INSTITUTE
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FIELD DRAINAGE IN EUROPE: A QUANTITATIVE SURVEY

by

F H W GREEN*

*Dept. of Agricultural Science, University of Oxford

ABSTRACT

This report is in three sections: the first two are factual accounts of under-drainage in firstly the British Isles and then in other parts of Europe while the third extrapolates from existing data to present more detail on the pattern of under-drainage. The drainage information is given in both cartographical and tabular form.

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CONTENTS

FIGURES

SECTION I

THE DISTRIBUTION OF FIELD UNDER-DRAINAGE IN THE BRITISH ISLES SINCE 1949

The rate at which water flows through the soil is of basic importance to agriculture and ecology, as well as to hydrology. This is not only because of the direct importance of water levels but also because of its influence on the passage through the soil - and into watercourses - of material both in suspension and in solution. This is recognised in the condiserable literature on the subject, some of the most relevant of which has been conveniently listed and discussed by A R Hill (1976).

Land drainage is carried out in various ways, which differ both in kind and in scale. Arterial drainage is concerned with the regulation of rivers, and may be carried out for navigational or other purposes as well as for drainage of potentially cultivable alluvial land. In engineering terms, it comprises major works and minor works. Major works, on rivers, are usually carried out by public authorities while minor works are generally the responsibility of landowners or tenants, for whom government grants are available. Typically, the minor works comprise clearing and otherwise improving ditches and streams into which water flows from the land. An intermediate category is dealt with by Internal Drainage Boards, which were set up in many areas in England under the Land Drainage Act of 1918. These Drainage Boards are in effect co-operative contractors and managers for minor works. Field drainage is, in all parts of the British Isles, the responsibility of farmers, who can obtain substantial grants for field under-drainage as well as for farm ditches.

By way of introduction to sub-surface field drainage, the subject of this report, it is useful to consider the recently published paper by Marshall, Wade and Clare (1978), who were concerned with surface drainage on level - essentially deltaic - areas in England and Wales, approximately at sea level. Surface land drainage channels are however not confined to these areas but are found in two other types of terrain. The first of these consists of inland level areas of alluvial deposition which are well above sea-level; examples are the Upper Thames valley near Oxford and in the Vale of York. These areas have not been quantified but are undoubtedly small in comparison with the sea-level tracts. Both are 'lowland' in the sense in which this term is used by field drainage engineers. The second type, not considered by Marshall, Wade and Clare, is what is described by the field drainage engineers as 'upland'. This is land which needs drainage primarily because of soil characteristics, typically clayland, with varying degrees of slope. It is drained partly by natural streams but over the centuries these have been supplemented by many artificial ditches. These have in turn been more and more supplemented, or even replaced, by various types of sub-surface drainage.

In some countries, notably in the Netherlands and Belgium, most sub-surface drainage has taken place in the 'deltaic' areas. In Britain, however, although some of the sub-surface drainage is found in these areas, for example in the Fen District, the greater part of it has been installed in the 'upland' areas of impeded drainage. This of course has led to changes in the streams and ditches into which the sub-surface drainage is led; some have been deepened to accord with the level of outflow from the tile drains, while others have become redundant. The tendency in those which are still in use is for more rapid response of the flow in them to heavy rain; they rise more quickly, but flooding is less, because the flow is not maintained for so long.

Marshall, Wade and Clare calculated the sea-level area drained by surface channels as 800,000 hectares, although they note other estimates as being slightly greater. This of course remains a relatively static amount, subject only to gradual reduction through being built over. It is not possible to estimate the total area under-drained with anything like the same accuracy, and it is continually increasing. But, as an indication of the area involved, 2,216,000 ha were under-drained between 1951 to 1972 in England and 97,000 ha in Wales for the same period.

It is important to note that much under-drainage was carried out in the British Isles from the end of the eighteenth century until the 1880s and that some of this is still effective without having been renewed. It was by no means all tile drainage, for stone slabs and other methods were used extensively. In England and Wales it has been estimated that more than 5 million hectares were under-drained during the nineteenth century (cf. Trafford, 1970), so that the total area under-drained in England and Wales is almost certainly not less than 7,500,000 ha, i.e. about ten times the area considered by Marshall, Wade and Clare for surface drainage. It was carried out when most land, now in agricultural use, was already in such use. In this the British Isles differ from, for example, Norway and Sweden where something approaching the present extent of the area in agricultural use was not achieved until about the time when the nineteenth century drainage effort in Britain and Ireland was slowing down. Under-drainage in Norway and Sweden, by contrast, often went hand in hand with the reclamation of new land for agricultural purposes.

Construction of the maps

Statistical data relating to drainage exist in each of the various national divisions of the British Isles only because of the substantial government grants now obtainable by farmers and landowners. Records have been kept by the Ministries of grants paid and the areas drained with their aid.

The unit areas are not the same for the whole of the British Isles. The simplest case is the Republic of Ireland, where the total figures for the period are available by counties, although for the Republic they are available for individual years only from 1963 onwards. Very

full data, year by year, are available for Northern Ireland. Figures for Scotland are available for counties, except for the period 1967 to 1970, for which there are only figures for the country as a whole: the county figures for these years were therefore estimated by allotting the national figures to the counties in proportion to the average distribution at the beginning and end of this four year period.

For England and Wales the position is rather more complicated. Figures are available by counties from 1963: for 1949 to 1962 they are available only by M.A.F.F. Divisional areas and therefore the map for the whole period had to be drawn on the basis of Divisional areas. Until 1973 the Divisional boundaries remained constant except in part of the East Midlands and adjoining East Anglia. After 1963 the Soke of Peterborough was transferred from the Northampton to the Huntingdon Division. At the same time, Holland County was removed from the Lincoln Division and transferred to Huntingdon. Finally, as a result of the Local Government reorganisation of 1973, several Division boundaries were again changed in 1974 but this area was not affected until 1976, when the Huntingdon Division was merged with Cambridge, except for Holland, which returned to the Lincoln Division.

These boundary changes in England and Wales have not seriously affected the picture as given by the map, Figure I.1, the boundaries on which are shown as they were between 1964 and 1973. For recent years more refined distribution maps can be drawn for England and Wales (cf. Green, 1976) and these will be referred to later.

Figures are available for the Isle of Man only from 1967 onwards, but it is clear that the Isle of Man is in the same drainage category as North Wales, and is so shown on the map.

