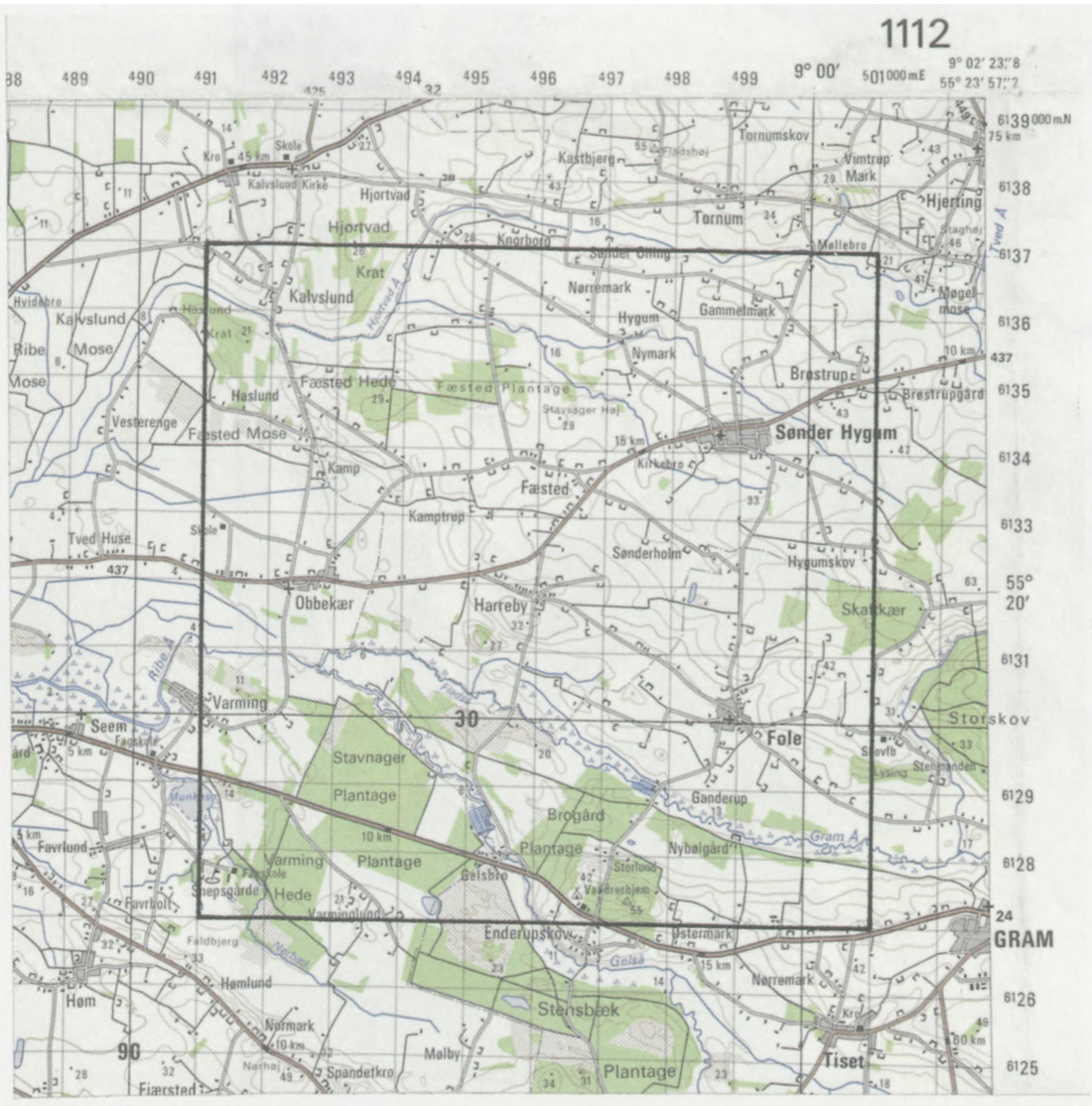



Vådbundsområder.
*Open water and wetlands.*

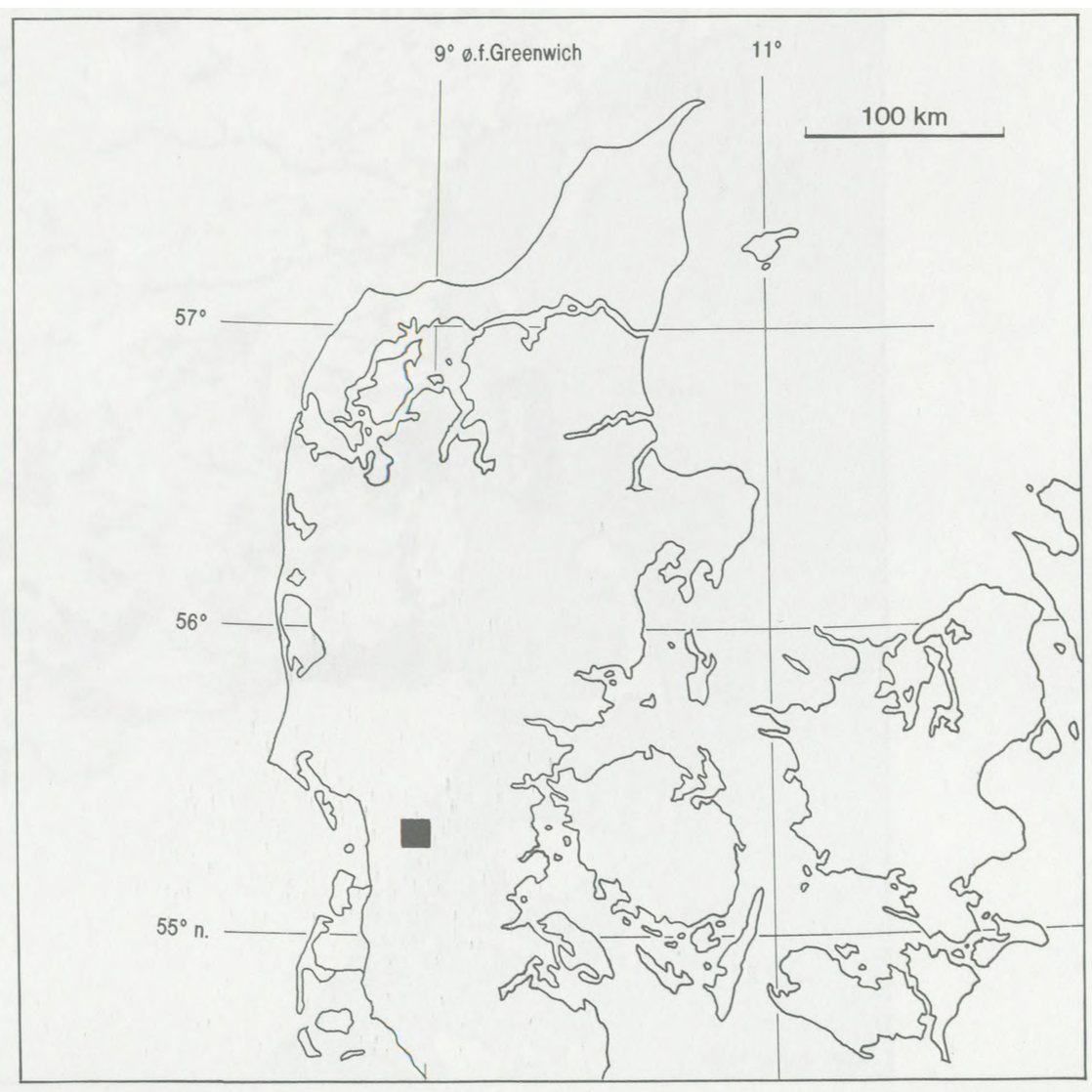



Topografi.
*Topography.*




Kort- og Matrikelstyrelsen A511-91



OKKERPOTENTIELLE OMRÅDER
Potentially acid sulfate soils
Uklas-sificeret
Unclas-sified
0 %
< 20 %
20 – 50 %
> 50 %
Vand
Water
0 10 20 30 40 50 km
ADK-KUGI 1989

*Fig. 17: Potentially acid sulfate soils. The map indicates areas to be examined for potential acidity before drainage permission is given.*

The soil texture and local geomorphology were also taken into account. Map 14 shows the areas of potentially acid sulfate soils. Figure 17 shows the location of classes 1, 2 and 3, which are the 3 classes for which drainage permission has to be obtained.

Table 18 shows the total wetland area for all seven counties of Jutland. The wetlands are divided into classes of potential acidity. The counties make up 70% of the total surface area of Denmark. Wetlands constitute 20% of this area. 5% of the total wetland area, equal to 294 km² remained unclassified. Within the classified area, the 4 wetland classes are distributed as follows: 27%, 11%, 15%, and 47% respectively. These figures reveal that about half of the wetlands are almost entirely free of potentially acid sulfate soils, while the other half may be subject to ochre formation if drainage is allowed to take place.

Table 18 also shows that there are definite regional differences in the concentration of these 4 classes. Class 1 only accounts for 13% of the wetland area in North Jutland, yet it accounts for 44% and 39% respectively for the counties of Ringkøbing and South Jutland. This is partly due to different geomorphological conditions, especially those under which the younger marine foreland deposits were formed.

Table 19 indicates where the areas of potential acidity occur in relation to the major landscape types and pre-Quatemary geology. Figure 18 shows that the pre-Quatemary bedrock of Jutland consists mainly of Miocene deposits, which are rich in pyrites. This region is bordered to the north and east by a narrow stretch of older Tertiary deposits. In northern Jutland, including part of Djursland, there is a predominance of limestone deposits from the late Cretaceous period. In areas with Tertiary bedrock, the potential for acid sulfate soils is far greater than in areas whose bedrock is from the Cretaceous period. This is due to the pyrites deposits of the Tertiary period having been mixed into the moraine in the south and west of Jutland. These pyrites deposits tend to dissolve at a very slow rate, and in the state of $Fe^{++}$ and $SO_4^{--}$, they are removed by groundwater into hollows and low-lying areas, where they may precipitate once again as pyrites in the moorland, creating a potential for ochre formation. Thus, land with a high potential for ochre formation, due to the presence of acid sulfate soils, occurs more frequently in wetlands with a Tertiary bedrock than those with a Cretaceous bedrock.

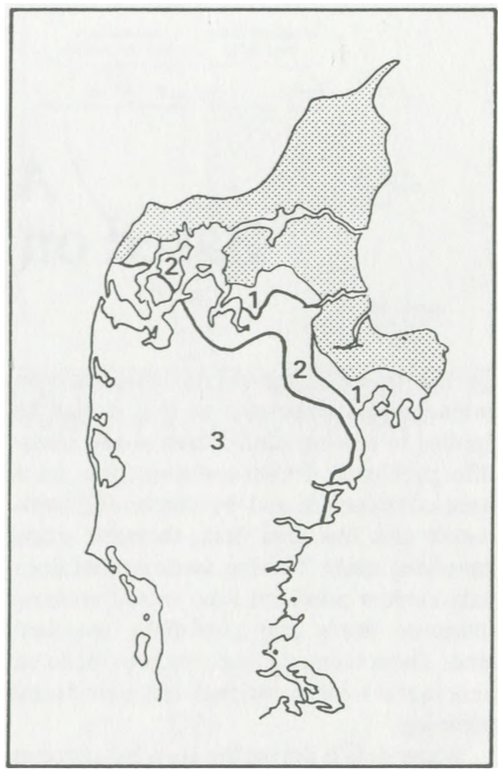



*Fig. 18: The pre-Quatemary geology of Jutland.*

*symbols: dotted: Senon, Danien*
*white 1: Palaeocene, Eocene*
*white 2: Oligocene*
*white 3: Miocene*

On the young marine foreland deposits which occur in southern Jutland, there is a wide occurrence of potentially acid sulfate soils as the soils of the saltmarsh bays and inlets. These sediments are mainly clayey and silty. They were deposited during calm conditions (low energy). The sediments are strongly anaerobic and pyrites is easily produced. By contrast, in northern Jutland, the marine foreland deposits consist of fine sands. In such an environment, which is more aerobic, pyrites is less often produced.

Table 19: Potentially Acid Sulfate Soils (PSJ) in relation to Landscape Type and Subsoil Geology.
Area is calculated as 0.75×Class 1. + 0.35×Class 2 + 0.1×Class 3.

| | Cretaceous Bedrock | | Tertiary Bedrock | |
|---|---|---|---|---|
| Landscape Type | km² Wetland | % PSJ in the Wetland area | km² Wetland | % PSJ in the Wetland area |
| Saltmarsh | - | - | 311 | 48 |
| Littorina | 1913 | 15 | 477 | 43 |
| Saale | - | - | 521 | 35 |
| Outwash Plains | 35 | 21 | 865 | 35 |
| Weichsel | 324 | 14 | 665 | 23 |
| Dune | 217 | 11 | 92 | 28 |

# CHAPTER 4

## An Explanatory Account of Thematic Maps Based on the Primary Data of the Danish Soil Classification

During the 1980's the soil database has been extended and elaborated so that it may be applied in solving administrative and scientific problems. Pedotransfer models have been constructed, and by combining parametric and line area data, thematic maps have been made. This has made it possible to map current problems such as soil erosion, irrigation needs and potentially marginal land. These thematic maps are proving to be very useful tools in regional and agricultural planning.

Water deficit during the growing season is one of the most limiting factors affecting plant production in northern Europe, especially on sandy soils. Therefore, up-to-date computerized information on soil water retention in the root zone, combined with climatic data, is very useful to water resource and irrigation planning. For water resource planning at county level, soil water retention data from the soil profile investigations have been used to produce regression equations that relate soil texture and humus content to soil water content at field capacity and permanent wilting point (Madsen & Platou 1983).

Furthermore, during a national survey of soil drainage conditions (Holst 1985, Holst & Madsen 1986), the texture of the plough layer and the subsoil, landscape types and wetland regions were used to classify the Danish agricultural land into four potential drainage classes. Moreover, 4,000 pedological classifications were used to determine the potential drainage requirements of clayey till deposits.

Database information on plough layer texture and organic matter content, combined with information on the structure and drainage conditions of some 800 profiles, have been used to calculate and map soil credibility (Madsen et al. 1986ab, Hasholt et al. 1990). Part of the catchment area of the Suså river, Zealand, and the county of South Jutland, were chosen as the areas for these investigations.

The database has also been used in several studies of marginal land financed by the National Forest and Nature Agency (Skov og Naturstyrelsen). This work included a report on the growth of woodland related to soil type (Svendsen & Pedeni 1987), and the nature of soil formation and nutrient status in dry, sandy areas (Rasmussen & Petersen 1987). The database has also been used in a national mapping of potentially marginal land. The mapping included an elaboration of national maps at a scale of 1:50,000 showing the following; root zone capacity (RZC), the irrigation requirements of grass and barley, the influence of slope gradient on land-use, wetland soil texture and the potential for ochre formation in drainage channels (Madsen & Holst 1987).

Finally, it should be mentioned that the data have also been used in a national investigation to measure the leaching of nitrates from the farmland. This work is being carried out by the Danish Department of Agriculture (Landbrugsministeriet 1984).

This chapter describes several of these thematic maps e.g. root zone capacity maps, irrigation maps and drainage maps. The maps are accompanied by written explanations.

### Mapping the Available Water Content in the Root Zone for Different Crops

The plant available water content in the root zone (AWC), also known as the root zone capacity (RZC), is the amount of water in the root zone that a plant can extract before wilting occurs due to water stress. The root zone capacity (RZC) does not include capillary rise due to a high water-table, or the precipitation that occurs during the growing season. The RZC is therefore just a part, although a very important part, of the total amount of water that a plant may utilize during the growing season. The total available water content (TAWC) may be calculated using the following equation, in which both evaporation from the bare soil surface and interception have been omitted.

$$TAWC = RZC + Pr + Cr - Sr - Pc$$

TAWC = Total Available Water Content
RZC = Root Zone Capacity
Pr = Precipitation
Cr = Capillary Rise
Sr = Surface Run-off
Pc = Percolation through the root zone

The RZC is a very significant parameter used in models for calculating the water balance in the root zone. It is one of the key parameters for predicting the drought resistance of different crops and their irrigation requirements. Furthermore, it is very important in determining leaching from different soils.

Based on the information from the Danish Soil Classification databases, the calculation and mapping of the RZC for different crops can be made step by step as follows:

1. The division of the country into wetlands and areas of well-drained soils, based on the Wetlands Database.
2. The construction of soil profiles from the 36,000 sites where texture analysis is available. Sites located in the wetlands have been omitted.
3. The calculation of the available water content (AWC) for different soil layers based on equations combining texture and organic matter content with water contents of pF 2.0 and pF 4.2.
4. The estimation of the effective root depths (ERD) for different crops in relation to soil types.
5. The calculation of the RZC, by relating the available water content of the different soil layers to the different effective root depth.

### *The Construction of the Soil Profiles*

The Danish Soil Classification contains many data on the texture and organic matter content from approximately 36,000 sites, the texture and organic matter content were determined on soil samples taken from the plough layer (0-20 cm). At about 20% of these sites, texture and organic matter content were also determined at a lower depth (35-55 cm).

In Table 20, the 36,000 soil sampling sites are shown, classified according to the type of topsoil, subsoil and landscape.

At each locality, a soil profile was made, providing information on the texture and organic matter of the upper 120 cm of the profile. Then, the available water content in the soil layers was calculated and the effective root depth estimated.

The following procedure was used in constructing the 36,000 profiles. The profiles were divided into three depth sections: 0-30 cm, 30-60 cm, and 60-120 cm. Data on plough layer samples (depth 0-20 cm) were used to determine the texture of the uppermost section (0-30 cm). Where possible, the texture of the middle section (30-60 cm) was based on existing data on samples that had been taken at a depth of 35-55 cm. Otherwise, data on the uppermost section was used, but the content of organic matter was changed to give an average value based on the samples taken at the depth of between 35-55 cm, (Table 21).

Table 21 : Mean Organic Matter Content in relation to Soil Type (MCC). Sampling Depth: 35-55 cm.

| | MCCl | MCC2 | MCC3 | MCC4 | MCC5 | MCC6 |
|---|---|---|---|---|---|---|
| % Organic Matter | 1.8 | 1.7 | 1.9 | 1.6 | 1.4 | 1.4 |

The determination of the soil texture for the depth section 60-120 cm has been based on three sources; the calculated or measured texture at 30-60 cm, soil profile investigations along the DONG pipeline, and the map showing the location of clayey and sandy subsoils.

The first step involved in the texture classification of the depth section 60-120 cm was to compare the distribution of soils of the Danish Soil Classification based on the Map Colour Codes (MCC) with the distribution of clayey and sandy subsoils to observe any differences in texture between the topsoil and subsoil. For example, there are instances where past sand-drifts or meltwater deposits have come to cover a clay till, or where clay illuviation has occurred in the original clay material (Fobian 1966, Madsen 1979 & 1983a, Dalsgaard et al. 1981, Madsen & Jensen 1985). In these cases, the plough layer often contains about 10% clay, while the subsoil may contain as much as 25% clay.

The soil profile investigations showed that sandy subsoils generally contain less than 10% clay (MCC1-3), while the clayey subsoils contain more than 15% clay (MCC5 and MCC6). On the other hand, MCC4 is very rare in the lowest layers, occurring in about 5% of the samples taken from the subsoils along the pipeline on the island of Zealand. This percentage increases to about 10% on Funen and in eastern Jutland, and is highest in western Jutland. On the basis of these observations, the following profiles have been constructed, Figure 19.

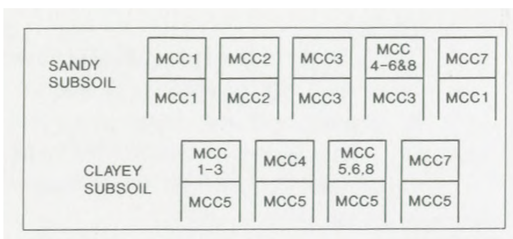



*Fig. 19: Comparison of MCC-values for the soil profile sections 60-120 cm and 30-60 cm.*

Using Figure 19 and the information on the texture of section 30-60 cm, the following texture allocations were ascribed to the soil profile section 60-120 cm.

- Where the topsoil is MCC 1-3, a sandy subsoil 60-120 cm section is judged to have the same texture as the 30-60 cm section, with a reduction of the organic matter content to 0.5%
- Where the topsoil is MCC 4-6 or 8, a sandy subsoil 60-120 cm section is judged to have the highest clay amount possible and has been classified as MCC 3, with a reduction of the organic matter to 0.5%.
- Where the topsoil is MCC 1-4, a clayey subsoil 60-120 cm section is judged to be MCC5 at a depth of 35-55 cm for the whole country, with a reduction of the organic matter content to 0.5%.
- Where the topsoil is MCC 5 or MCC 6, a clayey subsoil 60-120 cm section is judged to have the same texture as the middle section, with a reduction of the organic matter content to 0.5%.

Table 22 shows examples of these texture allocations.

### *The Calculation of the Available Water Content of Soil Layers*

A soil can be naturally divided into solids, water and air. Its porosity is the air volume of the soil, dried at 105°C. It is possible to determine the pore size distribution in soils by subjecting saturated soil samples to pneumatic pressure in a pressure plate membrane apparatus and letting them drain to equilibrium. By comparing the water content at different pressures, the soil water retention curve may be drawn. Its form will be determined by different factors such as; texture, structure, bulk density, pedological formation etc., Figure 20.

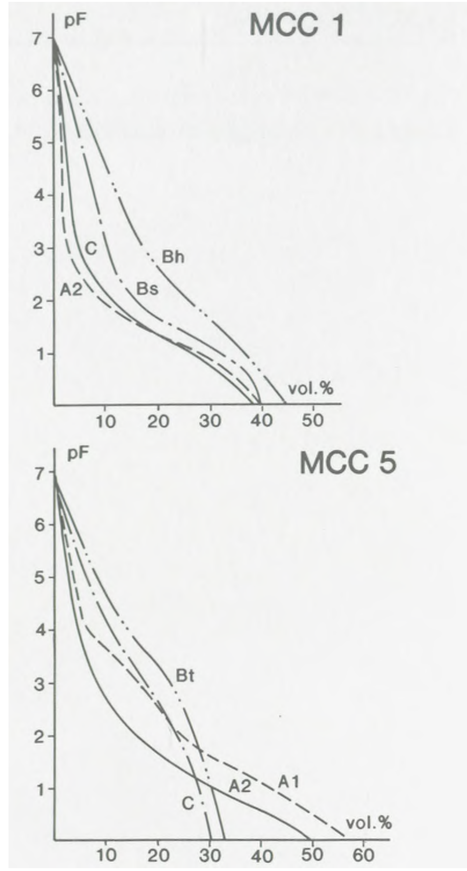



*Fig. 20: Soil water retention curves for a sandy soil (MCC1) and a clayey soil (MCC5)*

Table 20: Number of Samples in Relation to Topsoil Texture (JB), Clayey and Sandy Subsoil, and Landscape Type.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 39 | 1 | 494 | 4 | 1895 | 341 | 2725 | 3 | 2013 | 413 |
| 2 | 752 | 5 | 188 | 0 | 319 | 30 | 156 | 0 | 2325 | 256 |
| 3 | 32 | 0 | 24 | 1 | 509 | 299 | 571 | 1 | 818 | 845 |
| 4 | 437 | 6 | 8 | 0 | 579 | 311 | 245 | 0 | 3058 | 3922 |
| 5 | 0 | 0 | 4 | 0 | 20 | 69 | 35 | 0 | 161 | 1008 |
| 6 | 73 | 1 | 1 | 0 | 25 | 54 | 53 | 2 | 687 | 6924 |
| 7 | 42 | 2 | 2 | 0 | 9 | 15 | 29 | 1 | 177 | 2863 |
| 8 | 8 | 0 | 0 | 0 | 5 | 6 | 6 | 0 | 21 | 160 |
| 9 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 7 | 18 |

Table 22: Example of Texture Assessment for each Soil Profile Section.

| | section | % clay | % silt | % f.sand | % c.sand | % humus | subsoil |
|---|---|---|---|---|---|---|---|
| A | 0-30 | 2.5 | 3.5 | 30.5 | 60.0 | 3.5 | |
| | 30-60 | 2.5 | 3.6 | 31.0 | 61.0 | 1.8 | |
| | 60-120 | 2.6 | 3.6 | 31.4 | 61.9 | 0.5 | sandy |
| | 60-120 | 18.6 | 15.1 | 42.8 | 23.0 | 0.5 | clayey |
| B | 0-30 | 10.5 | 15.7 | 45.3 | 24.6 | 3.9 | |
| | 30-60 | 24.7 | 18.6 | 38.5 | 16.5 | 1.7 | |
| | 60-120 | 25.0 | 18.8 | 39.0 | 16.7 | 0.5 | clayey |
| | 60-120 | 7.1 | 8.5 | 45.9 | 38.0 | 0.5 | sandy |

A: Sites where samples were taken exclusively from the plough layer.
B: Sites where samples were taken from both the plough layer and the subsoil.

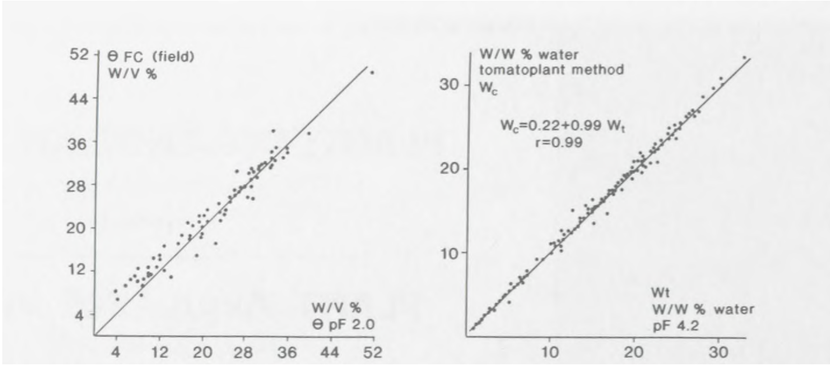



*Fig. 21: The relationship between soil water content at field capacity and pF 2.0, and between soil water content at permanent wilting point and pF 4.2.*

In well-drained soils, the pores can be categorized based on whether they are air-filled, or contain water that is either available or not available to plants at field capacity. The air-filled pores are the coarse pores (> 30µm). Pores containing water that is available to plants are the medium pores (0.2µm-30µm), whilst those containing water that cannot be extracted by plants are the fine pores (< 0.2µm).

Two terms are used; field capacity (FC) and permanent wilting point (PWP).

In the study of Danish soils, Madsen (1983a) proved that there is a close correlation between soil water content at pF 2.0 and FC, except in the case of sandy soils, Figure 21. For Danish soils, it is therefore acceptable to use pF 2.0 as a measure of FC.

Water content at PWP is defined as the amount of water in a soil layer with a dense root development when a crop begins to wilt due to lack of water. Wiklert (1964) proved, that there is a close correlation between soil water content at pF 4.2 and PWP. Hence, pF 4.2 is used as a measure of PWP, Figure 21.

As there is a close relationship between soil texture, organic matter content, and soil water content at FC and PWP, it is possible to calculate the available water content (AWC) of the 110,000 soil sections taken from the approximately 36,000 localities for which texture data has been measured. This requires the use of regression equations that relate the content of clay, silt, sand and organic matter to the water content at FC and PWP. In the actual case, the water content at field capacity and the permanent wilting point were calculated using regression equations based on results from South Jutland.

The pF 2.0 equation was based on 285 samples, while the pF 4.2 equation was based on 111 samples. Samples containing calcium carbonate, with a bulk density of less than 1.0 g/cm, or with an organic matter content of more than 10%, were excluded.

The following soil particle classification was used in the regression analysis; clay <2µm (Cl), silt 2-20µm (Si), fine sand 20-200µm (Fs), coarse sand 200-2,000µm (Cs), and organic matter (OM). The following equations were obtained:

$$pF\ 2.0\ (vol\%) = 3.68 + 2.34 \times OM + 0.70 \times Cl + 0.47 \times Si + 0.18 \times Fs$$

$$pF\ 4.2\ (vol\%) = 1.12 + 0.55 \times OM + 0.63 \times Cl + 0.18 \times Si$$

Based on these equations, it is possible to calculate the available water content (AWC) from the following equation:

$$AWC\ (vol\%) = 2.56 + 1.79 \times OM + 0.07 \times Cl + 0.29 \times Si + 0.18 \times Fs$$

The equation shows that the content of organic matter, silt and fine sand has a strongly positive influence on AWC, while clay only plays a minor role.

Table 23 shows the average AWC as calculated for the 3 soil sections; 0-30 cm, 30-60 cm and 60-120 cm, related to their type of soil texture, subsoil and landscape.

## *The Effective Root Depth of Crops*

The root system of a plant has two principle functions. Firstly, it secures the plant to the ground. Secondly, it provides the plant with nutrients and water from the soil profile. Whereas most of the nutrients are taken from the plough layer, the uptake of water is a process that involves the whole depth of the root profile, judging by the amount of water extracted from the soil during the growing season. The degree of desiccation decreases with depth, as does root density, and it is reasonable to assume that a relationship exists between the amount of water that plants extract from the soil and their root density, Figure 22.

In the uppermost soil layers, where root density is greatest, the soil often dries out to PWP if the plant is exposed to a long period of drought. On the other hand, this is not the case in the deeper soil layers, where a good deal of available water still remains, even though the plant has wilted. This may be due to too greater space between the roots of a plant, and the decreasing hydraulic conductivity as the soil dries out. Therefore, it is not sufficient to use the maximum root depth when estimating root zone capacity (RZC).

In order to calculate the RZC, the effective root depth (ERD) is defined as the depth of soil in which AWC is equal to the amount of soil water utilized by a plant before wilting occurs, Figure 22. The ERD will be shallower than the maximum root depth.

RZC and ERD can both be calculated using simulation models on the basis of soil water retention curves for different soil horizons and root density measured in cm root/cm² soil. This has been carried out on 18 soil profiles taken from several parent materials (Madsen 1979) in which the RZC was calculated by the "Heimdal" model, which is a dynamic, deterministic simulation model (Hansen 1975). The crop examined was spring barley. The model was used to simulate a period of drought at the end of May and early June, when barley has not normally begun to ear. An early root profile was put into the model, after which it was allowed to develop to the pre-determined maximum root profile in the field. At the start of the simulation experiment, the soil water content was fixed at field capacity, and the climatic data input was typical of a sunny, dry period at the end of May and early June.

Figure 23 shows some of the results of the simulation, such as the daily leaf water potential, and the evapotranspiration from both a podzol developed on drift sands and from an acrisol with a strongly acid subsoil developed on clayey till. On the hypothesis that the plant would wilt if leaf water potential at night remained under -20 bar, the AWC of the podzol was measured at 54 mm, and the AWC of the acrisol at 105 mm. The "best" clayey soils, which allow deep root development, were found to have an AWC of about 180 mm according to the simulation model.

Figure 24 shows that there seems to be a definite relationship between the amount of available water in soil layers with more than 0.1 cm root cm² soil Z(0.1) and the summarized evapotranspiration determined by the simulation model until wilting occurs. On this evidence, it was judged acceptable to use Z(0.1) as a measure of effective root depth (ERD).

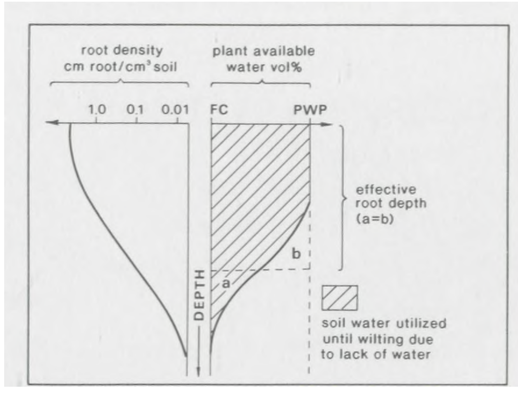



*Fig. 22: Root density, water utilization, and the effective root depth of a soil profile.*

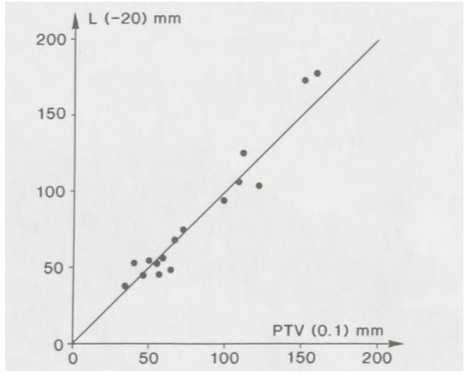



*Fig. 24: The relationship between the sum med-up available water content in the soil layers with more than 0.1 cm root/cm³ soil (PTV 0.1), and the summed-up transpirated water until leaf water potential at night does not exceed-20 bar (L(-20)), determined by simulation.*

During the past 10 years many experiments have been carried out to examine the root development of crops in Denmark (Madsen 1979, 1980, 1983a, 1985). On this basis, supported by the estimates of ERD in "Betænkning no. 841" (Landbrugsministeriet 1978), and foreign research (Vetter & Scharafat 1964, Wildert 1962), the following average effective root depths have been estimated for spring barley, winter wheat, sugar beet and short grass in relation to the Map Colour Code and subsoil texture, Table 24.

Grass has been selected as a suitable crop for the experiment, as it is widespread, and because it has a long growing season and a large water requirement. A single figure for the ERD of grass is not possible due to the many species. For example, Timothy grass has a less deeply developed root system in a clayey soil than Raj grass (Vetter & Scharafat 1964). A further important factor to take into account is the method of cultivation. It is very important to know whether the grass is to be kept short by grazing during the growing season, or whether it will be used for hay fodder or seed production. In a Danish report, called "Betænkning no. 841" (Landbrugsministeriet 1978), it is stated that the ERD is 50 cm for short grass growing in a fine sandy clay (JB6), whilst that of grass for hay or seed production is 75 cm. According to "Betænkning no. 841", the ERD is that depth down to which 80% to 90% of the water utilized by a plant is found. In coarse sandy soil (MCC1), the ERD will be about 50 cm, irrespective of the kind of grass.

Table 23: Plant available water (%vol.) at Different Depths in relation to Soil Type(JB), Clayey and Sandy Subsoil, and Landscape Type.

Soil Profile Section 0-30 cm.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 17.6 | 18.7 | 14.1 | 16.5 | 16.5 | 16.8 | 14.8 | 12.9 | 16.6 | 15.5 |
| 2 | 24.0 | 22.5 | 21.4 | - | 21.8 | 21.6 | 21.4 | - | 21.2 | 20.3 |
| 3 | 17.6 | - | 17.8 | 14.0 | 17.5 | 17.5 | 17.1 | 13.6 | 16.5 | 17.0 |
| 4 | 25.0 | 22.6 | 21.9 | - | 22.0 | 20.9 | 21.3 | - | 21.4 | 20.4 |
| 5 | - | - | 18.5 | - | 19.3 | 18.7 | 21.1 | - | 18.7 | 19.0 |
| 6 | 25.1 | 28.1 | 24.8 | - | 22.4 | 21.1 | 21.9 | 23.4 | 21.0 | 20.5 |
| 7 | 26.0 | 26.5 | 27.8 | - | 22.1 | 23.5 | 24.7 | 19.9 | 22.2 | 21.2 |
| 8 | 26.2 | - | - | - | 29.9 | 27.2 | 27.2 | - | 25.1 | 24.7 |
| 9 | - | - | 30.4 | - | - | - | - | - | - | 24.9 |

Soil Profile Section 30-60 cm.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 14.7 | 16.3 | 11.3 | 11.6 | 13.2 | 13.7 | 11.4 | 12.2 | 14.5 | 14.1 |
| 2 | 20.7 | 18.9 | 18.5 | - | 18.1 | 18.3 | 17.9 | - | 18.6 | 18.2 |
| 3 | 13.3 | - | 12.8 | 13.7 | 13.9 | 14.6 | 13.1 | 10.3 | 14.5 | 15.2 |
| 4 | 21.0 | 19.0 | 17.1 | - | 17.1 | 16.9 | 17.2 | - | 18.5 | 18.5 |
| 5 | - | - | 15.3 | - | 15.3 | 15.9 | 15.1 | - | 16.1 | 16.9 |
| 6 | 21.5 | 22.6 | 18.9 | - | 17.1 | 16.7 | 17.0 | 20.0 | 18.7 | 18.6 |
| 7 | 21.3 | 22.0 | 19.7 | - | 18.7 | 16.5 | 20.4 | 16.6 | 18.6 | 18.7 |
| 8 | 22.1 | - | - | - | 20.5 | 19.3 | 19.0 | - | 21.1 | 21.1 |
| 9 | - | - | 24.5 | - | - | - | - | - | - | 22.8 |

Soil Profile Section 60-120 cm.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 12.4 | 17.0 | 9.1 | 17.0 | 11.0 | 17.0 | 9.2 | 17.0 | 12.4 | 17.0 |
| 2 | 18.8 | 17.0 | 16.7 | - | 16.0 | 17.0 | 15.9 | - | 16.7 | 17.0 |
| 3 | 10.9 | - | 10.7 | 17.0 | 11.6 | 16.8 | 10.7 | 17.0 | 12.2 | 16.9 |
| 4 | 18.7 | 16.1 | 14.9 | - | 14.8 | 16.9 | 14.9 | - | 16.3 | 17.0 |
| 5 | - | - | 15.0 | - | 15.0 | 14.0 | 14.9 | - | 15.0 | 15.0 |
| 6 | 15.1 | 20.9 | 15.0 | - | 14.9 | 15.1 | 15.0 | 18.2 | 15.0 | 16.9 |
| 7 | 15.1 | 20.4 | 15.0 | - | 15.1 | 15.0 | 15.0 | 15.0 | 15.0 | 17.2 |
| 8 | 15.0 | - | - | - | 15.0 | 16.5 | 14.5 | - | 15.0 | 18.3 |
| 9 | - | - | 15.0 | - | - | - | - | - | - | 16.1 |

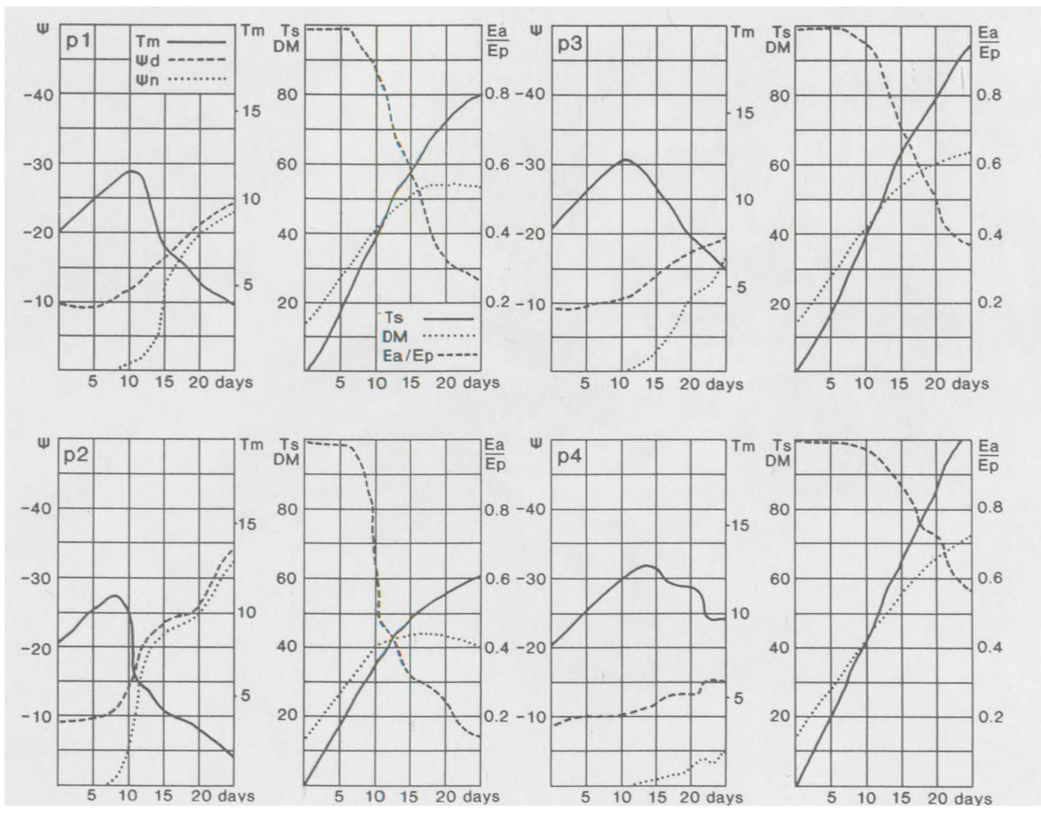
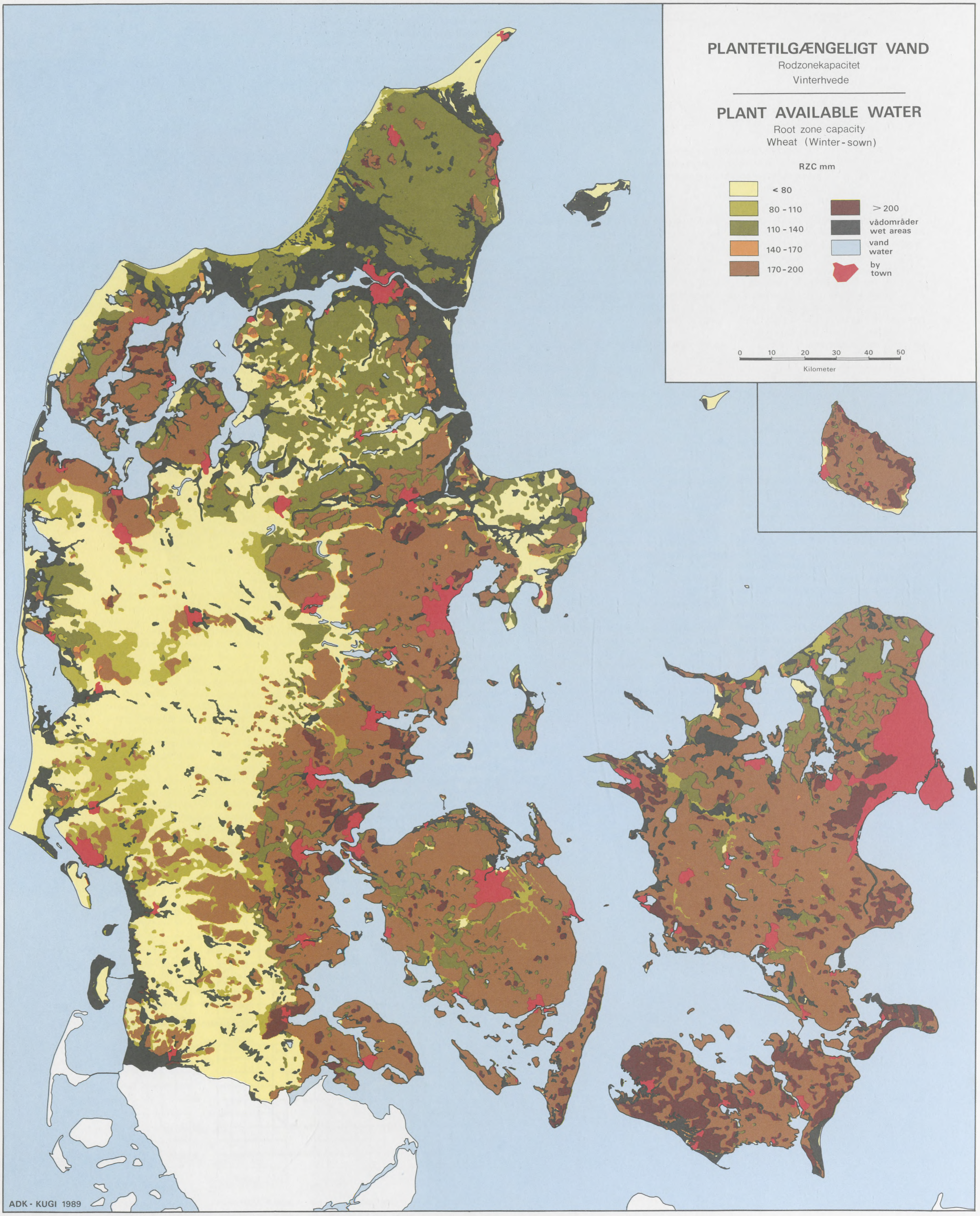