In the Channel Islands, grants have not been given for field drainage, and no statistics are available. A few low-lying areas have been tile-drained and a few more are recognised as needing under-drainage. Fragmentation of farms and of land ownership has inhibited drainage work, but there were some nineteenth century schemes which come to light from time to time in digging for building foundations.

Because of differences in the available statistical data between the different countries in the British Isles, there is no exact comparability on the maps. The chief problem is to what extent open drainage is included, as distinct from under-drainage. In England and Wales the maps can safely be said to show under-drainage alone. Statistics exist for ditching but are not included here; furthermore, no attempt is made in England and Wales to estimate the areas-to-benefit from ditching work.

In Northern Ireland, separate figures are available for ditching, including estimated areas-to-benefit. Such areas are excluded except that, up to 1961/62, lengths of 'sheughs' (farm ditches of less than 3 feet width) which had been constructed or improved, were given, and the areas-to-benefit included areas attributable to this work. Up to the mid-fifties this was a significant proportion of the total, and,

on the basis of lengths installed, may be estimated as about 10 per cent over the period 1946/47 to 1961/62. After that time, open drainage has been excluded from the data used although separate figures are available for estimated areas-to-benefit from open drains.

No details were available for the Republic, but it is to be expected that the areas-to-benefit include roughly the same proportion attributable to open drainage as in Northern Ireland, and that open drainage has been included throughout the period. Moreover, since the early fifties, records of grants for land reclamation (removal of boulders and scrub) have not been separated from those for land drainage; this is believed to be a significant proportion only in counties Clare, Galway and Wexford where it may reach 15 per cent. There is, in sum, little doubt that the maps exaggerate the amount of under-drainage carried out in the Republic since 1949.

In Scotland, during most of the period, the areas-to-benefit include a proportion attributable to ditching, estimated as about 10 per cent. There is evidence that this 10 per cent was unequally distributed through the country, the proportion being greatest in the west and north and in parts of the Southern Uplands; note the difference, in these areas, between maps I.1 and I.2.

Only for Northern Ireland was the amount of stone and 'other' under-drainage available. The figures from 1946/47 to 1970/71 show that the lengths of stone drains installed annually were greater than for tile-drainage up to 1953/54, but by 1970/71 they had fallen to insignificant amounts. It is believed that areas-to-benefit by stone drains were included in the totals for the Republic and for Scotland. It is legitimate to include stone, and 'other' drainage, since it is comparable to tile-drainage - i.e. they are all under-drainage. Stone drainage is not included in the England and Wales statistics used for the maps, however, and although it is not now of any importance, it is probable that some was carried out in the earlier part of the period; thus to some extent the maps understate the amount of under-drainage in England and Wales.

Maps I.1 and I.2 indicate the total areas under-drained over the 28 year period, in relation firstly to the area under crops and grass in each County or Division and secondly to the total land area of each County or Division.

It should be noted that the total land area drained is not precisely the accumulation of the totals for each year, since some land may have been drained more than once during the period. For instance, an area which was tile-drained in one year may have been sub-soiled or moled in a later year and, in any case, such secondary treatment needs periodical renewal. An attempt to portray an actual case of this kind is made in Figure I.3. This happens to be an extremely thoroughly drained area but in general the main maps refer to pipe drainage which will in almost all cases have been carried out only once during the period, no distinction being drawn between areas which had secondary treatment (moling and sub-soiling) and those which had not.

The spatial pattern

The regional differentiation in England and Wales has been discussed in some detail elsewhere (cf. Green, 1973, 1976) and need only be summarised here. The outstanding feature is the concentration of under-drainage in the East Anglian and Lincolnshire areas of low rainfall. This is accounted for by the high agricultural potential, coupled with the extensive occurrence of clay soils; these, while often short of water in the summer, tend to be too wet in the winter for the operation of farm machinery. More detailed maps which can be drawn for recent years (cf. Green, 1975, 1976) show the more intimate correlation with geology and soil types.

In the second half of the period covered by the map in Figure I.3 the eastern activity has extended north of the Humber and south-westwards across the clay lands of the South Midlands. In the west of England the greatest activity has been in the relatively drier areas of the Welsh Borderland and parts of Lancashire. Activity in the west and north of England and in Wales has accelerated recently as the benefits of under-drainage of pasture land have become apparent.

The regional distribution in Scotland as shown on map I.1 is markedly different from England and Wales. Bearing in mind that the necessity of portraying the distribution by counties distorts the picture in the case of the large western counties, it can nevertheless be seen that the greatest proportion of crop and grassland drained has been in the north-west - roughly, the Highlands, but also in the drier lowlands around the Moray Firth. Here a striking contrast is apparent with the counties around the Firths of Forth and Tay. The difference between these latter counties and the eastern counties of England, as well as the Moray Firth, is somewhat puzzling and may be because of the continued effectiveness in these well-farmed areas - especially during an exceptionally dry decade - of much early under-drainage, which in Scotland was generally closer spaced than in England and Wales. The distribution in the rest of the south of Scotland resembles that of neighbouring parts of England.

In a very general way the distribution in Ireland resembles that in England, i.e. the greatest concentration in the relatively dry south-east, but with parts of the west reminiscent of the west Highlands of Scotland. There is also a resemblance to Scotland in respect of the low amount of under-drainage in County Down. This may perhaps be accounted for in the same way as for Fife in Scotland, although there are two other factors operating there, viz. relatively light soils and delayed improvements in arterial drainage. The probable over-estimate in Ireland has been mentioned above.

It is very important to refer again to the great amount of under-drainage undertaken in the nineteenth century. This partly explains the relatively small amount carried out in some areas in the period covered in this report. It is known that some nineteenth century under-drainage is still effective in all parts of the British Isles but the amount installed at that period can be assessed with accuracy

only in respect of those areas where estates maintained records which are still extant; an investigation has now been started to see what extra information can be gleaned from the forms now filled in by inspectors approving grant applications in Great Britain.

Some idea of what can be learned from analysis of these forms is given in Figure I.4 which refers to the percentage of land area approved for grants in the year 1976/77, in which 'failure of old drains' was given as the reason for grant application. The chief source of inaccuracy in the regional distribution shown on this map is the degree to which, in this context, the areas approved in 1976/77 can be regarded as random samples. Bearing in mind that very little under-drainage was done in England and Wales between the late nineteenth century and 1939, it is at least clear that a great deal of drainage work had been done in the nineteenth century, and that much of it was done in areas where relatively little has been done since 1949 (as shown in Figures I.1 and I.2).

An analogous map of England and Wales was prepared from the approval forms of the year 1972/73 of the percentage of the area submitted for grants where pre-1939 drains were reported as 'partly functioning'; it shows a remarkably similar pattern to the map in Figure I.9. In more detail, a parish-by-parish map was made from the 1972/73 data for one county, Montgomeryshire (now part of Powys), and this reveals 'partly functioning' drains in most of the hill land classified as rough pasture for which grants were sought in that year; here we have an indication that much of the nineteenth century drainage was on hill land, in contrast to the distribution of effort shown on the map Figure I.2.

Ditching

Ditching has been mentioned above. In all parts of the British Isles farm ditching, which can be regarded as a concomitant of field under-drainage, is grant-aided to farmers in the same way as the under-drainage itself. As explained, the maps in this Section, so far as possible, do not include areas-to-benefit by ditching alone. Indeed, only in Scotland has the attempt been made to estimate such areas; Figures I.5 and I.6 show the estimated areas-to-benefit there by ditching from 1958 to 1966, and by comparing them with Figures I.1 and I.2 respectively, it can be seen that in some counties ditching appeared in that period to be more important than under-draining.

The same was undoubtedly true also in England and Wales for some areas and during part of that period, but this can be shown only by indirect methods, as illustrated in Figures I.7 and I.8. It should be seen that areas where relatively substantial grants were paid for ditching fall broadly speaking into two categories: (i) in East Anglia, as a concomitant to extensive under-drainage, and (ii) in areas where ditching was more urgent or necessary than under-drainage, e.g. the Wessex Chalk country, and the wetter west generally; much of this was cleaning out of existing ditches to preserve the status quo. Figure I.9, for the same catchment area as Figure I.3, shows in detail

the ditching work which was undertaken in conjunction with under-drainage of adjoining fields.

Separate information for ditching is not available in the Republic of Ireland, while lengths of ditching undertaken in each year are all that was recorded in Northern Ireland.

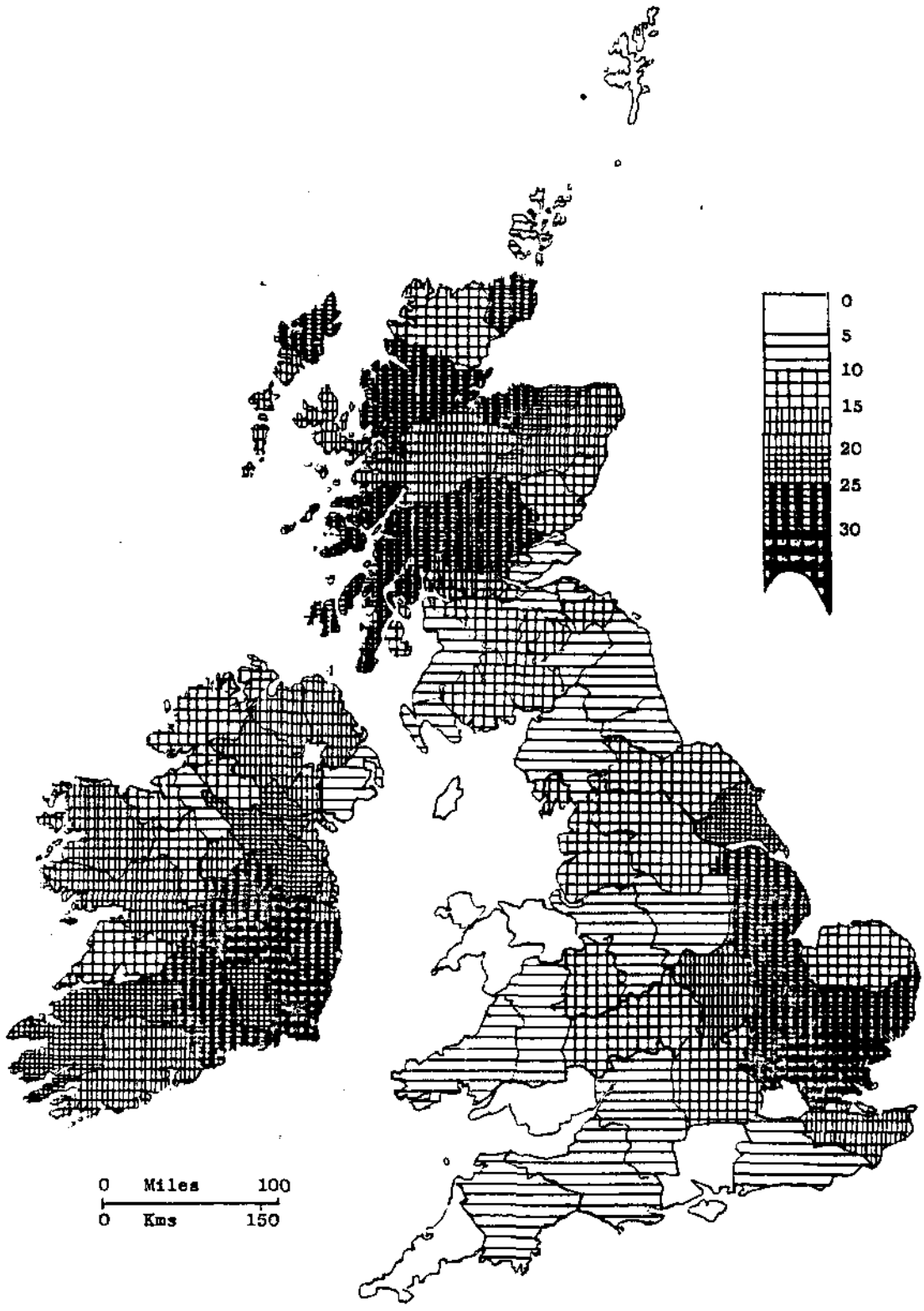

FIGURE I.1 Extent of field under-drainage in the British Isles, 1949 to 1976, expressed as percentage of area under crops and grass