*Fig. 23: Variations in the leaf-water potential (Ψ), the daily maximum transpiration rate (Tm), the summed-up evapotranspiration (SUME), the summed-up production of dry matter (DM) and the ratio between actual and potential evapotranspiration (Ea/Ep) throughout a drought period (Madsen 1979).*

KORT 15

MAP 15



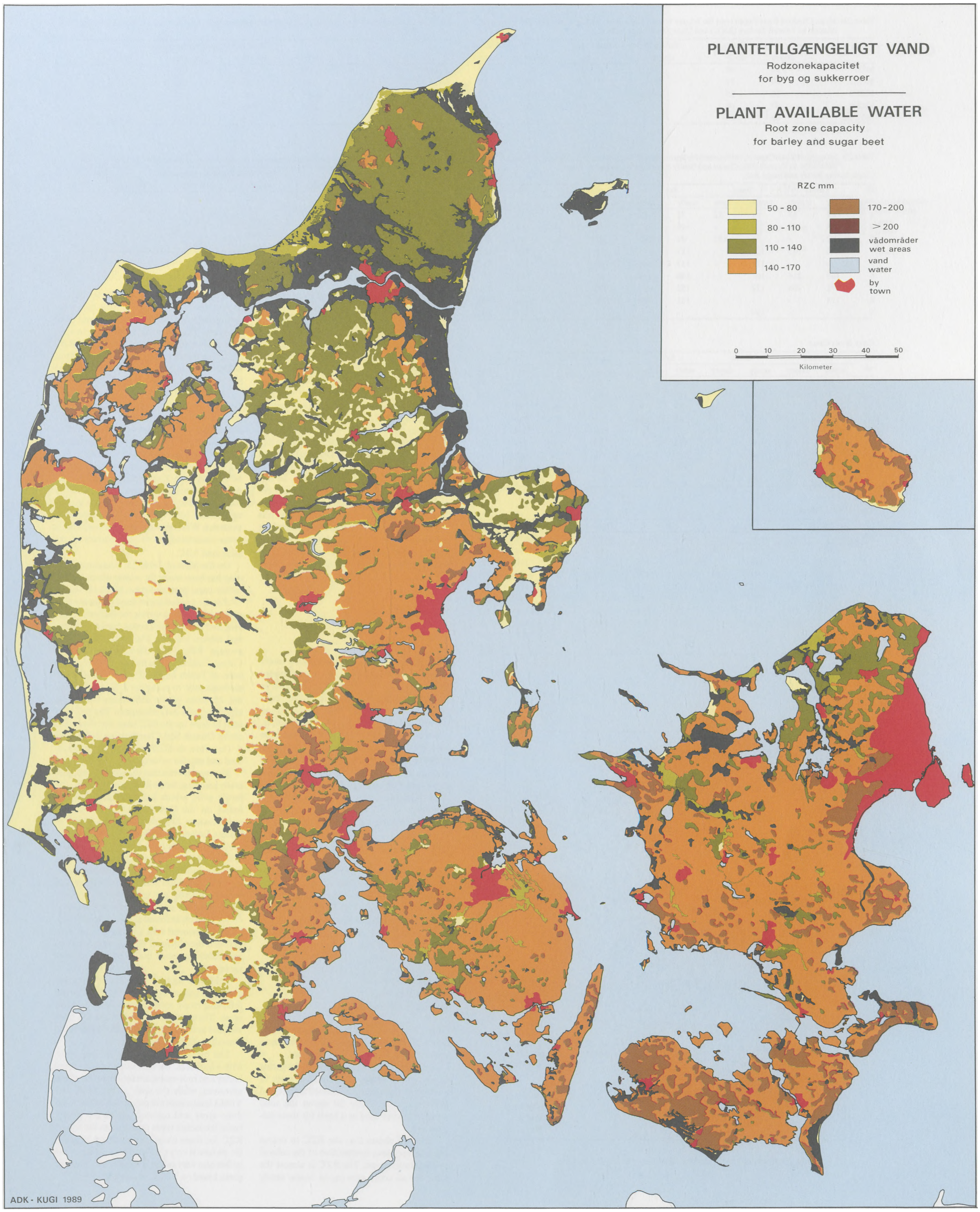

PLANTETILGÆNGELIGT VAND
Rodzonekapacitet
for byg og sukkerroer
PLANT AVAILABLE WATER
Root zone capacity
for barley and sugar beet
RZC mm
50 - 80
80 - 110
110 - 140
140 - 170
170 - 200
> 200
vådområder
wet areas
vand
water
by
town
0 10 20 30 40 50
Kilometer
ADK - KUGI 1989

Table 24: Mean Effective Root Depth (cm) for Winter Wheat, Sugar Beet, Spring Barley and Short Grass in relation to Topsoil Texture (MCC) and Clayey and Sandy Subsoil.

| | Grass | | Spring Barley & Sugar Beet | | Winter Wheat | |
|---|---|---|---|---|---|---|
| | clayey | sandy | clayey | sandy | clayey | sandy |
| MCC1 | 50 | 50 | 50 | 50 | 50 | 50 |
| MCC2 | 60 | 55 | 80 | 60 | 90 | 60 |
| MCC3 | 60 | 55 | 90 | 60 | 100 | 60 |
| MCC4 | 60 | 60 | 90 | 80 | 110 | 100 |
| MCC5-6 | 60 | 60 | 90 | 80 | 110 | 100 |

Table 25: Mean Root Zone Capacity (mm water) for Spring Barley, Sugar Beet, Short Grass and Winter Wheat in relation to Topsoil (JB), Clayey and Sandy Subsoil and Landscape Type.
Crops: Spring Barley and Sugar Beet

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 82 | 88 | 64 | 72 | 75 | 77 | 67 | 63 | 78 | 74 |
| 2 | 134 | 158 | 119 | - | 119 | 153 | 117 | - | 119 | 149 |
| 3 | 92 | - | 91 | 133 | 94 | 146 | 90 | 122 | 93 | 147 |
| 4 | 138 | 173 | 117 | - | 117 | 163 | 115 | - | 119 | 167 |
| 5 | - | - | 131 | - | 133 | 145 | 138 | - | 134 | 152 |
| 6 | 169 | 214 | 161 | - | 148 | 158 | 149 | 185 | 149 | 167 |
| 7 | 172 | 206 | 172 | - | 152 | 165 | 165 | 154 | 152 | 171 |
| 8 | 175 | - | - | - | 181 | 188 | 168 | - | 168 | 192 |
| 9 | - | - | 194 | - | - | - | - | - | - | 191 |

Crop: Short Grass

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 82 | 88 | 64 | 72 | 75 | 77 | 67 | 63 | 78 | 74 |
| 2 | 123 | 124 | 110 | - | 110 | 119 | 108 | - | 110 | 115 |
| 3 | 86 | - | 85 | 82 | 87 | 96 | 84 | 71 | 85 | 96 |
| 4 | 127 | 124 | 108 | - | 108 | 113 | 106 | - | 110 | 116 |
| 5 | - | - | 101 | - | 103 | 103 | 108 | - | 104 | 107 |
| 6 | 139 | 152 | 131 | - | 118 | 113 | 119 | 130 | 119 | 117 |
| 7 | 142 | 145 | 142 | - | 122 | 119 | 135 | 109 | 122 | 119 |
| 8 | 145 | - | - | - | 151 | 139 | 139 | - | 138 | 137 |
| 9 | - | - | 164 | - | - | - | - | - | - | 143 |

Crop: Winter Wheat

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| 1 | 82 | 88 | 64 | 72 | 75 | 77 | 67 | 63 | 78 | 74 |
| 2 | 134 | 173 | 119 | - | 119 | 168 | 117 | - | 119 | 165 |
| 3 | 92 | - | 91 | 168 | 94 | 180 | 90 | 157 | 93 | 181 |
| 4 | 138 | 204 | 117 | - | 117 | 197 | 115 | - | 119 | 200 |
| 5 | - | - | 156 | | 163 | 174 | 167 | - | 164 | 183 |
| 6 | 198 | 254 | - | - | 177 | 188 | 178 | - | 178 | 201 |
| 7 | 201 | 248 | - | - | 183 | 196 | 194 | - | 182 | 206 |
| 8 | 204 | - | - | - | 211 | 221 | 197 | - | 197 | 230 |
| 9 | - | - | 224 | - | - | - | - | - | - | 225 |

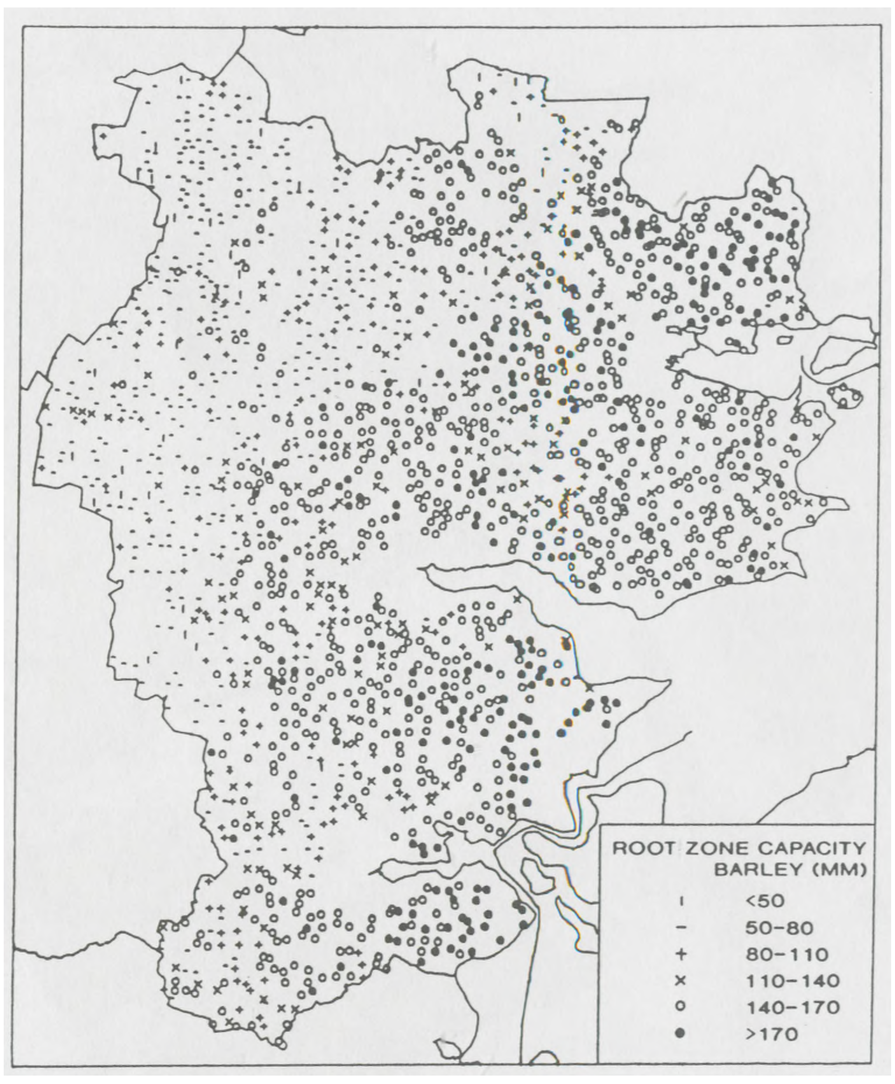



*Fig. 25: Root zone capacity for spring barley in Vejle County.*

Table 26 Distribution of Root Zone Capacity for Spring Barley and Sugar Beet in relation to Landscape Type ($km^2$).

| | Root Zone Capacity (mm water) | | | | |
|---|---|---|---|---|---|
| | 50-80 | 80-110 | 110-140 | 140-170 | >170 |
| Yoldia | 0 | 20 | 678 | 59 | 18 |
| Dune | 592 | 11 | 103 | 0 | 0 |
| Saale | 2065 | 863 | 202 | 630 | 12 |
| Outwash Plain | 2335 | 448 | 186 | 54 | 0 |
| Weichsel | 1592 | 0 | 4270 | 11678 | 2060 |

Table 27: The Distribution of Root Zone Capacity for Short Grass in relation to Landscape Type ($km^2$)

| | Root Zone Capacity (mm water) | | | | |
|---|---|---|---|---|---|
| | 50-80 | 80-110 | 110-140 | 140-170 | >170 |
| Yoldia | 0 | 20 | 743 | 12 | 0 |
| Dune | 592 | 115 | 0 | 0 | 0 |
| Saale | 2065 | 1635 | 72 | 0 | 0 |
| Outwash Plain | 2335 | 634 | 52 | 1 | 0 |
| Weichsel | 1592 | 4184 | 13819 | 4 | 0 |

That is to say, that the ERD of short grass is more or less the same in all kinds of soil. On the other hand, the ERD is much deeper in clayey soils than in sandy soils for grass that is to be cultivated for hay or seed production. Thus, by choosing short grass, it is easier to present a clearer picture of the climatic influence on the water requirements of crops in Denmark, than by choosing other types of grass. Throughout the atlas, grass is therefore to be understood as being short grass, unless otherwise stated.

Spring barley has been chosen because it is the most common crop in Denmark. Generally speaking, the ERD of spring barley is representive of spring-grown crops, as opposed to winter barley whose deeper root development is more similar to that of winter wheat. Winter wheat has been chosen as it is typical of a cereal sown in autumn. Sugar beet has been chosen from the point of view that it is grown widely in Denmark as a fodder crop, and its growing season is unlike that of corn and grass.

## *The Results*

The RZC for the four crops growing under different soil conditions has been calculated on the basis of the 36,000 sites described in Table 20. The calculations have been achieved through combining the information shown in Tables 23 and 24. For example, given that a clayey soil on a clayey subsoil has an AWC of 21%, 19% and 17% at the corresponding soil profile section depths of 0-30 cm, 30-60 cm and 60-120 cm, the RZC for sugar beet with an ERD of 90 cm will be:
0.21 ×30 cm m. + 0.19×30 cm + 0.17×30 cm = 171 mm.
The RZC for short grass with an ERD of 60 cm will be:
0.21×30 cm+ 0.19×30 cm = 120 mm

Figure 25 shows the RZC for spring barley in Vejle county, Jutland. The map is a dot map, where each dot represents the calculated RZC for a particular site. The RZC has been divided into the following categories:

Extremely low : < 50 mm.
Very low : 50-80 mm.
Low : 80-110 mm.
Medium : 110-140 mm.
High : 140-170 mm.
Very high : > 170 mm.

Only a few sites were found to have a RZC above 200 mm, and there was no reason to make a special category for this depth.

Table 25 shows the average RZC for spring barley, winter wheat, sugar beet and grass, in relation to topsoil texture, subsoil texture and landscape type. Table 20 shows the total number of sites used as a basis for these calculations.

Table 25 shows that the RZC in coarse sands is very low, irrespective of the subsoil and landscape type. The RZC is almost the same for all crops growing in coarse sandy soils, but in the case of other soils, the RZC is highest for winter wheat, a little lower for spring barley and sugar beet, and lowest of all for grass. This is certainly the case in soils with a clayey subsoil. As an example, the RZC for spring barley in soils with a clayey subsoil will normally be high, although it will only be average for grass.

In relation to the landscape type, the highest RZC for the different classes of topsoil and subsoil texture is found on the Yoldia plain, especially in clayey soils. The RZC is also high in the loamy soils that have developed on the younger moraines deposited during the Weichsel glaciation. In general, it may be said that the Yoldia plains contain most water for plant growth. However, it should be made clear that the calculations made for certain classes have been based on rather thin evidence. With regard to these classes, there is some uncertainty as to the accuracy of the estimated RZC.

On the basis of Table 25, a national RZC map has been made for winter wheat, spring barley, sugar beet, and grass, Maps 15, 16 and 17. For the production of these maps, average values have been used for the different mapping units (map colour codes, landscape types and subsoil texture). The transformation of average RZC from JB-numbers to Map Colour Code numbers has been made on the basis of Tables 20 and 25. Compared to the methods used to make the RZC map of Figure 25, some of the differences within the mapping units may disappear. The soil map used to draw up the RZC map was the generalized Danish Soil Classification Map, Map 8. Therefore, the RZC is also given for woodland and smaller urban areas.

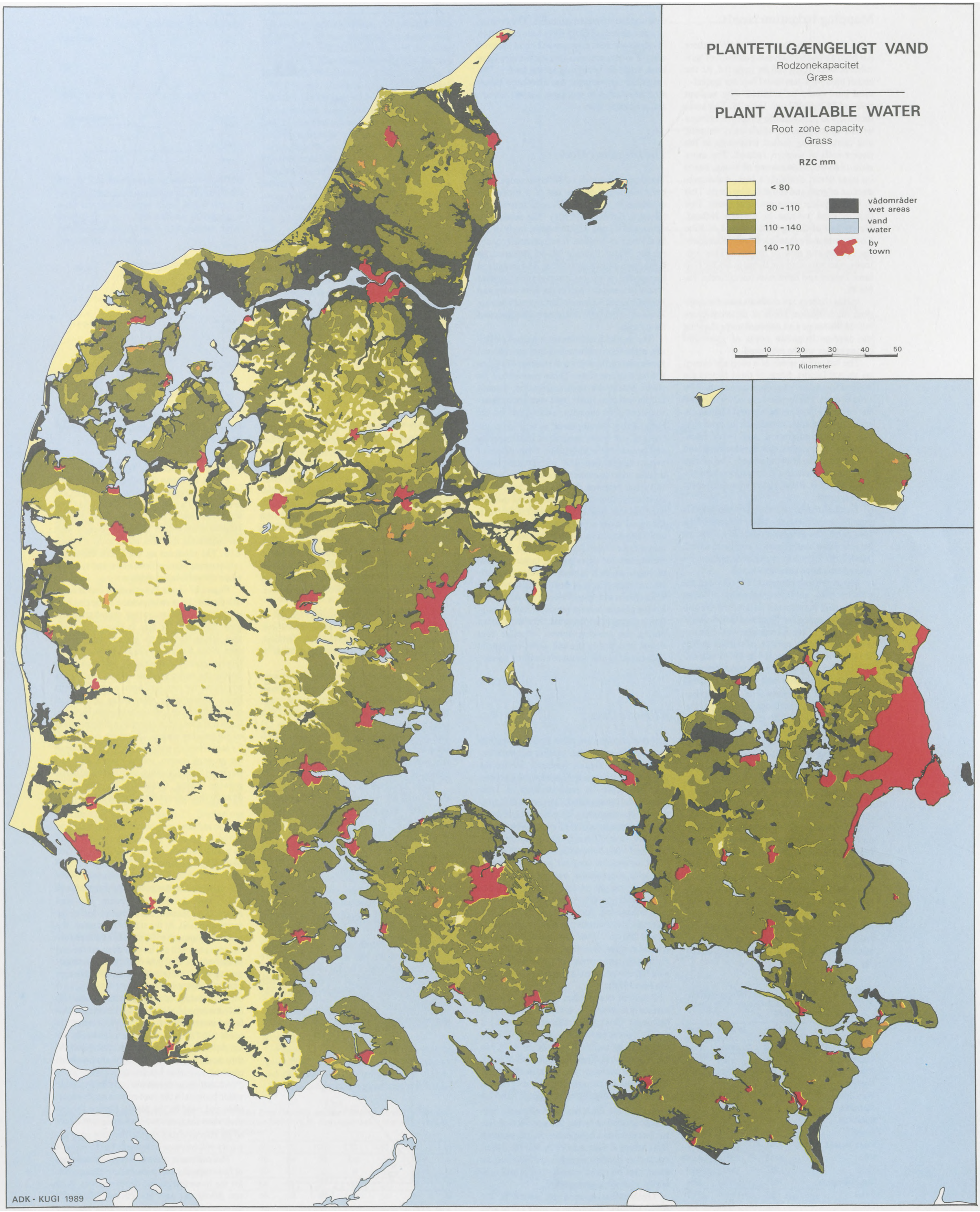
The map reveals that the country can, generally speaking, be divided into 3 regions. The fertile soils, which have a high RZC, are found on the Danish islands, apart from north-eastern Zealand. They are found in eastern Jutland, apart from Djursland, and in north-western Jutland in the area in and around Mors. North-eastern Zealand and northern Jutland have soils of medium quality with a medium RZC, whilst the soils of western Jutland are poor and have a low RZC, with the exception of a few isolated clayey pockets as found at the village of Rødding. The poorest soils are found in the area between the village of Brande and Alheden, immediately west of the main terminal moraine.

Tables 26 and 27 show the relation between the type of landscape and RZC for the following crops; spring barley, sugar beet and grass. The statistics are based on the non-wetland area within the classified area of the Danish Soil Classification.

The two tables show that the best soils, with a high RZC for the cultivation of spring barley and root-crops, are found on the young moraines, while the soils of the Saale and Yoldia landscapes are reasonably good. Sand dune areas and outwash plains are clearly those landscape types that possess the lowest RZC for these crops. With respect to grass, the picture is very similar. The Yoldia plain is in fact also very suitable for the cultivation of grass, based on a RZC evaluation.

KORT 17

MAP 17



## Mapping Irrigation Needs

Since the end of the Second World War, there has been a steadily increasing amount of agricultural land which can be irrigated. At the end of the 1940s, less than 1% of the agricultural land could be irrigated. The amount rose to 15% by 1987, see Table 28. This great increase was partly due to structural changes within agriculture, in which dairy farming and cattle-rearing shifted westwards to the poorer soils of western Jutland. The more industrialized cattle-rearing of today, based on large herds, demands a high, stable production of grass and rough fodder crops. This in turn requires irrigation most years. This fact is most evident in western Jutland. Nearly half of the agricultural land of Ribe County and more than one third of Ringkjøbing County can now be irrigated. This contrasts markedly with the figure of 3% for Lolland, Falster and Bornholm respectively, Table 28.

In this chapter, the methods used for mapping the irrigation needs of different crops will be discussed and national maps showing the average irrigation needs of grass and spring barley will be presented.

The irrigation needs of a crop are caused by several factors. Some of these factors are created by natural phenomena and others by human ones. The former normally lie beyond the control of human beings and include climatic or botanical factors such as; precipitation, evapotranspiration, soil water retention, leaf surface area, root development, and the length of the growing season. The human phenomena include e.g. irrigation methods, especially how, when, and to what degree water is applied.

Through the use of simulation models, it is possible to calculate the water balance of the root zone. The irrigation needs of a crop can be calculated and irrigation strategies tested. Models to calculate regional irrigation requirements have been developed.

Mogensen and Hansen (1979) divided the country into nine geographically different areas, using the climatic data of the Danish Research Service for Plant and Soil Science. The number of times irrigation was to be implemented during periods of rainfall deficit from April till October (1956-1976) was calculated. In connection with water resource planning, Gregersen and Knudsen (1980) made a report, at county level, of the irrigation needs of different crops in relation to the root zone capacity. The climatic data used during the calculations were obtained from the Danish Research Service for Plant and Soil Science. County boundaries were used to delineate areas with the same climatic data instead of using boundaries of natural climatic regions. Mapping the irrigation needs of crops ought to be based on natural regions instead of administrative regions.

In order to map the distribution of potentially marginal land, a national mapping of the irrigation needs of grass and barley was carried out based on the data in the national soil database combined with the climatic data of the Danish Research Service for Plant and Soil Science.

In the following, the method of calculating the irrigation needs of different crops will be presented. Firstly, the irrigation model will be described, followed by a description of the data and the irrigation strategies. The average irrigation needs of crops have been calculated in relation to root zone capacity and climatic zone. Finally, national irrigation maps have been made for grass and spring barley. The irrigation requirement has also been tabulated in relation to soil type, subsoil texture and landscape type.

Table 28: The Number of Farms using Irrigation and the Area of each County which can be irrigated (29/05/87).

| County | Number of Farms | Irrigible Area (hectares) | %of Total 1987 |
|---|---|---|---|
| Copenhagen | 70 | 693 | 7.6 |
| Frederiksborg | 247 | 5086 | 8.4 |
| Roskilde | 131 | 1711 | 3.1 |
| West Zealand | 435 | 11315 | 5.6 |
| Storstrøm | 250 | 6762 | 2.8 |
| Bornholm | 31 | 570 | 1.6 |
| Funen | 577 | 10747 | 4.5 |
| South Jutland | 1741 | 59843 | 21.1 |
| Ribe | 3168 | 92656 | 45.3 |
| Vejle | 1081 | 33103 | 16.9 |
| Ringkjøbing | 3655 | 121330 | 38.4 |
| Århus | 792 | 19916 | 7.0 |
| Viborg | 919 | 25269 | 9.4 |
| North Jutland | 964 | 29945 | 7.4 |
| Whole Country | 14061 | 418944 | 15.0 |

### *The Irrigation Model*

The irrigation needs of different crops have been calculated by the use of a model for determining actual evapotranspiration, (Holst & Kristensen 1981). The model was developed during a hydrological study of the Suså valley in Zealand. It was primarily based on the Water Balance Model designed by Kristensen and Jensen (1975). The model has been tested on various crops at such places as Aversi in the upper part of the Suså valley and Højbakkegård Research Centre near Tåstrup, Zealand. It has been tested on both clayey and sandy soils.

The model functions on a budget principle, using those parameters that are relevant to calculating the soil water reserves of a given soil at a given time. These parameters include; potential evapotranspiration, precipitation, leaf area index, and root zone capacity. Root zone capacity is calculated on the basis of root development, as well as on the basis of soil water content at field capacity and permanent wilting point. Daily values of evapotranspiration and precipitation were used in order to calculate the daily changes in soil water reserves. In periods of excess precipitation, when the water content of the root zone exceeds field capacity, the model treats the excess water as percolation. However, this will not happen as long as the root zone remains drier than field capacity. The model is well-suited for carrying out larger regional calculations, as it is based on relatively little information which is easily obtainable. For calculations at regional level, data on the following parameters are required; daily precipitation, evapotranspiration, leaf area index during the growing season, effective root depth, and finally the soil water content at field capacity and permanent wilting point.

### *Climatic Data*

The climatic data are taken from the weather records of the weather station network belonging to the Danish Research Service for Plant and Soil Science. This network has been extended since its establishment in 1956 (Aslyng & Hansen 1960, Gregersen & Knudsen 1980). More than 50 stations have functioned in this network, of which 13 have existed for over 30 years, others are more recent, and a few have since been closed down.

At the weather stations, precipitation and potential evaporation are measured daily during the period 1st April till 31st October.

Precipitation (P) is measured by a Hellman Measuring Instrument placed on the ground. The receptive gauge has a surface area of 200 $cm^2$. If the instrument is placed at ground surface level, there is no need to allow for aerodynamic inaccurracies, which otherwise have to be taken into account (Allerup & Madsen 1980).

Potential evaporation (Ep) from a water surface is measured by a HL315 Evaporation Measurer. This has a surface area of about 1/3 $m^2$. The water surface is kept free of dirt and impurities by means of a crude mesh. When the evaporation measurer is not full of sand, convection currents take place in the water. These must be compensated by means of a correction factor ranging between 0.7 and 1.4 (Aslyng 1976). Each month is allotted a particular correction factor. This correction factor, precipitation compensation, the oasis effect (Aslyng & Hansen 1982), and the different shelter conditions existing at the site, all mean that potential evaporation is still estimated with some uncertainty.

The weather stations are stored in the ADK-database according to their UTM grid reference. Weekly values of potential evaporation and precipitation measurements are stored at the ADK database. The daily values fed into the model are 1/7 of the weekly data.

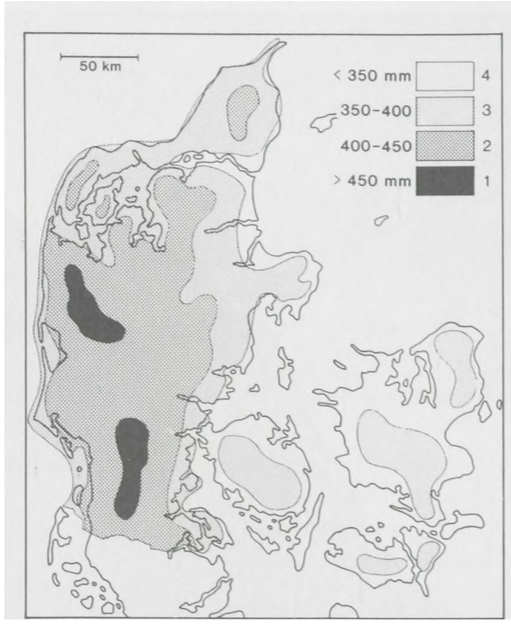



*Fig. 26: Denmark: Map showing the distribution of precipitation covering the period from May to November. The mean is based on figures for the 30-year period, 1930-1960.*

Table 29: Mean Precipitation (P), Potential Evapotranspiration (Ep), and the Precipitation Deficit (P-Ep) for the period DAY 100-280 for each of the 4 Precipitation. Zones. Data based on the 30-Year Period 1956-85.

| | P (mm) | Ep (mm) | P-Ep (mm) |
|---|---|---|---|
| Precipitation Zone 1 | 408 | 424 | -16 |
| Precipitation Zone 2 | 385 | 436 | -51 |
| Precipitation Zone 3 | 340 | 433 | -93 |
| Precipitation Zone 4 | 310 | 441 | -131 |

On the basis of the Meteorological Institute map showing the average precipitation amounts for the summer period 1st May until 31st October for the years 1930-1960, the country was divided into 4 precipitation zones, Figure 26. The national precipitation map, at the scale of 1:2,000,000, was digitized, and each weather station was grouped due to its location into one of the four zones.

Zone 1 : May-October, average rainfall > 450 mm.
Zone 2: May-October, average rainfall 400-450 mm.
Zone 3: May-October, average rainfall 350-400 mm.
Zone 4: May-October, average rainfall < 350 mm.

All of the recorded data from each zone were used to give a fair regional representation. Zone 1 has 4 stations and the other zones have 16, 15 and 18 stations repectively. On a weekly basis, the average precipitation (P) and potential evaporation (Ep) were calculated for each of the 4 zones during the summer period, April to October, for the 30 year period of 1956-1985.

Table 29 shows the average P and Ep for the 4 zones for the time period "Day 100 to Day 280". The results reveal that there is roughly a 35 mm precipitation difference from zone to zone, whereas potential evaporation is very similar in all zones. The difference in the rainfall deficit between the 4 zones is almost the same, 40 mm.

### *The Leaf Area Index*

The actual evapotranspiration (Ea) is highly dependent on the leaf area. When soils are bare (without crops), actual evapotranspiration falls very quickly as the ground surface dries. As growing plants begin to show above the surface, the Ea will increase, along with the increasing leaf area index, until it reaches a value of approximately 3 (Kristensen 1974).

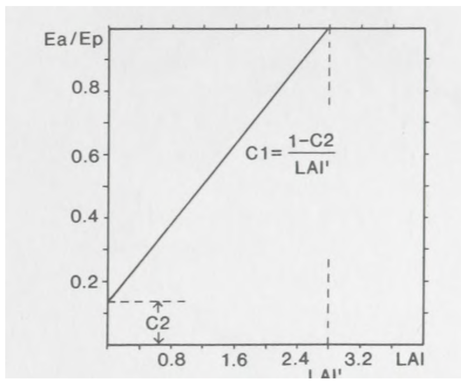



*Fig. 27: The relationship between relative evapotranspiration and the leaf area index of a green crop that is optimally irrigated.*

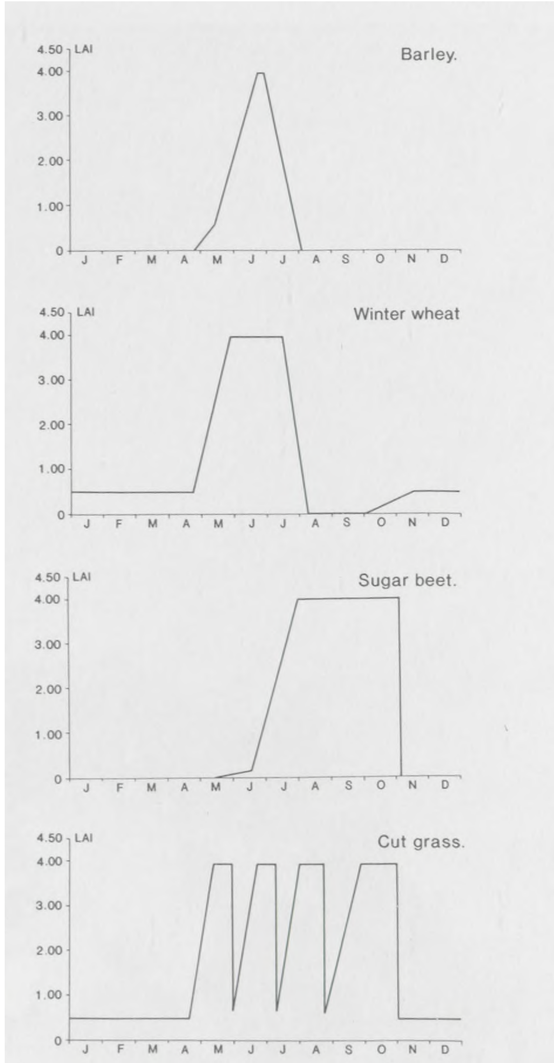



*Fig. 28: The standard leaf area index of different crops.*

Figure 27 shows the relationship between the relative evapotranspiration and the leaf area index of a crop which is not affected by a water deficiency. It should be noted that the relative evaporation increases linearly with the increasing leaf area index until reaching 2.78. The intercept on the Y-axis shows the relative evaporation from a bare soil at a time when the surface has dried out.

Figure 28 shows the standard leaf area index during the growing season for spring barley, winter wheat, sugar beet, grazed grass and grass harvested for hay. It should be noted that spring barley only has an optimal leaf area index for a very short period of time. Grazed grass has an optimal leaf area index during the entire growing season, while grass harvested for hay will have a low leaf area index immediately after being cut. Cereal crops differ from root crops because their optimal leaf area index occurs at a different time of the growing season. Therefore, cereals suffer most from drought during the early part of the growing season, whereas sugar beet suffers most from drought towards the end of the growing season. Grass will be affected by drought throughout the growing season.

### *Soil Water Storage Capacity*

The root zone is that part of the soil profile in which root development occurs. The root zone is not constant, but increases during the growing season. At the start of the season, the root development will be small and therefore the root zone will not be very deep. At the end of the season, it will have obtained its maximum profile, which will give an effective root depth as shown in Table 24.

When using the irrigation model, the initial root zone is taken as being 20 cm, and this is not increased until the leaf area index exceeds 1.0. Then the root zone increases by 1.8 cm daily until the maximum root depth, in this case the effective root depth, has been reached.

According to the model, all the available water content in the root zone is easily accessible and used by the plants. During the period when the root zone increases from 20 cm to its effective root depth, the root zone capacity will increase daily by 2-5 mm.

The soil water retention is given as values of field capacity and permanent wilting point for the three soil profile depth sections; 0-30 cm, 30-60 cm and 60-120 cm. Figure 29 shows the increase in the root zone capacity of a barley field during the growing season where the available water content of the soil

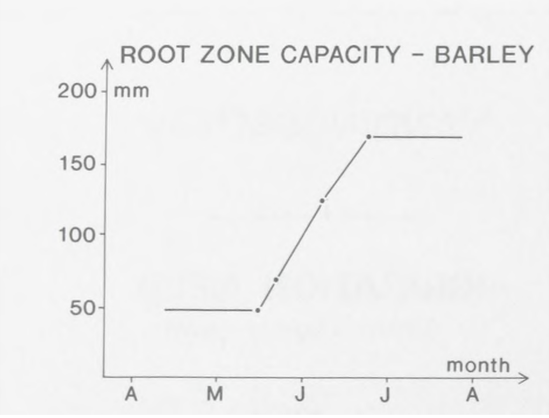



*Fig. 29: The development of root zone capacity forspring barley in a clayey soil. The available water content is related to soil profile sections depth:0-30 cm. = 23% volume; 30-60 cm. = 18% volume;60-120 cm. = 15% volume. Effective root depth = 90 cm.*

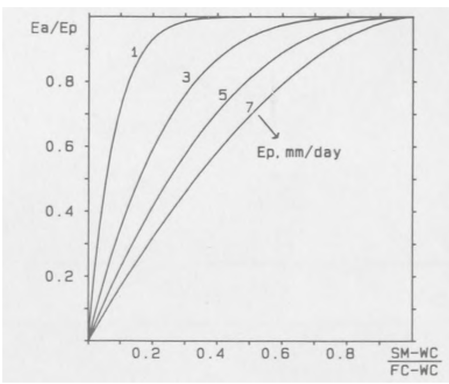



*Fig. 30: Relative evapotranspiration as a function of the relative desiccation of the root zone.*

profile sections is 23%, 18% and 15% by volume respectively.

In periods when the leaf area index is > 2.78, the calculation of actual evapotranspiration (Ea) for DAY "X" may be based on the following equation which shows the relationship between Ea and the relative desiccation of the root zone.

$$Ea = Ep\ (1 - (RZC - AWT) : RZC)^{C3:Ep}$$

In this equation, RZC is the water content at field capacity minus the water content at permanent wilting point, multiplied by the effective root depth for DAY "X". AWT is the available water content for DAY "X". Ea and Ep are the actual and potential evapotranspiration for DAY "X", and C3 is a constant value (normally 10). Figure 30 shows the relationship between the degree of desiccation of the root zone capacity and the relative evapotranspiration Ea/Ep of a clayey soil, when given different values of Ep.

During the periods without vegetation, the daily value of Ea alters. When the surface is wet or waterlogged, Ea is equal to Ep, but when the surface is dry, Ep is multiplied by the intercept value in Figure 27. During the periods when the leaf surface area has not yet fully developed, the daily Ea is equal to the daily Ep multiplied by a reduction factor in Figure 27. Finally, during periods when the leaf surface area is greatest, Ea is calculated by the above-mentioned equation.

## *Irrigation Strategy*

Besides climatic and soil factors, the irrigation needs of a crop depend on the irrigation strategy employed. The timing and quantity of water applied will greatly influence the total irrigation requirements. Mogensen and Hansen (1979) came to the conclusion, based on the works of Kristensen (1961) Friis-Nielsen (1963) and Aslyng (1965), that half of the root zone capacity can be extracted by a plant before a significant reduction in yield occurs. The report, "Betænkning no. 841", agrees that once a plant has utilized 50%-60% of AWC in the root zone, further uptake will be impeded and plant growth will decrease. Gregersen & Knudsen (1980) allowed for this fact in their simulation of irrigation needs.

Using the Heimdal Simulation Model, Madsen (1979) proved that relative evapotranspiration drops below 1.0 when about half of the root zone capacity has been utilized by a plant growing in a sandy soil. In a clayey soil, the same will occur before half of the root zone capacity has been utilized, but relative evapotranspiration decreases much more slowly in areas with clayey soils than areas with sandy soils. As irrigation, in practice, takes place on sandy soils, it was decided, for the purpose of this study, to apply irrigation after half of the RZC had been utilized.

When operating the irrigation model, irrigation was not applied until half the root zone capacity had been utilized. The allotted amounts of water used in the model were "effective", meaning that all the water reached the ground. On average, it is estimated that about 10% of all potential irrigation water evaporates before reaching the ground, and this percentage is far greater on hot summer days.

When using the model, two irrigation strategies were adopted. Firstly, drip irrigation was applied in daily-adjusted amounts according to how much the RZC had fallen below 50%. In the second instance, 30 mm of water was applied when the RZC had fallen below 50%, except for soils with a RZC less than 60 mm. In this case, an amount equal to half of the RZC was applied.

In the earlier irrigation calculations by Mogensen & Hansen (1979) and Gregersen & Knudsen (1980), they chose to irrigate to field capacity. However, this tends to lead to greater leaching during the growing season and a higher irrigation requirement by a crop than when the two irrigation strategies above are applied. This is illustrated by Table 30, where the irrigation needs in relation to the RZC and irrigation strategy are shown. The conclusion is that the irrigation requirements of crops are considerably greater when irrigation to field capacity is applied than when either drip irrigation or irrigation with 30 mm of water is applied.

## *Results*

Figure 31 gives the results of a simulation using climatic data from Højbakkegård Research Centre, Tåstrup (Zealand) in 1983. The crop is grass for hay production. Four hay harvests are achieved during the growing season, as can be seen from the leaf area index. The maximum root depth is 60 cm and the water capacity is given for field capacity and wilting point at three depths. It should be noted that actual evapotranspiration is greatest during early summer, and that leaching does not occur from the end of May until the middle of December.

The model was used for the period - day 100 until day 280 - for each year during the 30 year period of 1956 to 1985. The climatic data were recorded as mean weekly values throughout the period at the stations in the four precipitation zones (Figure 26). For each year, and for each of the 4 precipitation zones, the irrigation requirements of spring barley and short grass were calculated, based on 7 root zone capacities and 2 irrigation strategies. The average, annual irrigation requirements for the thirty year period were then calculated.