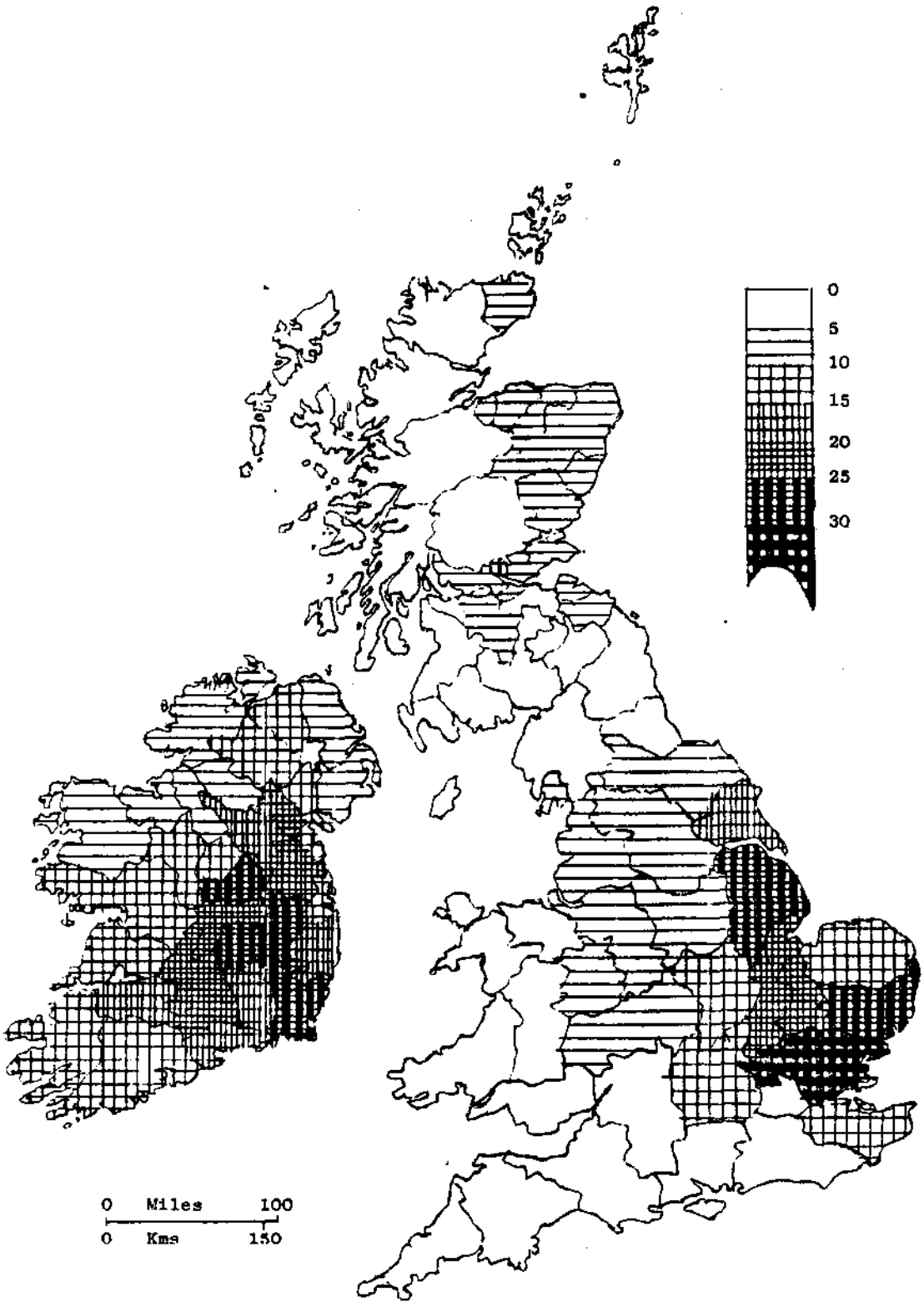

FIGURE I.2 Extent of field under-drainage in the British Isles, 1949 to 1976, expressed as percentage of total land area