Figure 32 shows the irrigation needs of spring barley and grass in the climatic zones 1 and 4 for the same 30 year period of 1956 to 1985. The irrigation requirement was calcu-

Table 30: Irrigation Requirement (mm) related to Root Zone Capacity, and the Irrigation Strategy employed during a Period of Drought with a Precipitation Deficit of 81 mm. Irrigation is applied as soon as half of the Root Zone Capacity has been utilized.

| Root Zone Capacity (mm) | | 60 | 80 | 100 | 120 | 140 | 160 | 180 |
|---|---|---|---|---|---|---|---|---|
| A. Irrigation to Field Capacity | 1. watering | 30 | 40 | 50 | 60 | 70 | 80 | 0 |
| | 2. watering | 30 | 40 | 0 | 0 | 0 | 0 | 0 |
| | Total | 60 | 80 | 50 | 60 | 70 | 80 | 0 |
| B. Irrigation with 30 mm. | 1. watering | 30 | 30 | 30 | 30 | 30 | 30 | 0 |
| | 2. watering | 30 | 30 | 30 | 0 | 0 | 0 | 0 |
| | Total | 60 | 60 | 60 | 30 | 30 | 30 | 0 |
| C. Drip Irrigation | | 51 | 41 | 31 | 21 | 11 | 1 | 0 |

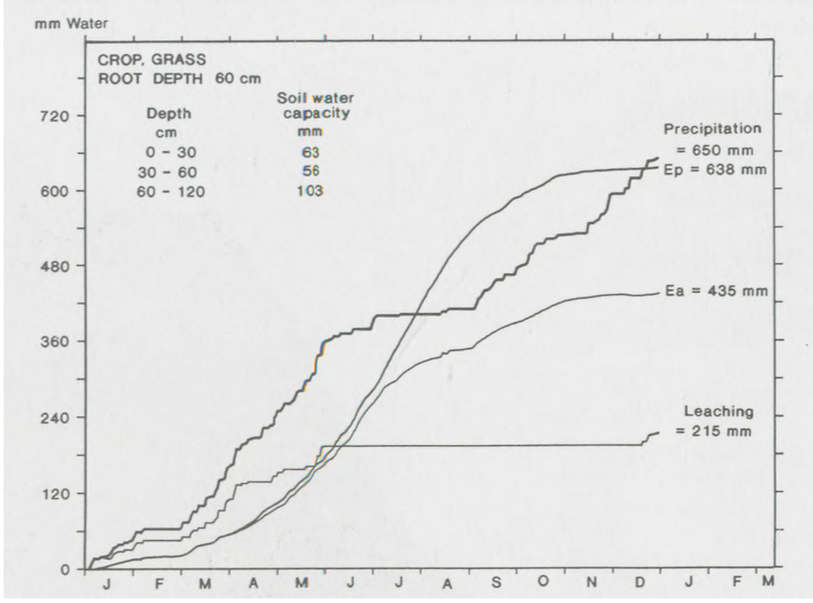



*Fig. 31: Actual evapotranspiration and leaching in a field with short grass, calculated by the irrigation model developed by Holst & Kristiansen (1981), using data from Højbakkegård Research Centre, Tåstrup, Zealand, 1983.*

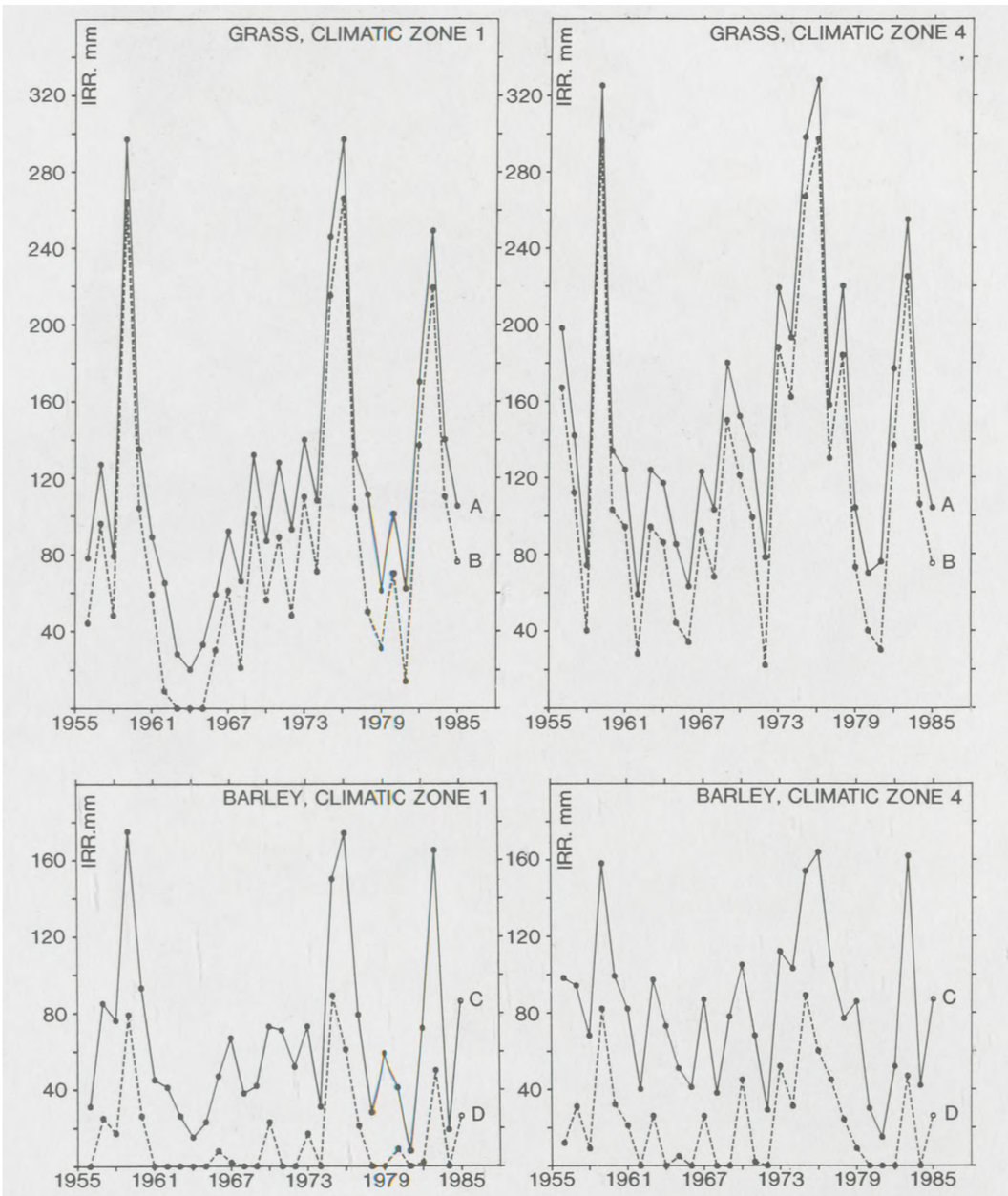



*Fig. 32: The irrigation needs of spring barley and short grass in the climatic zones 1 and 4, based on figures for the 30-year period, 1956-1985.*

*A & C: Sandy soil with a root zone capacity of 50 mm.*
*B: Clayey soil with a root zone capacity of 110 mm.*
*D: Clayey soil with a root zone capacity of 170 mm.*

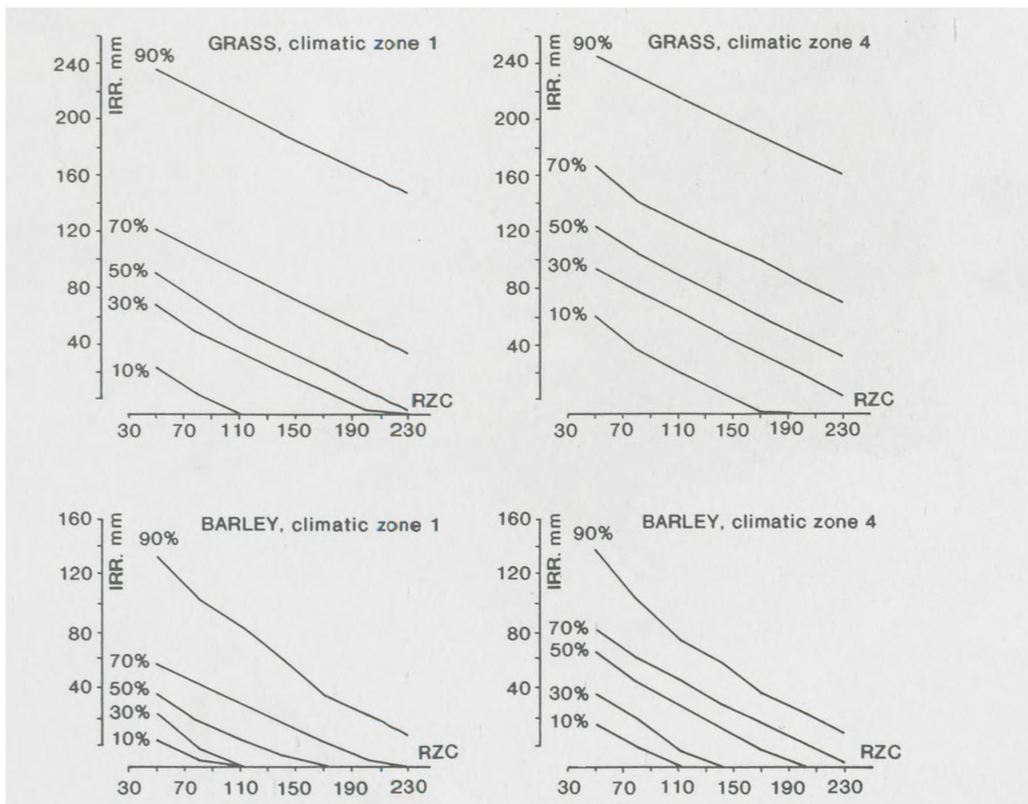
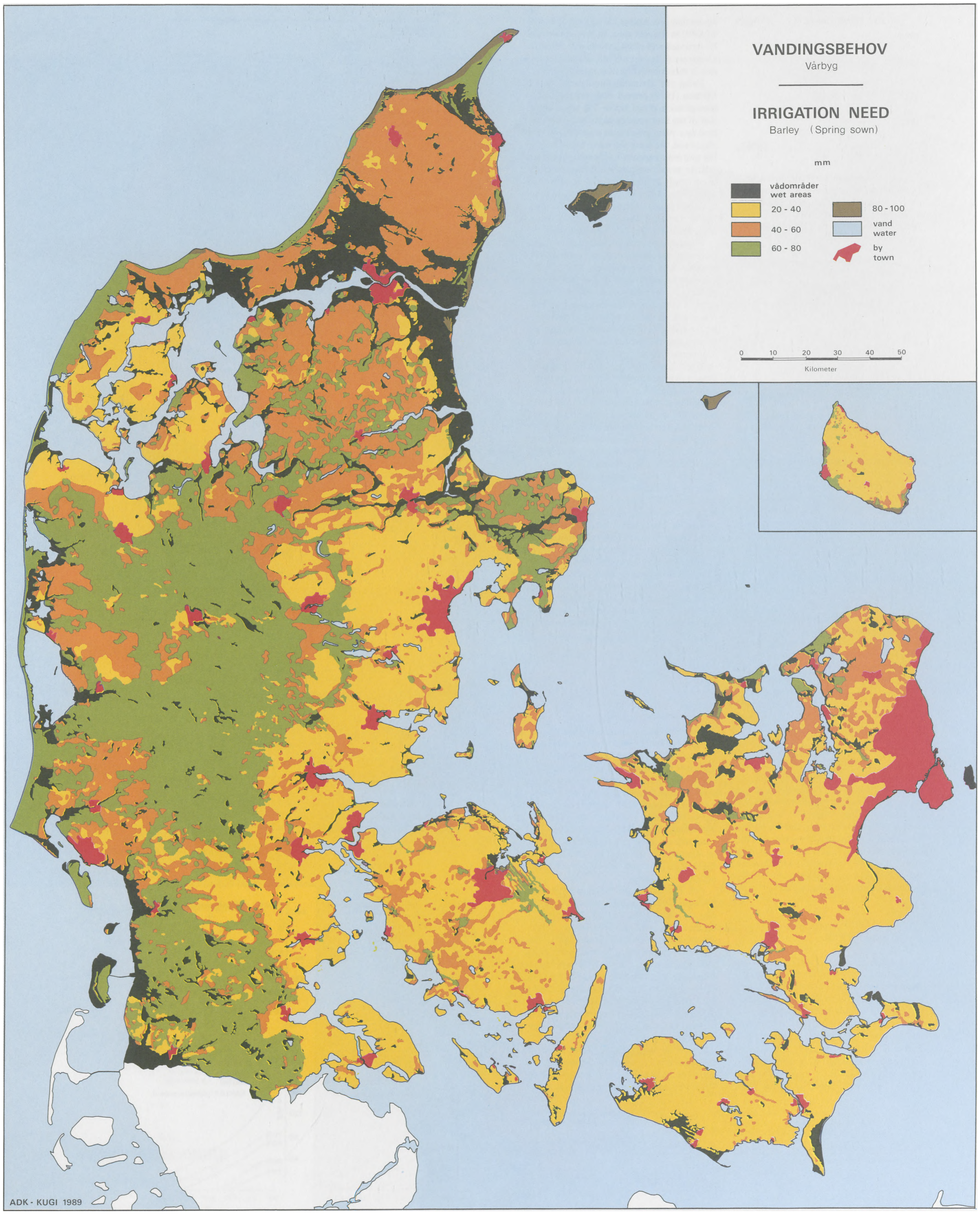
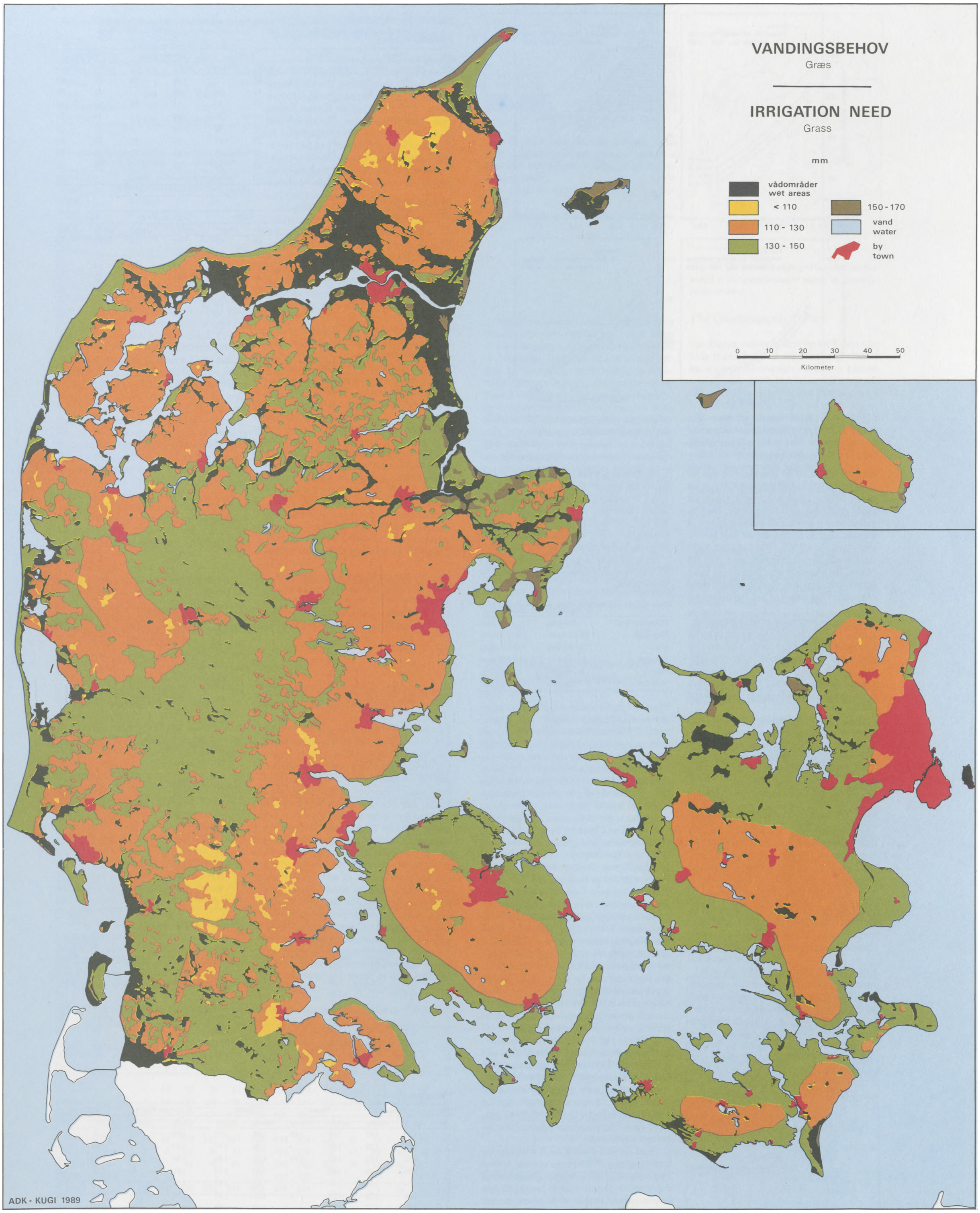



*Fig. 33: Irrigation needs related to; root zone capacity, climatic zone, and the frequency of years during which optimal irrigation should be applied.*


VANDINGSBEHOV
Vårbyg
IRRIGATION NEED
Barley (Spring sown)
mm
vådområder
wet areas
20 - 40
40 - 60
60 - 80
80 - 100
vand
water
by
town
0 10 20 30 40 50
Kilometer
ADK - KUGI 1989


VANDINGSBEHOV
Græs
IRRIGATION NEED
Grass
mm
vådområder
wet areas
< 110
110 - 130
130 - 150
150 - 170
vand
water
by
town
0 10 20 30 40 50
Kilometer
ADK - KUGI 1989

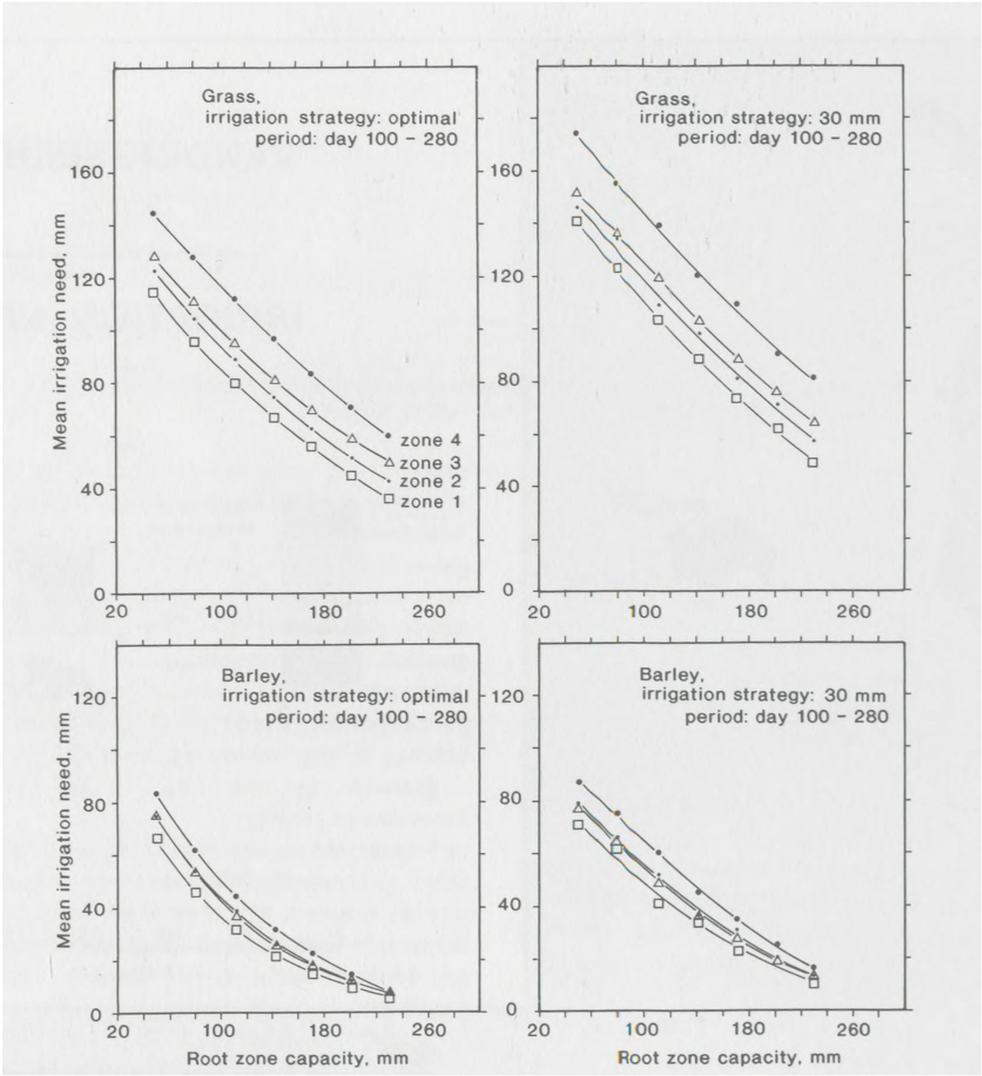



*Fig. 34: The irrigation needs of; sugar beet, winter wheat, spring barley and short grass in relation to; root zone capacity, climatic zone and irrigation strategy.*

lated for a RZC of 50 mm and 110 mm for grass, and a RZC of 50 mm and 170 mm for spring barley. These are typical values for sandy and clayey soils respectively. The irrigation need is greatest on sandy soils and in climatic zone 4. During the 30 year period, four years, 1959, 1975, 1976 and 1983, had a significantly higher irrigation need than the others. The irrigation need differs very much from year to year, and there is no fixed trend throughout the length of the thirty-year period.

For spring barley and grass in the climatic zones 1 and 4, Figure 33 shows the relationship between irrigation needs, root zone capacity, and the frequency of years when optimal irrigation can be applied. The percentage value indicates the possibility of irrigating optimally, e.g. 90% will signify 9 years out of 10.

Figure 34 shows the mean irrigation needs of barley and grass for the two irrigation strategies. The irrigation needs are related to the root zone capacity, and a curve is drawn for each of the four precipitation zones. In each case, the irrigation need is shown to be less when drip irrigation is applied. Furthermore, drip irrigation seems to produce a more even curve than irrigation with 30 mm of water. The irrigation needs of grass are far greater than those of other crops, given the same root zone capacity. This is due to the fact that grass has a longer growing season and a higher leaf area index for much of the growing season. Of note, is the fact that the irrigation needs of grass, given a constant root zone capacity, differ greatly according to the precipitation zone. This is not the case for barley. Spring barley has similar irrigation needs in zones 2 and 3, even though there is a 45 mm precipitation difference. This can be explained by the fact that this difference tends to occur outside the period when the irrigation needs of spring barley are greatest.

Average daily irrigation needs have been divided into the following classes for the different crops.

| | Spring Barley | Short Grass |
|---|---|---|
| Extremely high | >100 mm. | > 170 mm. |
| Very high | 80-100 mm. | 150-170 mm. |
| High | 60- 80 mm. | 130-150 mm. |
| Average | 40- 60 mm. | 110-130 mm. |
| Low | 20- 40 mm. | 90-110 mm. |
| Very low | < 20 mm. | < 70 mm. |

Figure 35 shows a map of the average irrigation needs of spring barley in Vejle county, Jutland. The map is a dot map as is the root zone capacity map of the same district (Figure 25). The irrigation needs are greatest in the western half of the county, on the sandy soils near the main terminal moraine, while being least in the clayey moraine landscape. In the far east of the county, the needs increase due to the lower annual precipitation.

Maps 18 and 19 show the irrigation needs of spring barley and grass for the whole of Denmark. The irrigation strategy is that of applying 30 mm of water when half of the root zone capacity has been utilized by a plant. The information in Tables 31 and 32 has been used to construct maps which relate irrigation needs to; soil type, subsoil texture, landscape type and the four precipitation zones. In the case of spring barley, there is a pronounced relationship between its irrigation needs and the soil type in which it is grown. However, this is not the case for grass, which is more dependent on climatic factors, such as precipitation. This is due to its longer growing season and the small difference in its RZC when grown in either sandy or clayey soils.

Tables 33 and 34 indicate the regional differences in the irrigation needs of grass and spring barley in relation to landscape type. The statistics are entirely based on the areas of well-drained soils contained within the classified area. The average, annual irrigation needs of spring barley lie between 40-60 mm, while those of grass are far greater lying between 120-140 mm.

Of all the well-drained areas where spring barley is grown, 99% have an average, annual irrigation needs below 80 mm. The irrigation needs on the Danish islands are clearly less than in Jutland, in spite of the greater precipitation in the latter region. More than 80% of the average, annual irrigation needs on the Danish islands are less than 40 mm.

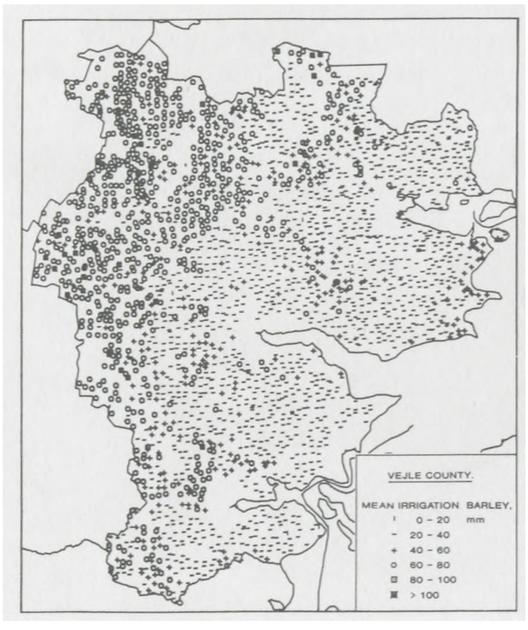



*Fig. 35: The average irrigation requirements of spring barley in Vejle County, Jutland.*

Table 31: The Irrigation Requirement (mm) of Spring Barley related to Precipitation Zone, Soil Type (JB), Subsoil and Landscape Type.

Precipitation Zone 1.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 60 | 56 | *68* | 64 | 63 | 62 | *66* | *68* | 62 | 63 |
| *2* | 34 | 27 | 41 | - | 41 | 28 | 41 | - | 41 | 29 |
| 3 | 54 | - | 53 | 35 | 53 | 30 | 55 | 39 | 54 | 30 |
| 4 | 33 | 24 | 41 | - | 41 | 26 | 42 | - | 41 | 25 |
| 5 | - | - | 35 | - | 35 | 30 | 33 | - | 34 | 28 |
| *6* | 24 | 16 | 26 | - | 29 | 27 | 29 | *22* | 29 | 25 |
| 7 | 24 | 18 | 24 | - | 28 | 25 | 25 | 28 | 28 | 24 |
| *8* | 23 | - | - | - | *22* | *21* | 25 | - | 25 | *21* |
| 9 | - | - | *20* | - | - | - | - | - | - | *21* |

Precipitation Zones 2 and 3.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 64 | 62 | 73 | 69 | *68* | 67 | 72 | 73 | 67 | *68* |
| *2* | 41 | 32 | 47 | - | 47 | 34 | 48 | - | 47 | 35 |
| 3 | 60 | - | 60 | 41 | 59 | 36 | 61 | 46 | 59 | 36 |
| 4 | 39 | 28 | 48 | - | 48 | 30 | 49 | - | 47 | 29 |
| 5 | - | - | 42 | - | 41 | 36 | 39 | - | 41 | 34 |
| *6* | 29 | 18 | 31 | - | 35 | 32 | 35 | 24 | 35 | 29 |
| 7 | 28 | *20* | 28 | - | 34 | 30 | 30 | 33 | 34 | *28* |
| *8* | 27 | - | - | - | 25 | 24 | 29 | - | 29 | 23 |
| 9 | - | - | - | - | - | - | - | - | - | 23 |

Precipitation Zone 4.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 74 | 71 | 82 | 79 | 78 | 77 | 81 | 83 | 76 | 78 |
| *2* | 49 | 39 | 56 | - | 56 | 41 | 57 | - | 56 | 43 |
| 3 | 69 | - | 70 | 50 | *68* | 44 | 70 | 55 | 69 | 44 |
| 4 | 47 | 34 | 57 | - | 57 | 37 | 58 | - | 56 | 36 |
| 5 | - | - | 50 | - | 50 | 44 | 47 | - | 49 | 42 |
| *6* | 35 | *21* | 38 | - | 43 | 39 | 43 | 30 | 43 | 36 |
| 7 | 34 | 24 | 34 | - | 42 | 37 | 37 | 41 | 42 | 35 |
| *8* | 33 | - | - | - | 31 | 29 | 36 | - | 36 | 28 |
| 9 | - | - | 27 | - | - | - | - | - | - | 28 |

Table 32: The Irrigation Requirement (mm) of Short Grass related to Precipitation Zone, Soil Type (JB), Subsoil, and Landscape Type.

Precipitation Zone 1.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no. | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 122 | 118 | 132 | 128 | 126 | 125 | 131 | 133 | 124 | 127 |
| *2* | 97 | 97 | 105 | - | 105 | 99 | 106 | - | 105 | 102 |
| 3 | 119 | - | 120 | 122 | 118 | 113 | 120 | 128 | *120* | 113 |
| 4 | 95 | 97 | 106 | - | 106 | 103 | 107 | - | 105 | *101* |
| 5 | - | - | *110* | - | 109 | 109 | 106 | - | 108 | 106 |
| *6* | 89 | 82 | 93 | - | *100* | 103 | 99 | 93 | 99 | *101* |
| 7 | 87 | *86* | 87 | - | 98 | 99 | 91 | 105 | 98 | 99 |
| *8* | *86* | - | - | - | 83 | 89 | 89 | - | 89 | 89 |
| 9 | - | - | 77 | - | - | - | - | - | - | 87 |

Precipitation Zone 2.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 132 | 128 | 141 | 137 | 135 | 134 | 140 | 142 | 134 | 136 |
| *2* | 105 | 105 | 113 | - | 113 | 108 | 115 | - | 113 | *110* |
| 3 | 129 | - | 129 | 131 | 128 | *122* | 130 | 138 | 129 | *122* |
| 4 | 103 | 105 | 115 | - | 115 | *111* | 116 | - | 113 | *110* |
| 5 | - | - | 119 | - | 118 | 118 | 115 | - | 117 | 115 |
| *6* | 96 | 90 | *101* | - | 104 | *111* | 108 | *101* | 108 | 109 |
| 7 | 95 | 93 | 95 | - | 106 | 108 | 99 | 114 | 106 | 108 |
| *8* | 93 | - | - | - | 91 | 96 | 96 | - | 97 | 98 |
| 9 | - | - | 85 | | - | - | - | - | - | 94 |

Precipitation Zone 3.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 136 | 132 | 145 | 141 | 139 | 138 | 143 | 145 | 137 | 139 |
| *2* | 113 | *112* | *120* | - | *120* | 115 | *121* | - | *120* | 117 |
| 3 | 133 | - | 134 | 135 | 133 | 128 | 134 | 141 | 134 | 128 |
| 4 | *111* | *112* | *121* | - | *121* | 118 | *122* | - | *120* | 117 |
| 5 | - | - | 125 | - | 124 | 124 | *121* | - | 123 | *121* |
| *6* | 104 | 98 | 108 | - | 115 | 118 | 115 | 109 | 115 | 116 |
| 7 | 103 | *101* | 103 | - | 113 | 115 | 106 | *120* | 113 | 115 |
| *8* | *101* | - | - | - | 98 | 104 | 104 | - | 105 | 105 |
| 9 | - | - | 92 | - | - | - | - | - | - | *102* |

Precipitation Zone 4.

| JB | Yoldia | | Dune | | Saale | | Outwash Plain | | Weichsel | |
|---|---|---|---|---|---|---|---|---|---|---|
| no | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey | sandy | clayey |
| *1* | 148 | 151 | 165 | 160 | 158 | 157 | 163 | 165 | 156 | 159 |
| *2* | 132 | 139 | 139 | - | 139 | 134 | 140 | - | 139 | 136 |
| 3 | 152 | 152 | 152 | 154 | 151 | 146 | 153 | 160 | 152 | 146 |
| 4 | 130 | 140 | 140 | - | 140 | 137 | 141 | - | 139 | 136 |
| 5 | - | 144 | 144 | - | 143 | 143 | 140 | - | 142 | 141 |
| *6* | 124 | 128 | 128 | - | 135 | 137 | 134 | 129 | 134 | 135 |
| 7 | *122* | *122* | *122* | - | 133 | 134 | 126 | 140 | 133 | 134 |
| *8* | 121 | - | - | - | 117 | 124 | 124 | - | 124 | 125 |
| 9 | - | 110 | 110 | - | - | - | - | - | - | 122 |

Table 33. Irrigation Requirement of Spring Barley related to Landscape Type. Area in km².

| | Irrigation Requirement (mm) | | | |
|---|---|---|---|---|
| Landscape Type | 20-40 | 40-60 | 60-80 | 80-100 |
| Yoldia | 76 | 679 | 20 | 0 |
| Dune | 1 | 112 | 556 | 39 |
| Saale | 649 | 1,059 | 2,065 | 0 |
| Outwash Plain | 25 | 554 | 2,437 | 6 |
| Weichsel | 13,528 | 4,480 | 1,592 | 0 |

Table 34. Irrigation Requirement of Short Grass related to Landscape Type. Area in km².

| Landscape | Irrigation Requirement (mm) | | | | |
|---|---|---|---|---|---|
| Type | 70-90 | 90-110 | 110-130 | 130-150 | 150-170 |
| Yoldia | 0 | 161 | 581 | 29 | 5 |
| Dune | 0 | 1 | 107 | 561 | 39 |
| Saale | 4 | 249 | 1,989 | 1,531 | 0 |
| Outwash Plain | 0 | 21 | 434 | 2,562 | 7 |
| Weichsel | 0 | 1,256 | 10,591 | 7,631 | 122 |

With regard to landscape type, the Yoldia plain and the younger Weichsel moraine areas have the lowest irrigation needs. 10% of the Yoldia and 69% of the Weichsel have average, annual irrigation needs of between 20-40 mm if the land is well-drained. By contrast, only 23% Weichsel moraine landscape has irrigation needs of between 40-60 mm per annum, compared to 88% of the Yoldia plain.

The outwash plain and dune landscapes have high irrigation needs. 80% of the well-drained land needs between 60-80 mm per annum. The Saale landscape possesses a mixture of soil types requiring various amounts of irrigation, although generally the annual needs are high. 55% of the area has average annual irrigation needs of between 60-80 mm, while only 17% has average needs of between 20-40 mm.

Based on the map colour code, the average, annual irrigation needs will lie between 60-80 mm for MCC1, 40-60 mm for MCC2 and MCC3, and 20-40 mm for MCC4, MCC5 and MCC6.

With respect to grass, as with cereals, all of the well-drained land has irrigation needs, which lie between 70-170 mm per annum. As the difference in RZC based on different soil types is much less pronounced for grass than for corn crops, climatic factors play a greater role in determining its regional variation in irrigation needs. Average annual irrigation needs are a little higher on the Danish islands due to the lower precipitation. The island irrigation needs average between 130-140 mm per annum, being 10 mm higher than those in Jutland. Mogensen and Hansen (1979) discovered the same tendency during their study. From April to October, the average irrigation needs of a Zealand clay soil with a root zone capacity of 120 mm will be 192 mm (3.2×60 mm), while those of a mid-Jutland sandy soil with a root zone capacity of 60 mm will be 156 mm (5.2×30 mm). On the islands, about 35% of the area has average annual irrigation needs of between 110-130 mm, while 65% area has needs of 130-150 mm. In Jutland, some parts of the counties of Ribe and Ringkøbing have very high irrigation needs, while areas with very low needs can be found in Vejle or South Jutland, where 20% and 15% of the agricultural land respectively has needs of 90-110 mm.

When relating the irrigation needs of short grass to the type of landscape on which it is grown, they are lowest in the Saale, Weichsel and Yoldia landscapes. The landscape types with the greatest irrigation needs are the outwash plains and the dune landscapes.

## Mapping the Potential Drainage Needs of the Danish Farmland

In order to guarantee optimal plant production, it is necessary for the soil to be well-drained. Excess rainfall must be quickly removed to prevent the formation of high-lying groundwater in the root zone. This will ensure that the soil contains a sufficient number of air-filled pores through which air can circulate and be changed. This will enable the plants to develop a deep root network, which can reach deep down into the soil in order to supply the plants with their necessary water and nutrient requirements.

A well-drained soil will enhance fertility and be less susceptible to erosion. The farmer will benefit from even growing conditions across a wide area. This will enable the plants to grow at a similar rate and in a similar way. Optimal plant production necessitates a long growing season, and this can be partly ensured by securing good drainage so that the farmer may work the soil and sow early in spring.

Late sowing in spring-time can often lead to a reduction in yield, or, in the worst circumstances, to total crop failure. A reduction in yield can also be a result of inadequate root development during the early summer due to late sowing caused by temporarily high water tables. Plants will not then be able to extract a sufficient amount of water, if the summer is dry. Furthermore, during dry summers, there is the risk that fertilizers will not be optimally absorbed by crops if only shallow root profiles have been developed. Good soil drainage is therefore very important to securing stable crop yields from year to year. When drainage conditions are maintained at an optimal level, economic savings can be made on fuel, chemical weed killers and farm machinery. These are further economic benefits gained besides those from maintaining a regularly high yield.

During the past hundred years, an ever-increasing amount of the Danish farmland has been drained (Table 35). There are large regional variations. The greatest amount of drainage has taken place in clay areas.

### *Recipient and Texturally dependent Drainage Requirements*

It is possible to distinguish between the need for drainage caused by the presence of a nearby recipient such as a lake or stream, and that which is caused by the soil texture. The former are most typically found in valley bottoms, low-lying areas beside rivers and lakes, and in the saltmarsh, littorina and marine forelands areas. Their drainage requirements may be described as being recipient-dependent. On the other hand, areas whose subsoils are of low permeability have drainage requirements that may be defined as being texturally-dependent. In these soils, temporary shallow water tables are built up in periods when precipitation surplus (P-Ea) exceeds the amount of water which can be drained out of the soil profile. These are often clay soils that have developed on tills or meltwater deposits. Figure 36 is a transect through a hilly area, showing areas where the drainage is dependent on recipient-related or texturerelated conditions.

Table 35. The Drained Area of Denmark in Hectares and as % of the Total Agricultural Land till 1979 (Aslyng 1980).

| | ← 1,000 ha | | | | | | | | → ← % | | | | | →|
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | 1861 | 1871 | 1881 | 1896 | 1907 | 1929 | 1972 | 1979 | 1861 | 1881 | 1907 | 1929 | 1972 | 1979 |
| Zealand[1)] | 11 | 75 | 195 | 224 | 235 | 260 | 248 | 247 | 2.2 | 35 | 42 | 45 | 73 | 73 |
| Bornholm | - | 5 | 15 | 18 | 19 | 21 | 21 | 22 | 0.3 | 38 | 47 | 52 | 57 | 60 |
| Lolland-Falster[2)] | 3 | 18 | 57 | 79 | 85 | 95 | 201 | 198 | 2.6 | 43 | 63 | 66 | 81 | 80 |
| Funen | 6 | 36 | 80 | 108 | 109 | 123 | 136 | 135 | 2.3 | 29 | 40 | 43 | 55 | 55 |
| Islands | 20 | 134 | 347 | 429 | 448 | 499 | 606 | 602 | - | - | - | 48 | 70 | 69 |
| Eastern Jutland | 9 | 51 | 110 | 125 | 127 | 148 | 232 | 234 | 2.0 | 21 | 24 | 26 | 46 | 46 |
| Northern Jutland | 1 | 4 | 18 | 30 | 33 | 60 | 129 | 129 | 0.4 | 47 | 11 | 30 | 30 | |
| Western Jutland | 3 | 11 | 33 | 48 | 51 | 80 | 285 | 288 | 0.7 | 79 | 11 | 35 | 35 | |
| Southern Jutland | - | - | - | - | - | 17 | 182 | 183 | - | - | - | 5 | 62 | 62 |
| Jutland | 13 | 66 | 161 | 203 | 211 | 305 | 828 | 834 | - | - | - | 14 | 40 | 41 |
| Whole Country | 33 | 200 | 508 | 632 | 659 | 804 | 1434 | 1436 | 1.6 | 21 | 26 | 25 | 49 | 49 |

1) 1972 and 1979 excluding the part of Zealand belonging to Storstrøm County.

2) 1972 and 1979 including the part of Zealand belonging to Storstrøm County.

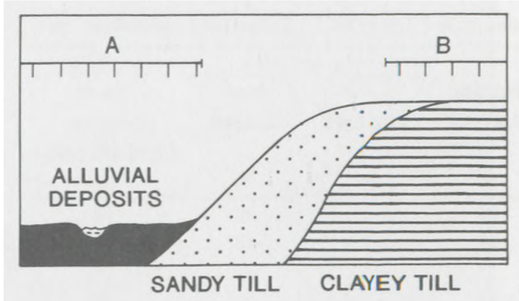



***Fig. 36: Schematic drawing showing areas with no drainage requirement, and with a recipient- and a texturally- dependent drainage requirement.***
***A = recipient-dependent drainage requirement.***
***B = texturally-dependent drainage requirement.***

Water that passes through the root zone as a result of excess rainfall will either reach down to deeper ground water or else be led off by a drainage system into the nearest recipients. In those areas where drainage is determined by the recipient, most of the excess rainfall will pass into the drainage channels. By contrast, excess rainfall will pass into both the lower soil layers and drainage channels in soils where drainage is texurally determined. The way in which water passses out to a drainage channel or percolates down to lower layers depends on the hydraulic conductivity of the sub-strata, as well as on the amount and intensity of the excess rainfall. Obviously, soils of lower hydraulic conductivity will force water into surface drainage channels. This is mainly pipe drainage in Denmark. Table 36 indicates the amount of drainage water that is led into drainage pipes or open channels and that which is led underground. A higher percentage of water passing through clayey moraine is led into drainage channels than that which passes through sandy moraine.

### *Methods and Materials used for Mapping Potential Drainage Requirements*

The making of national maps showing the potential drainage requirements of different areas falls naturally into two parts:

1) The construction of mapping units for the whole country for areas that have similar drainage requirements. These units have been based on the information stored at the national database at ADK.
2) The calculation and evaluation of the potential drainage requirements for each mapping unit. This has been based on a questionnaire survey of farmers and these soils, and on pedological investigations. Drainage types have been classified and given values.

A national map showing mapping units used for the assessment of potential drainage requirements has been constructed on the basis of map information from the following four national databases (described in Chapters 2 and 3):

The Basic Data Map (with the MCC)
The Landscape Map
The Subsoil MapThe Wetlands Map

The following is a short description of the different types of investigation used for drainage assessment of the different mapping units.

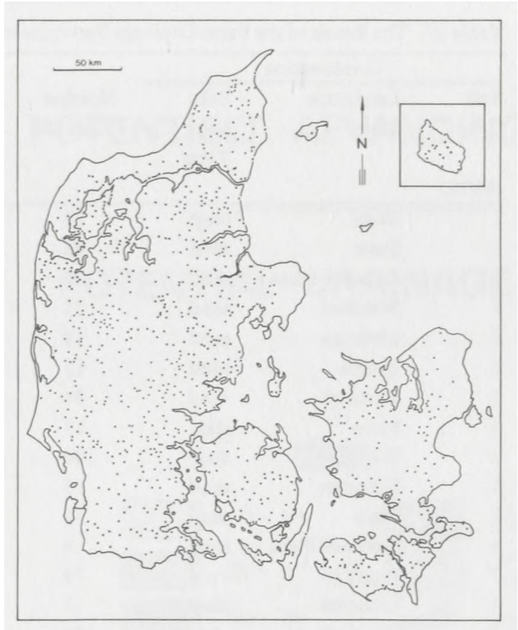



*Fig. 37: The location of properties that participated in the questionnaire survey of drainage requirements.*

### *The Questionnaire Survey*

The Danish Advisory Service for Plants and Soils (Landskontoret for Planteavl) carried out a survey of drainage conditions and requirements in 1972-73 (Skriver & Hedegaard 1973). The investigation was carried out by its own consultants, supported by the expert advice of the Danish Heath Society. The study was a spot check of 1% of all farmland properties. The soil of each property was divided into mineral and organic soils. The following measurements were made:

The % area already drained or being drained.
The % area requiring local drainage.
The % area requiring a completely new drainage network.

Figure 37 shows the location of the 929 properties that participated in the investigation.

It should be noted that the investigation does not always show the total potential drainage needs because some wet areas drained by open drains and the lowering of the water-table by deepening and straightening the recipients are not registered as having a potential drainage need. However, the results of pedological studies, described later, give direct information as to the potential drainage requirements based on the gleys and pseudogleys discovered in the various soil profiles.

The total area of the farmland studied came to 28,465 hectares, of which 3,973 hectares were organic soils, while the remainder were mineral soils. The following calculations were made for the two soil groups. Of the mineral soil area, 47% was already found to be drained, 4% required local drainage, while a further 4% required an entirely new drainage network. For the total area of organic soils the figures were 62%, 5% and 16% respectively.

The 929 properties and their drainage characteristics were registered, by their grid references, for future use in connection with the digitized maps of the database. This makes it possible to relate the drainage situation to different soil areas and landscape types. The drainage requirements of the most important types of soil, subsoil and landscape are shown in Table 37.