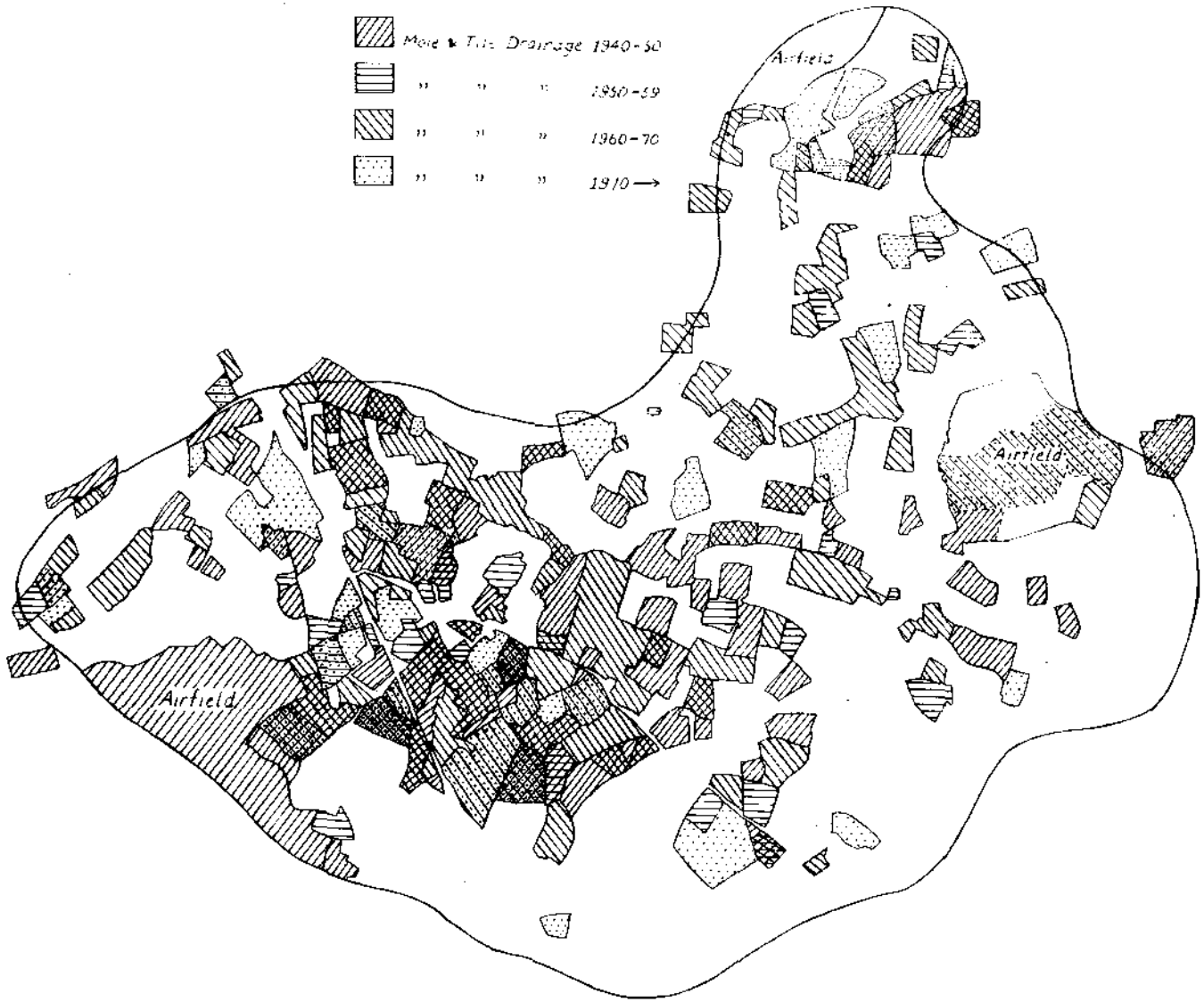

FIGURE I.3 Under-drainage, 1940 to 1974, in a small catchment area in Cambridgeshire, Huntingdon District

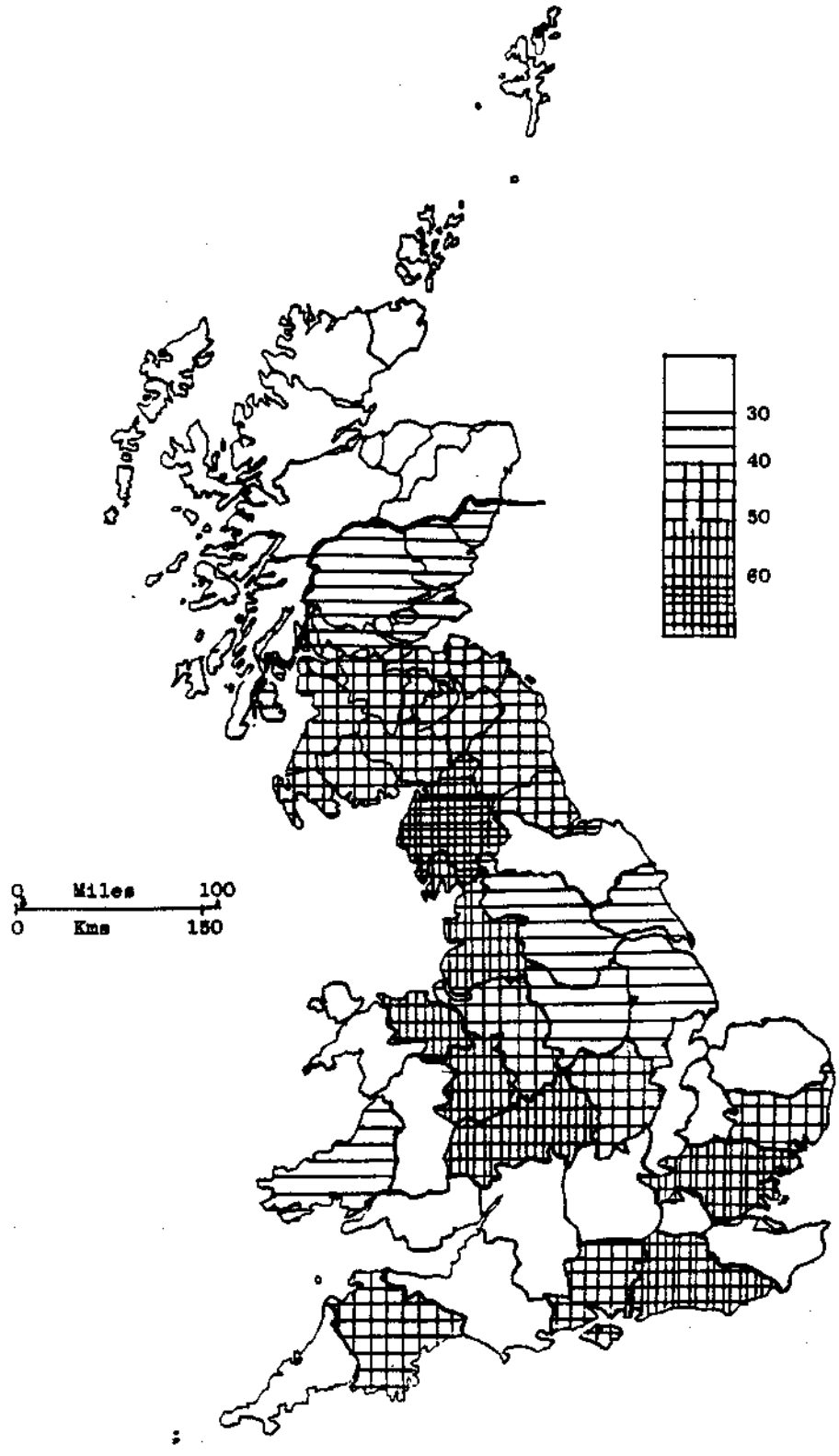

FIGURE I.4 Percentage of land area under-drained in the year 1976/77 for which 'failure of old drains' was given as the reason for grant application. NB Data inadequate north of heavy line