Between 1977 and 1981, a hydrological research project was carried out in the upper Suså valley on Zealand. In this connection, a report was made on the extent of the existing drainage situation and drainage requirements. The amount of drained farmland calculated for 4 separate catchment areas was found to be: 80%, 77%, 72% and 73%. The 4 areas are located in the region of the young Weichsel moraine landscape. The subsoil is mainly clayey, while the topsoil is sandy clay.

Table 36. Surface Drainage and Percolation measured on Selected Farms.
a) Upper Valley of the Suså River (as an average based on the period 1977-80 (Hansen 1981)).
b) South Jutland (as an average based on 4 years (Kjellerup 1983)).

| | Run-off mm./year | | Soil Type/Subsoil |
|---|---|---|---|
| | Surface Drainage | Percolation | Geology |
| a. Aversi Østergård | 145 | 147[1)] | MCC4-5 moraine clay |
| a. Lille Egesgård | 140 | 152[1)] | MCC4-5 moraine clay |
| b. Sdr. Stenderup | 259 | 125[1)] | MCC5 moraine clay |
| b. Agervig | 251 | 332[2)] | MCC3 diluvial sand |

1) Precipitation - 400 - Drainage Water Run-off.

2) Precipitation - 350 - Drainage Water Run-off.

Table 37. The Result of the Farm Drainage Survey in relation to Soil Type (MCC), Subsoil and Landscape Type.

| Combination | | | | | Requirements | | |
|---|---|---|---|---|---|---|---|
| Soil Type (MCC) | Landscape Type | Sub-soil Type | Number Properties | Existing Drainage % | Local Drainage % | New Drainage % | Total Drainage Requirement % |
| 1 | Saale | clay | 12 | 66 | 2 | 4 | 72 |
| 1 | Saale | sand | 43 | 21 | 1 | 1 | 23 |
| 1 | Outwash Plain | sand | 41 | 15 | 2 | 2 | 19 |
| 1 | Weichsel | sand | 27 | 13 | 3 | 4 | 20 |
| 2 | Littorina | sand | 19 | 44 | 1 | 10 | 55 |
| 2 | Yoldia | sand | 12 | 37 | 1 | 1 | 39 |
| 2 | Weichsel | sand | 34 | 7 | 0 | 2 | 9 |
| 3 | Saale | clay | 17 | 61 | 6 | 2 | 69 |
| 3 | Weichsel | clay | 100 | 42 | 2 | 3 | 47 |
| 3 | Littorina | sand | 12 | 38 | 1 | 7 | 46 |
| 3 | Saale | sand | 32 | 21 | 2 | 4 | 27 |
| 3 | Outwash Plain | sand | 9 | 37 | 1 | 2 | 40 |
| 3 | Weichsel | sand | 79 | 38 | 8 | 2 | 48 |
| 4 | Littorina | clay | 17 | 60 | 5 | 7 | 72 |
| 4 | Weichsel | clay | 186 | 62 | 7 | 4 | 73 |
| 4 | Weichsel | sand | 11 | 46 | 0 | 5 | 51 |
| 5 | Weichsel | clay | 58 | 82 | 4 | 3 | 89 |

## *Pedological Investigations*

These investigations described and classified the soil profiles according to their physical and chemical properties, such as gley characteristics.

Gley formation may be descibed as the way in which soil colour changes, taking on marbled or mottled tones, or bluish hues due to the presence of permanent or temporary groundwater. This colour change is brought about by aerobic and anaerobic conditions and the presence of oxidation or reduction zones in the profile. When exposed to oxygen, ferric iron produces a yellowish or reddish brown colour in the subsoil. On the other hand, under anaerobic conditions it is reduced to ferrous iron, and blues or greens will be produced. Furthermore, ferrous iron is mobile, and even at a high pH-value, it will be attracted by the more oxidized parts of the soil, creating rust-red nodules and mottles. Deeper down, where there is little or no oxygen, the earth will be totally bluish without any red spots.

Broadly speaking, gleys may be divided into two kinds; groundwater gleys and pseudogleys (Sheffer & Schachtschabel 1989).

Groundwater gleys are normally found in areas with permanent groundwater in the soil profile. These soils will normally have a recipient-dependent drainage. Most of the aerobic parts of the soil will be found close to the macropore system, and red iron oxides will form in the root network and on the aggregate surface, while the rest of the soil will be blue or grey due to the reduction of iron or the complete absence of iron.

Pseudogleys develop in soils with low hydraulic conductivity, where excess precipitation is not able to percolate quickly down through the soil profile causing waterlogged conditions to prevail (Figure 38). Pseudogleys occur mainly in clayey sediments that possess an inferior ability to conduct water down throught the different horizons. Many of the Danish till soils experience pseudogley conditions. Pseudogleys are formed when excess precipitation passes through the soil macropore system under positive soil water potentials, while the soil water in the inner part of the aggregates has still negative potentials. Due to the fact that the macropore system is more weakly-developed lower down in the profile, as a result of decreasing biological activity, it tends to be filled up to the clay eluvial horizon (at a depth of between 0-50 cm). Here, the greater hydraulic conductivity caused by the low clay content and vigorous biological activity may lead to a lateral removal of excess water on sloping terrain. The filling of the pores will reduce the ferric iron and it will then be attracted by the interior aggregates. This will lead to the characteristic mottling of profiles, where the external surfaces of aggregates become pale, while the inner parts, being enriched in iron, take on a more pronounced rust colour. This mottling characteristic of pseudogleys contrasts strongly with groundwater gleys, where the oxygen-rich red zones are found close to the macropores.

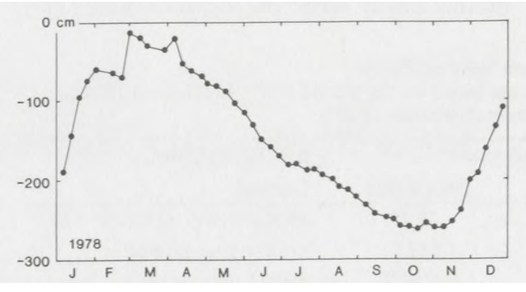



*Fig. 38: The variation of the water table through 1980 in a loamy till in Glumsø Østerskov, Zealand (Holst & Kristensen 1981).*

Regional pedological investigations that report on the prevailing gley conditions can be useful in estimating the potential drainage requirements of the different mapping units. Three major pedological investigations are used in connection with the assessment of potential drainage needs: The DONG Study, The Himmerland Study and The Gadbjerg Study.

The DONG Study involved soil profile investigations along the DONG natural gas pipe-line trench. Soil profiles were classified at 25 metre intervals over long distances. One of the aims was to describe the existing groundwater gley or pseudogley in the uppermost 120 cm of the profile (Madsen 1983b). The discovery of pseudogleys, due to the slow percolation of rainwater through the horizons, proved the existence of temporary, shallow groundwater and hereby a potential drainage need. In 1981, about 3,000 soil profiles were examined and classified along the pipe-line stretch from the village of Frøslev on the German border to the village of Egtved in central Jutland. In 1982, 1,000 classifications were added from Egtved to the town of Nyborg (eastern Funen), and finally, in 1983, 5,000 classifications were made, partly from Egtved to the west coast of Jutland, and partly from the town of Korsør (western Zealand) to Copenhagen (eastern Zealand). Table 38 indicates the percentage of soils that have developed on clayey subsoils with pseudogley in the uppermost 120 cm of their profiles. Wetland soils were excluded.

Table 38. The Potential Drainage Requirements of Different Landscape Types related to Soil Type (MCC) and Subsoil Texture.
a) The DONG Soil Profile Investigation.
b) The Himmerland Study.
c) The Gadbjerg Study.

| Landscape Type | Soil Type (MCC) | Subsoil | Potential Drainage Requirement |
|---|---|---|---|
| a) Weichsel | 3 | clayey | 58% |
| a) Weichsel | 4,5,6 | clayey | 89% |
| b) Weichsel | 3 | sandy | 61% |
| b) Weichsel | 1,2,3 | sandy | 27% |
| b) Dune | 1,2 | sandy | 14% |
| b) Littorina | 1,2 | sandy/clayey | 100% |
| c) Weichsel | 1,2 | clayey | 28% |
| c) Weichsel | 3 | clayey | 12% |
| c) Weichsel | 4 | clayey | 70% |
| c) Weichsel | 1,2 | sandy | 12% |
| c) Weichsel | 3 | sandy | 10% |
| c) Dune | 1,2 | sandy | 27% |
| c) Dune | 3 | sandy | 6% |

The Himmerland Study was a comprehensive investigation of the soil conditions of the Himmerland region of Jutland (Madsen 1983a). A study of the gley characteristics was an integral part of the work, making it possible to estimate the potential drainage requirements of certain soil types and landscapes. In the young moraine landscape with clayey and sandy subsoils, 48 soil profiles were examined. Another 7 profiles were examined in areas with dune deposits, and 13 in areas with littorina deposits. The potential drainage requirements were calculated (Table 38). The results revealed a marked difference in the drainage requirements of the young moraine deposits, according to whether the subsoil was clayey or sandy. On the other hand, all the littorina deposits had gley characteristics and hence a potential drainage requirement.

The Gadbjerg Study was based on 2,100 hectares of land west of the town of Vejle in Jutland. It was carried out between 1976 and 1979. The study made it possible to determine the drainage requirements of certain types of soil and landscapes (Madsen 1979). The investigation was based on 40 profile studies and 1,000 borings. The result has been a soil map of the area which, apart from other characteristics of interest, shows the potential drainage requirements.

By matching different drainage classes, landscape types and the different MCC soil types, it is possible to estimate the potential drainage requirement for different areas.

Table 38 indicates that there is great variation in the potential drainage requirements within the total area of the young moraine landscape. Sandy soils have been found to have a much lower potential drainage requirement than clayey soils.

## *Fixing Values to Classify the Potential Drainage Requirement*

Based on the database information described above, it is possible to fix values in order to classify the potential drainage requirement. This can be made according to different combinations of factors available from the different databases such as; topsoil texture, subsoil texture, landscape type and wetland class.

For the classified area of the Danish Soil Classification, four potential drainage requirement classes have been established. A fifth class has also been established for the unclassified area. The definition of the first four classes is given in Table 39.

The division of the classified area into drainage classes may be simplified as certain landscape types or soil types, due to their particular location or waterlogging, can be automatically placed in Drainage Class 1. This is the case for the humus soil (MCC 7), wetland areas as delineated on the mapsheets, and the landscape types; saltmarsh, littorina and reclaimed land. Due to the their physical situation, their drainage conditions are typically recipient-dependent. Generally speaking, they are located in the wetlands area shown on Map 11.

For all other areas, the drainage requirement will normally be texturally-dependent. The drainage class for such areas is determined by combining the results of the drainage investigations with those of the pedological investigations, Tables 37 and 38. The combinations whose drainage classes are to be fixed are combinations of; clayey or sandy subsoils, MCC 1-6, MCC 8, and the landscape types of the Yoldia, dune, Saale, outwash plain and Weichsel.

Table 40 shows the drainage classes as fixed for areas with a texturally-dependent drainage requirement. Some of the allotted drainage classes are based on much data material, whereas other drainage classes are allotted on the basis of very few data. The latter cover only small areas and their class is shown in brackets in Table 40. Unrealistic combinations are indicated by a minus sign (-).

Table 39. A Definition of the 4 Drainage Classes on the basis of Potential Drainage Requirement.

| Drainage Class | Potential Drainage Requirement % |
|---|---|
| 1 | 75-100 |
| 2 | 50-75 |
| 3 | 25-50 |
| 4 | 0-25 |

Table 40. Drainage Class Allocation related to Topsoil (MCC), Subsoil, and Landscape Type.

Clayey Subsoil.

| Soil Type | Yoldia | Dune | Saale | Outwash Plain | Weichsel |
|---|---|---|---|---|---|
| MCC 1 | (2) | 3 | 2 | - | 3 |
| MCC 2 | (2) | (3) | (2) | - | (3) |
| MCC 3 | (2) | 3 | 2 | - | 2 |
| MCC 4 | (1) | - | (1) | - | 1 |
| MCC 5+6 | (1) | - | (1) | - | 1 |
| MCC 8 | - | - | - | - | 1 |

Sandy Subsoil.

| Soil Type | Yoldia | Dune | Saale | Outwash Plain | Weichsel |
|---|---|---|---|---|---|
| MCC 1 | (3) | 4 | 4 | 4 | 4 |
| MCC 2 | 3 | (4) | (3) | (3) | 3 , |
| MCC 3 | (3) | 4 | 3 | 3 | 3 |
| MCC 4 | - | - | - | - | 2 |
| MCC 5+6 | - | - | - | - | - |
| MCC 8 | - | - | - | - | 4 |

## *National Potential Drainage Requirements*

Map 20 shows the national distribution of drainage classes. The map is based on a simplified version of the national soil map, scale 1:500.000. The map indicates that the drainage requirement for eastern Denmark and the littorina landscape of Jutland is high, while it is low for most of Jutland.

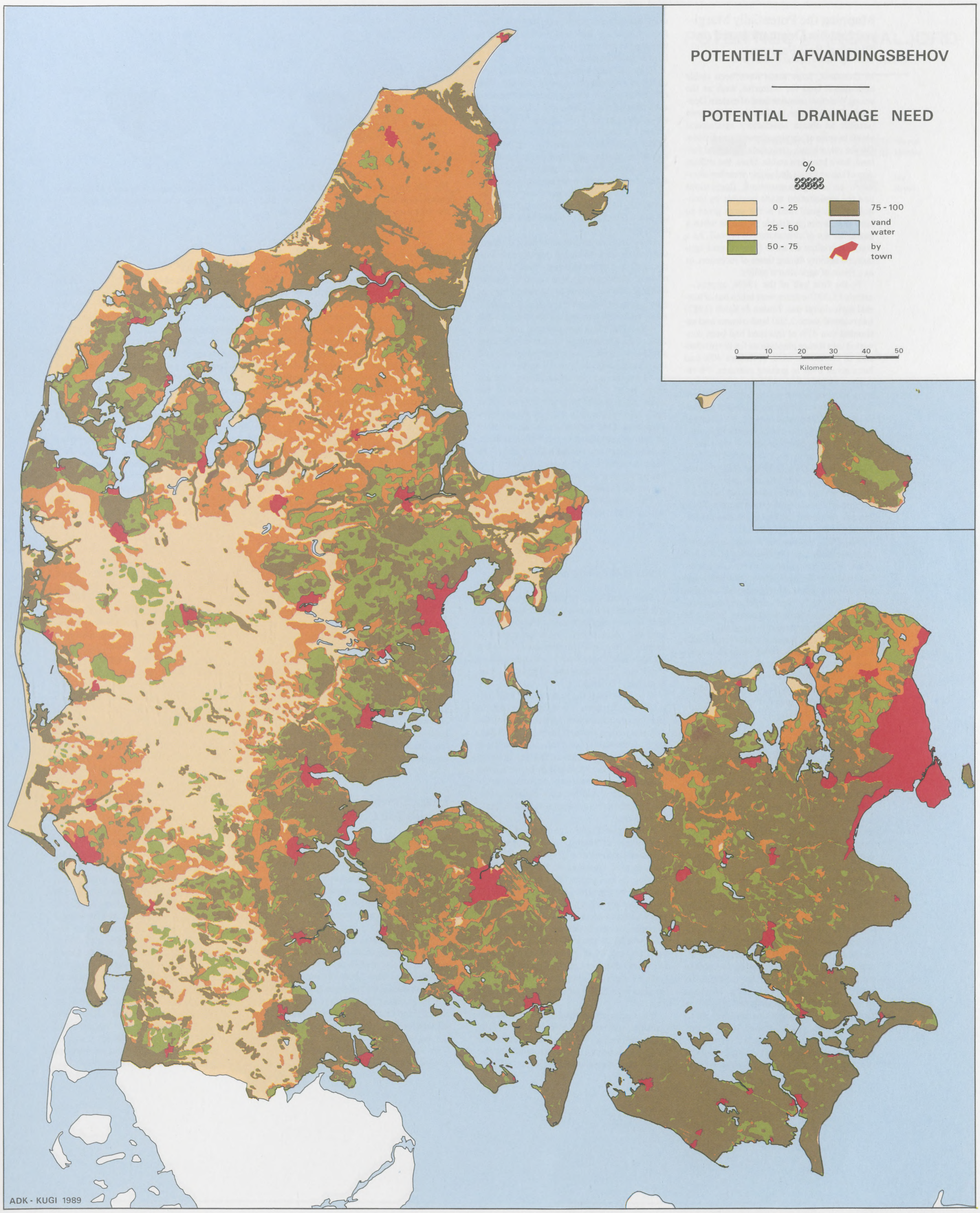
Table 41 gives the total area of each Danish county and the percentage area that is occupied by the classified area. Furthermore, the different drainage classes are also given as a percentage of the classified area.

The statistics show that all counties have areas requiring drainage, although this varies greatly from region to region. In the moraine areas, there is much land in Drainage Class 1, whilst the outwash plains tend to contain a mixture of Drainage Classes 1 and 4, the former being close to water courses and wetlands.

On the assumption that the potential drainage requirement is distributed as follows, being 87.5%, 62.5%, 37.5% and 12.5% for the four divisions 1, 2, 3, and 4, respectively, it will be possible, based on Table 41, to calculate the total potential drainage need for the different counties and on a national scale. The calculation is based on the classified area, but not on farmland alone. Using the statistics showing the area under agricultural land-use for each county, it is possible to estimate the potential drainage need in relation to farmland. Out of a total 2.9 million hectares of agricultural land in Denmark, 1.79 million hectares have a potential drainage requirement.

Table 41. The 4 Drainage Classes as % of the Classified Area by County.

| County | Total Area km² | Classified Area % of County Area | Drainage Classes 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Copenhagen & Frederiksberg | 110 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Greater Copenhagen | 538 | 26.6 | 79.5 | 12.4 | 8.0 | 0.0 |
| Frederiksborg | 1349 | 59.0 | 28.8 | 29.8 | 40.6 | 0.7 |
| Roskilde | 893 | 74.5 | 83.6 | 10.9 | 5.4 | 0.1 |
| West Zealand | 2975 | 80.8 | 71.9 | 17.4 | 10.4 | 0.3 |
| Storstrøm | 3400 | 82.3 | 85.0 | 11.5 | 3.4 | 0.1 |
| Bornholm | 588 | 72.0 | 80.3 | 13.7 | 3.7 | 2.4 |
| Funen | 3484 | 81.1 | 61.0 | 23.3 | 14.6 | 1.1 |
| South Jutland | 3856 | 87.2 | 46.6 | 14.8 | 7.3 | 30.7 |
| Ribe | 3123 | 84.0 | 23.9 | 10.5 | 22.6 | 43.0 |
| Vejle | 2997 | 79.8 | 47.5 | 16.8 | 16.4 | 19.3 |
| Ringkjøbing | 4861 | 82.2 | 28.1 | 10.2 | 15.3 | 46.5 |
| Århus | 4562 | 76.2 | 41.4 | 26.7 | 19.4 | 12.5 |
| Viborg | 4110 | 83.8 | 35.1 | 17.9 | 26.2 | 20.9 |
| North Jutland | 6160 | 83.8 | 40.1 | 2.6 | 47.4 | 9.9 |
| Whole Country | 43005 | 80.2 | 47.0 | 14.6 | 20.4 | 18.0 |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## Mapping the Potentially Marginal Land in Denmark based on Physical Soil Factors.

In Denmark, large areas have been stable agricultural land for centuries, such as the young Weichsel moraine land of eastern Denmark. This is due to the fact that it has been possible to obtain satisfactory agricultural yields in spite of varying climatic conditions. On the other hand, areas such as central Jutland, have been less stable. Here, the utilization of the wetlands and sandy areas has alternated according to economic fluctuations and the exploitation made possible by technology. Marginal land is the term given to land that is not profitable to utilize when a particular set of circumstances prevail. As a result, it is often set aside from current agricultural activity during times of recession, or as a result of agricultural policy.

In the first half of the 1980s, approximately 15,000 hectares were taken out of normal agricultural use. Jensen & Koch (1987) interviewed some 2,500 land-owners and estimated that 47% of this land had been converted into spruce plantations for the production of Christmas trees. A further 40% had been given over to grazing pastures, 7% remained as lay fallow, while another 6% had been assigned to alternative purposes (Figure 39). The reasons for the conversion of agricultural land to other land-uses varied. Of all the reasons, 55 % pointed to physical soil factors; the soil having been too dry or too wet, or slopes having been too steep, while 15% of the reasons focused on field size and distance from the farmstead. The remaining 30% of the reasons signalled economic, social, or environmental and conservation factors. These reasons remained unchanged during the latter half of the 1980s (Figure 39).

As 55% of the reasons focused on natural or physical causes, the Department of Land Data (ADK) cooperated with the Geographical Institute of Copenhagen University and carried out a national mapping of all soils that were ”very dry”, ”wet”, or located on undulating terrain. Such land areas might be termed as being potentially marginal.

The wetlands, areas of well-drained soils and areas of sloping terrain were all investigated to see how much of their respective territories might be classified as potentially marginal land. In this connection, these three areas will now be treated in turn.

### *The Wetlands*

The wetlands are those areas that lie relativity low in relation to a nearby recipient, such as a water course, lake or hollow. They are subject to permanently high groundwater. They will often have a top soil layer that is rich in humus or peat, or else a layer that is poor in oxygen lying near the surface. In areas away from a recipient, the same conditions may prevail in low areas and hollows that do not possess a natural outlet. Water takes a long time to seep down through the subsoil and conditions of almost permanent waterlogging may occur. This is, for example, typical of dead-ice landscapes in Denmark.

Within the wetland regions, environmental and conservation issues will probably determine whether an agricultural area shall remain as before or be converted to another purpose. The land might, for example, be used more extensively for grazing. The soils of the wetlands are usually peaty or rich in pyrites. It has been suggested that the former should be kept from being used for any intensive agricultural activity due to their value as areas of natural interest. Since the early 19th century, the total area of peaty soils in Denmark has fallen drastically (Figure 13). Consequently, a law has now been passed preventing the drainage of moorland or heathland areas that exceed a certain size.

Potentially acid sulfate soils have a tendency to produce ochre when drained. The ochre will pollute water courses and bodies, such as streams, ditches, and lakes. Map 14 shows these areas. They belong to Drainage classes 1, 2 and 3 and contain potentially acid sulfate soils. They are being protected from any form of drainage by strict regulations. When applying for the right to drain these areas, a preliminary investigation is required to estimate whether ochre pollution may occur or not. Where this will happen, a drainage permit will be necessary. These days, it is very rarely given.

In wetland areas that have been drained, the surface tends to shrink due to consolidation and peat decomposition. This may lead to more waterlogging and the need for further drainage. However, due to the recent, tighter restrictions, this might be refused. Therefore, many areas revert to a status of marginal land.

The ADK database indicates that about 20% of the Danish land surface may be classified as wetland. The greatest extent is found in Jutland, particularly in the north.

As mentioned previously, those wetland areas likely to become marginal land are those characterized by peaty soils or potentially acid sulfate soils. The potentially marginal land of the wetland areas can therefore be defined, according to the ADK database, as land where soils contain more than 10% organic matter or where soils require a preliminary ochre investigation before a drainage permit is issued.

The potentially marginal wetland area represents a little less than 50% of the total wetland area.

### *Areas of Well-drained Soils*

In these areas, the potentially marginal land will be land which is not particularly profitable to work agriculturally. Normally, this land will contain soils that require a lot of irrigation, or else lie on steep slopes. The latter have often long since been converted to woodland, plantations and alternative forms of marginal land-use.

When mapping the areas with a high irrigation requirement, it was first necessary to map the available water content of the soil for different crops, defined as the RZC. Then, the country was divided into climatic zones based on precipitation during the growing season. Next, the relationship between crop irrigation requirements and root zone capacities was calculated for each climatic zone. The irrigation requirement was then mapped for each crop.

Map 18 reveals the large irrigation require ment in central Jutland, based on the average irrigation requirement for spring barley. Map 5 shows that woodland and plantations are common in this region. This is an area characterized by marginal land-use. It should be noted, that the larger part of these plantations and woodland areas is found in the regions with the highest irrigation requirement. In other words, they are unsuitable for agricul tural land-use. Of all the well-drained areas in Denmark, those in central Jutland have the highest irrigation requirement and represent the area with the most potentially marginal land.

Once agricultural land has been retracted from the normal crop rotation system, it is usually afforested. The shape and form of the forest plantations often indicate where the former field system once lay (Jensen 1976).

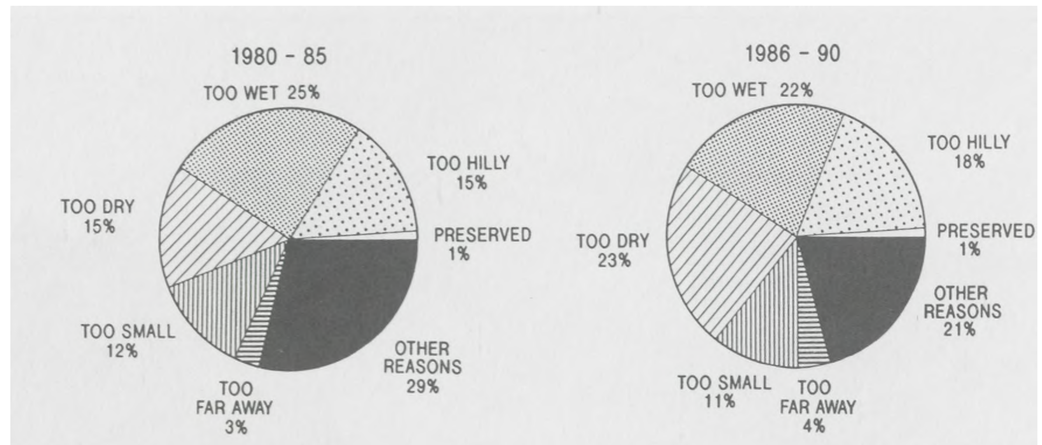



*Fig. 39: Reasons for the marginalization of agricultural land in Denmark 1980-85, and the expected trends for the years 1986-90, based on a questionnaire survey of approximately 2,500 farmers by Jensen & Koch (1987).*

### *Sloping Terrain*

The slope characteristics of a given area will determine its agricultural suitability and its potential as a stable area for agriculture. Farm machinery often has difficulty in negotiating steep terrain, and irrigation methods are often confronted with problems. Soil erosion can occur, although in Denmark this seldom leads to problems for agriculture. However, the soil erosion of slopes can possibly lead to environmental problems due to the downward movement of phosphorous in soil particles to water courses and drainage channels (Hasholt et al. 1990).

Map 12 shows Denmark divided into three slope classes based on gradient:

Class 1 = 0-6°,
Class 2 = 6-12°,
Class 3 = > 12°.

These three slope classes can be summarized as follows. Class 1 includes land where the slope gradient does not restrict cultivation. In Class 2, slope conditions will normally make the cultivation of root-crops problematic, while in Class 3 slope conditions will normally preclude any form of cultivation.

Texture can also play a role in determining the degree to which slope factors are decisive. Slopes with clayey soils are easier to operate on than those with sandy soils.

On the basis of these characteristics, it can be assumed that cultivated areas on slopes with a gradient > 12° constitute potentially marginal land. These tend to occur patchily across the total Danish landscape, normally present as thin strips of land rather than as large surface features. However, they occupy less than 1% of the total Danish agricultural land area.

## Latest Developments within the Danish Soil Classification.

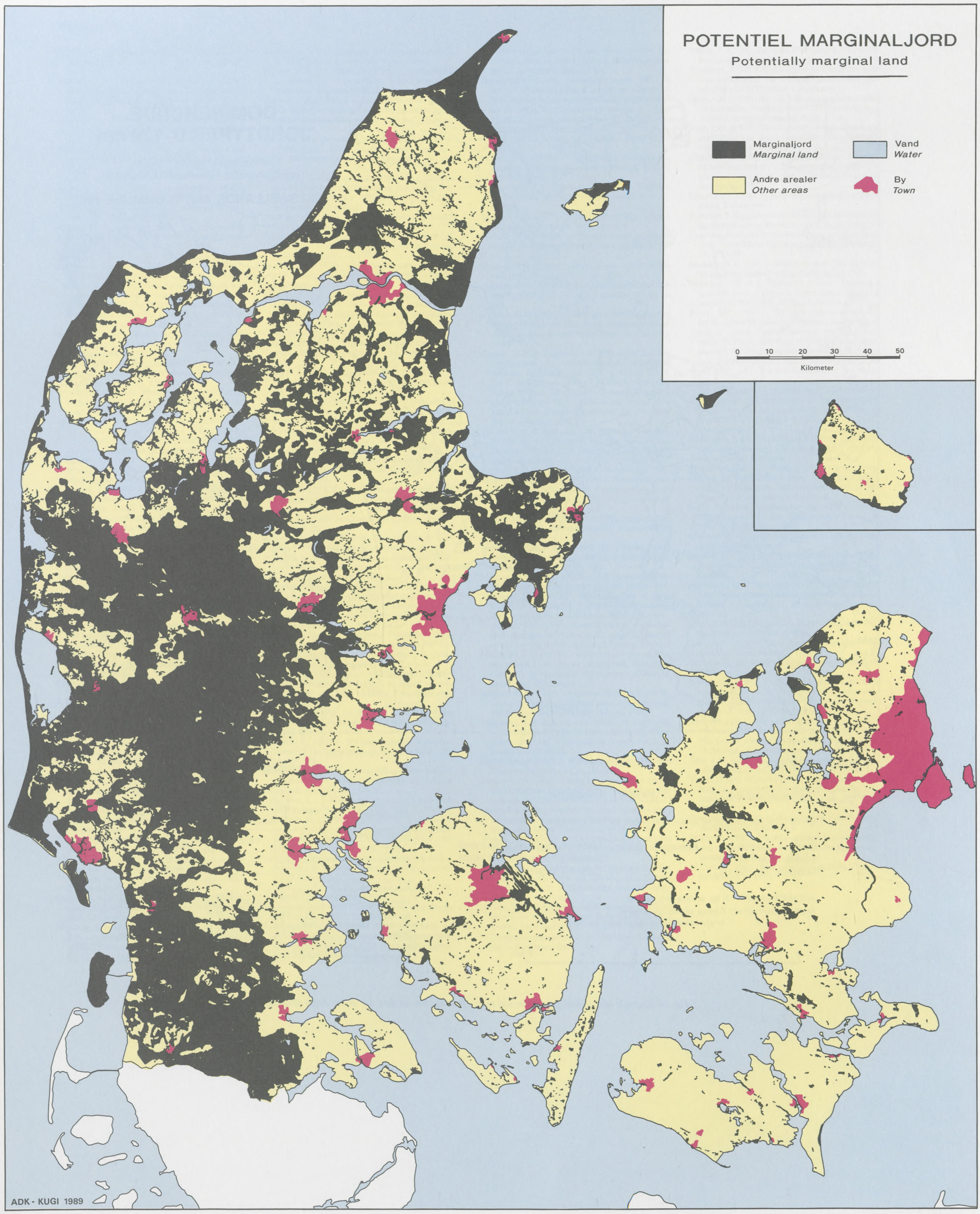
During the 1980’s, the role of the Danish Soil Classification was extended to produce computer maps used for solving regional and national problems. Simulation models were involved in this process. Some of these models and the resulting maps are presented in this atlas. In the years to come, such work will continue.

At present, during the early 1990’s, calculations are being made for each point of the national nitrate grid in order to predict the leaching of nitrates. These amounts are calculated in relation to; soil type, land-use, cultivation practices, fertilization methods and the climatic conditions. Nitrate leaching can be estimated at regional and national level. To make these calculations, the Nitrogen Turnover Model ”DAISY” has been employed (Hansen et al. 1990).

A knowledge of regional land-use, and its practice, is also important for e.g. calculating the degree of erosion and the leaching of plant nutrients on a regional scale. At present, site observations of the land-use and the results of point calculations of plant nutrient leaching must be accepted as being representative of the conditions prevailing over a greater surface area at regional level. Therefore, land-use databases are now being developed as part of the development of the Danish Soil Classification. The land-use information is partly derived from satellite images (SPOT), in which the land-use pattern is interpreted by means of multitemporal analysis. Constant updating is necessary as land-use patterns change from year to year.

The Danish Soil Classification was started in 1975. The basic data maps for most of the country were completed by 1980. Since then, there has been a pressing need to classify the woodland areas. Work has now started and is expected to be completed by the end of the 1990’s. However, the density of observation sites used for classifying woodland soils will be far lower than that used for classifying farmland soils.

To improve the basis for regional policy-making and other forms of physical planning, it has been decided to obtain soil texture information from soil layers lying deeper than the plough layer. In previous projects, such as the calculation and mapping of root zone capacity, it was necesssary to construct soil texture for the depths of 30-60 cm and 60-120 cm based on the plough layer and information on clayey and sandy subsoil. Based on the new soil profile data available, it is now possible to construct new soil maps that show the texture at three depths. These maps, known as second generation soil maps, are based on the existing basic data maps, landscape map, DGU surface geology map, connected to texture analysis information from the soil profile investigations and the Danish Soil Clasification registration. This has already been carried out in a pilot project in West Zealand County (Vestsjællands Amt). The county made the new classification at a scale of 1:50,000 during a revision of its land-use planning policy (Frandsen 1991). The project, which was supported by ADK and The Institute of Geography at Copenhagen University, consisted of classifying the texture of farmland soil at three depths; 0-30 cm, 30-60 cm, and 60-120 cm (Figure 40). The JB Classification System, defined in Table 6, was used. During the preparation, existing pedological data was taken from; the Danish Soil Classification, the national nitrate grid, the pipe-line investigations, and DGU’s soil maps. New texture data was not collected during the pilot project. ADK plans on constructing similar second generation soil maps for the whole country during the 1990’s.


POTENTIEL MARGINALJORD
Potentially marginal land
Marginaljord
Marginal land
Vand
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Other areas
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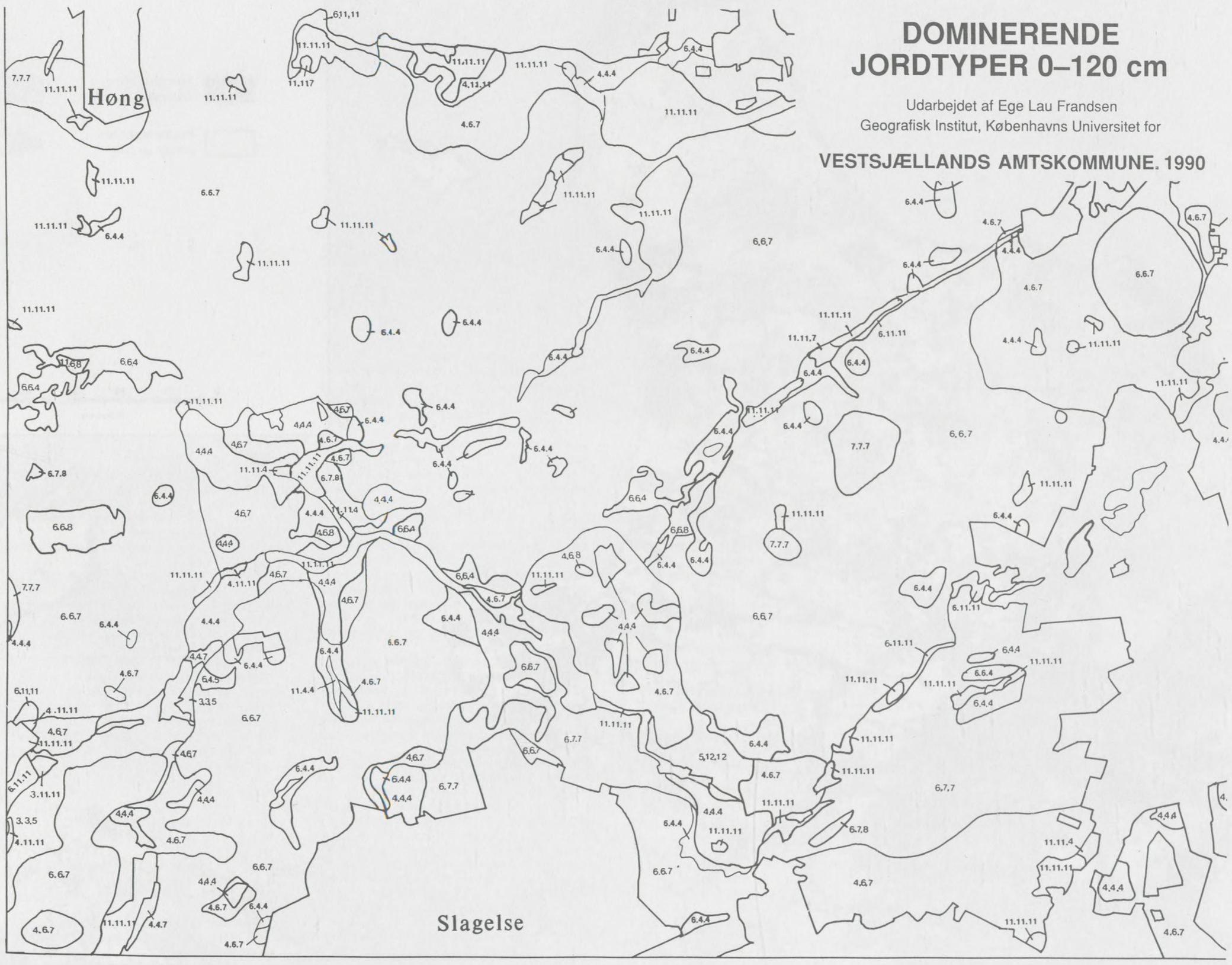
ADK - KUGI 1989




**Signaturforklaring:**

6.6.7 Grænse for jordtype

●●●●● Amtsgrænse

De tre JBnr. kombinationer refererer til dybderne i henholdsvis

Sektion 1. 0 – 30 cm
Sektion 2. 30 – 60 cm
Sektion 3. 60 –120 cm

**Eksempel: 6.6.7**

Sektion 1. Fin sandblandet lerjord
Sektion 2. Fin sandblandet lerjord
Sektion 3. Lerjord

**AREALER UNDER 1.6 ha er ikke medregnet**
**Arealer uden JB nr.: Større skove, plantager, byzone/sommerhusområder og søer.**

0 1 2 3 4 5 km

**Teksturdefinition for jordtype**

| TEKSTURDEFINITION FOR JORDTYPE | Symbol | JB-nr. | Vægtprocent | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ler under 2 µm | Silt 2-20 µm | Finsand 20-200 µm | Sand, ialt 20-2000 µm | Humus 58,7 % C |
| Grovsandet jord | GR.S. | 1 | 0-5 | 0-20 | 0-50 | 75-100 | Under 10 |
| Finsandet jord | F.S. | 2 | | | 50-100 | | |
| Grov lerblandet sandjord | GR.L.S. | 3 | 5-10 | 0-25 | 0-40 | 65-95 | |
| Fin lerblandet sandjord | F.L.S. | 4 | | | 40-95 | | |
| Grov sandblandet lerjord | GR.S.L. | 5 | 10-15 | 0-30 | 0-40 | 55-90 | |
| Fin sandblandet lerjord | F.S.L. | 6 | | | 40-90 | | |
| Lerjord | L. | 7 | 15-25 | 0-35 | | 40-85 | |
| Svær lerjord | SV.L. | 8 | 25-45 | 0-45 | | 10-75 | |
| Meget svær lerjord | M.SV.L. | 9 | 45-100 | 0-50 | | 0-55 | |
| Siltjord | SI. | 10 | 0-50 | 20-100 | | 0-80 | |
| Humus | HU. | 11 | | | | | Over 10 |
| Speciel jordtype | SPEC. | 12 | | | | | |

*Fig. 40: Example of a second generation soil map showing the texture in three depth (Frandsen 1991).*

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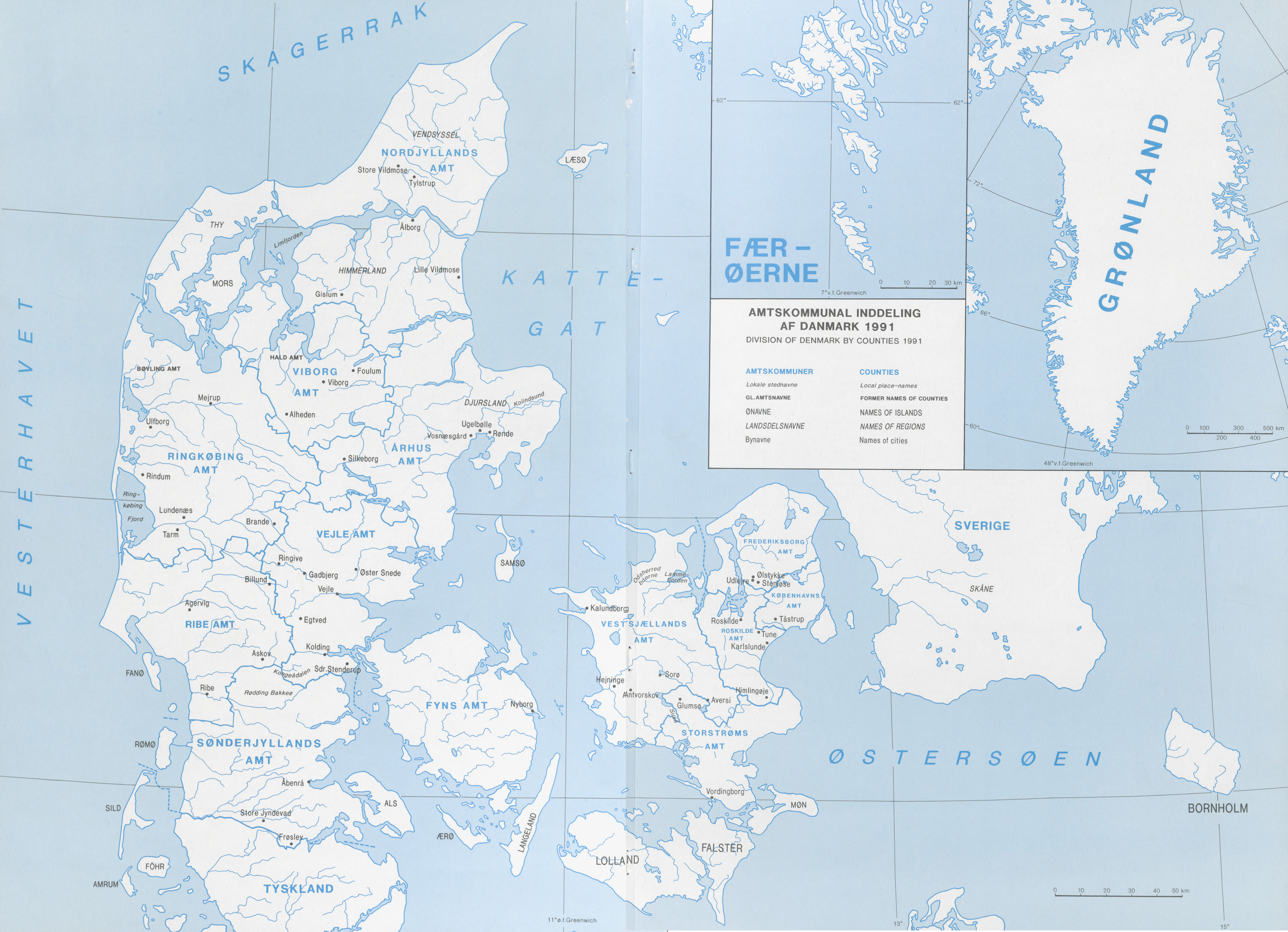
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