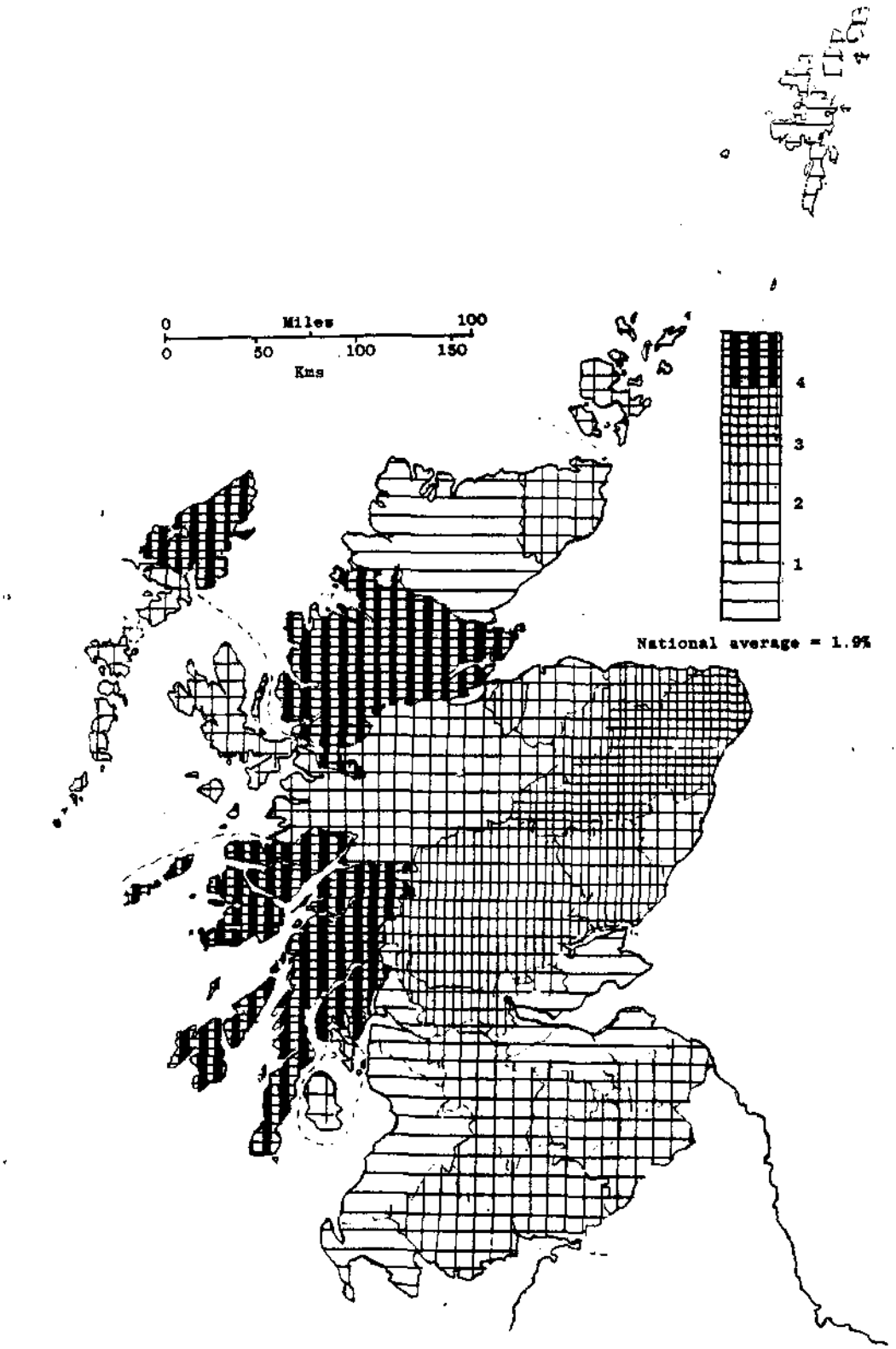

FIGURE I.5 Field under-drainage in Scotland, 1958-66, as percentage of area under crops and grass

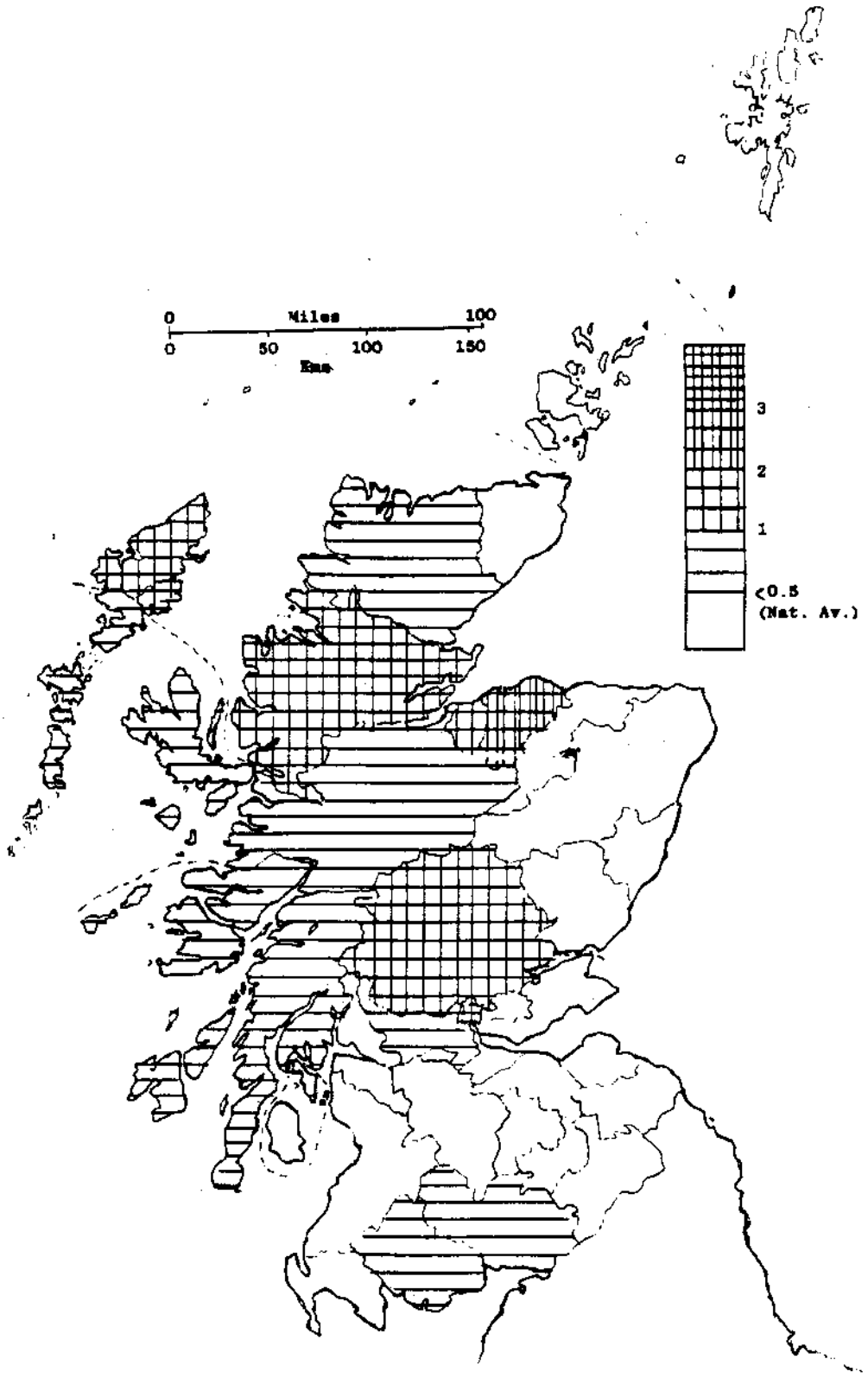

FIGURE I.6 Scotland, 1958-66: Estimated area benefiting by improvement to watercourses, as percentage of area under crops and grass

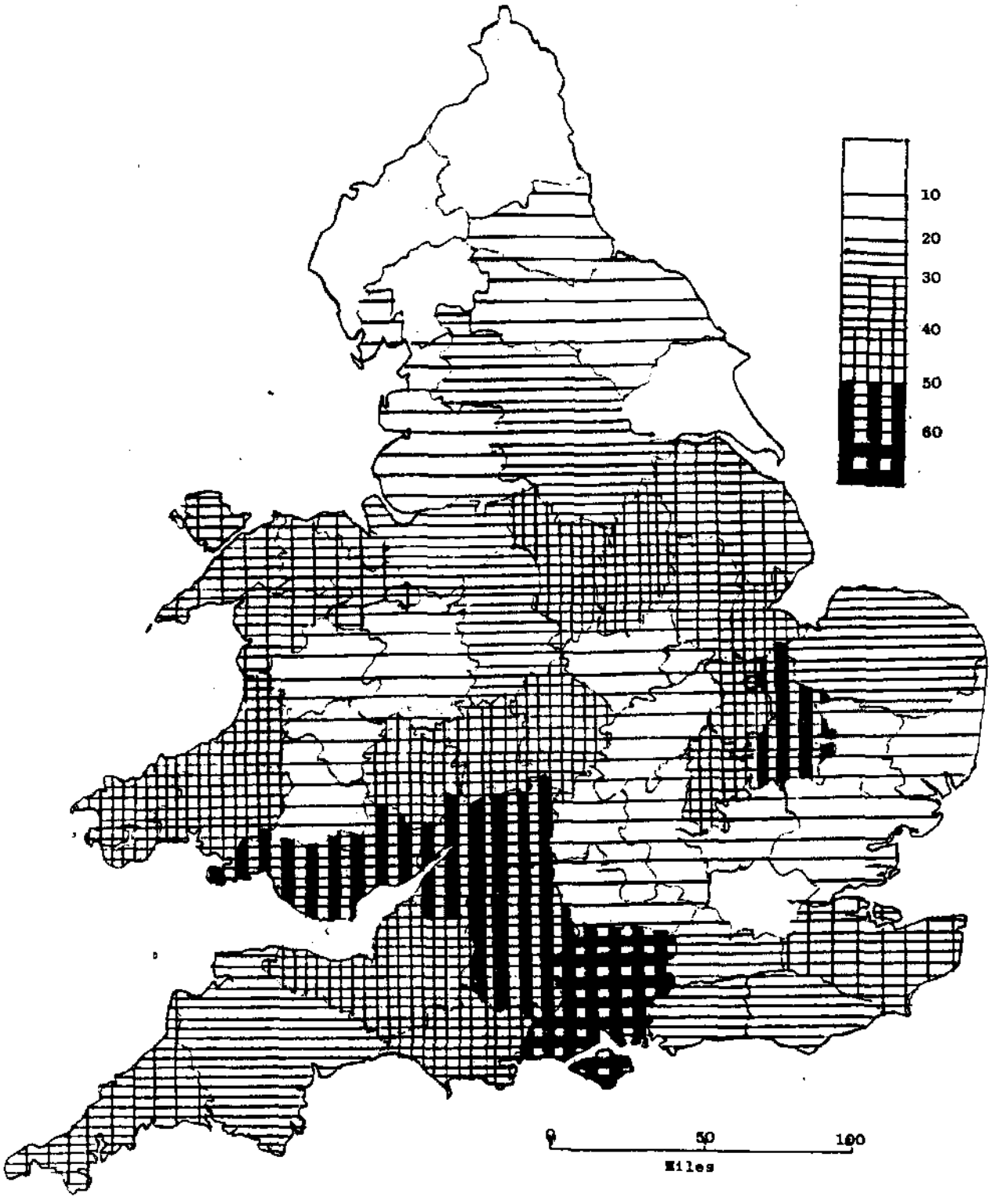

FIGURE I.7 Percentage of grants paid for ditching in relation to those paid for under-drainage, 1972/73, by MAFF Divisional areas

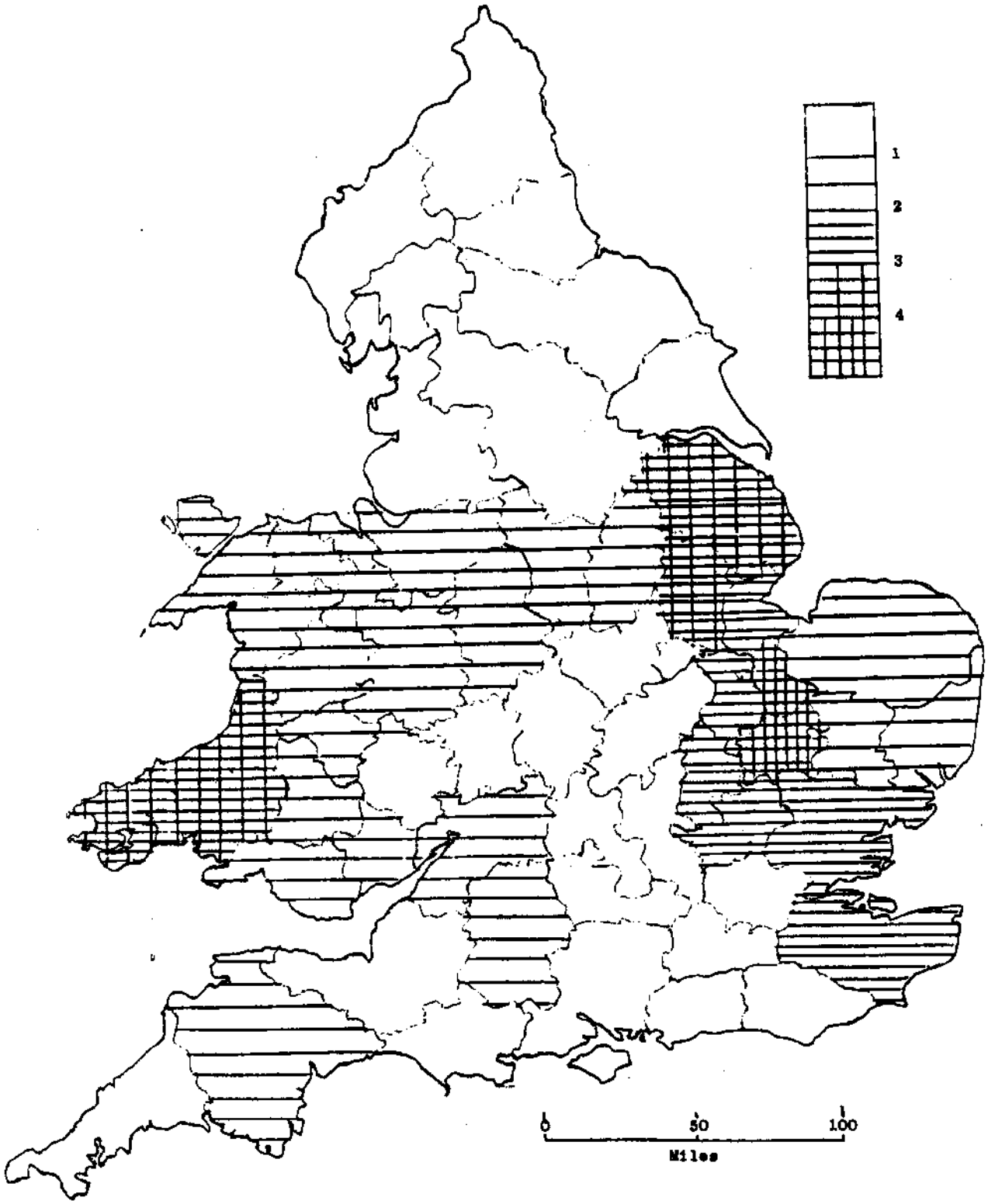

FIGURE I.8 Grants for ditching, in relation to acreage under crops and grass, in pence, 1972/73, by MAFF Divisional areas

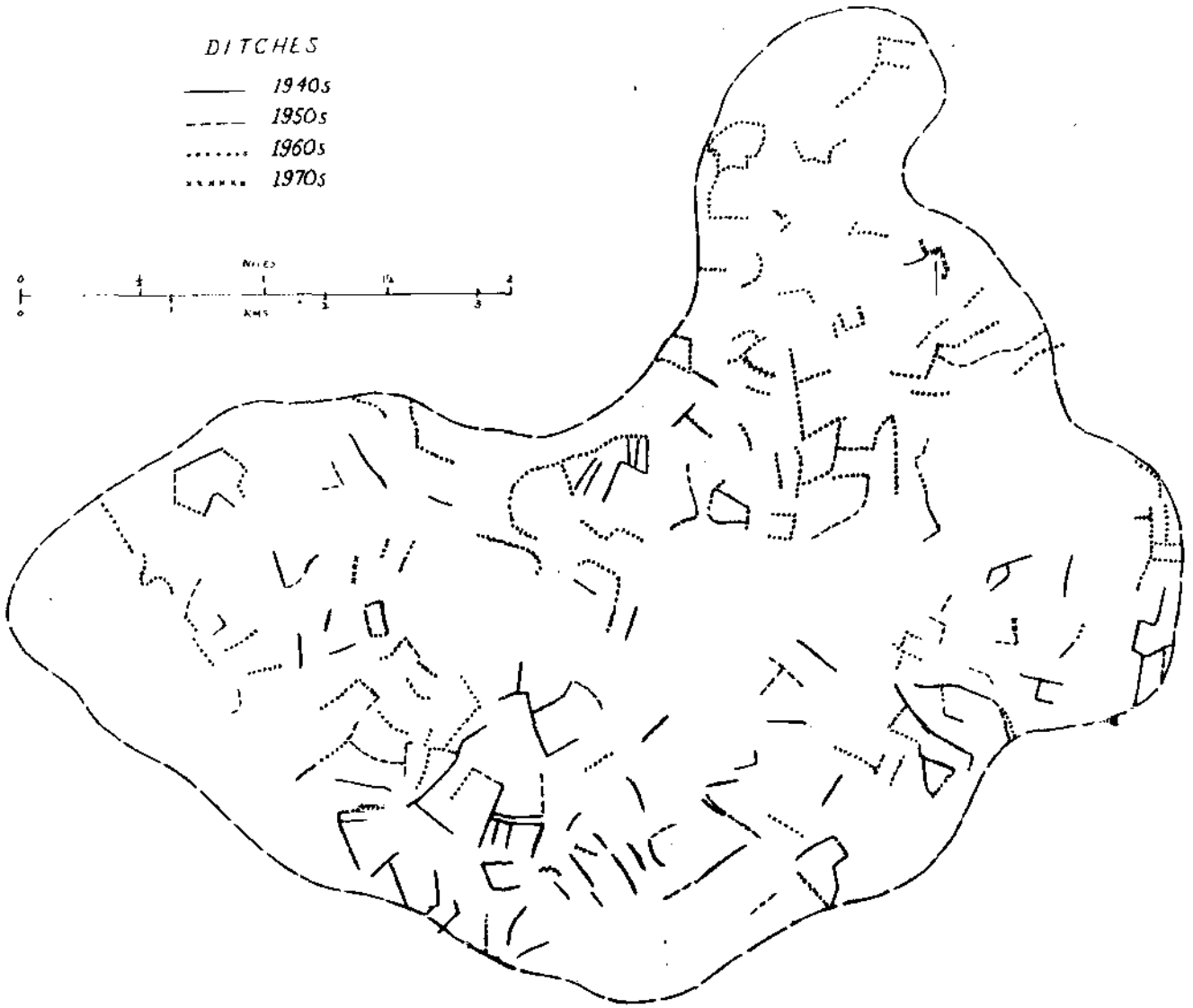

FIGURE I.9 Approximate lengths of ditches improved with the aid of Ministry grants within a clay catchment in Cambridgeshire (Huntingdon District), up to 1974

SECTION II

FIELD UNDER-DRAINAGE IN EUROPEAN COUNTRIES

From the earliest days of agriculture man has tried to regulate the amount of soil-water by irrigating when and where there was a shortage, and by drainage when and where there was a surplus. There is a considerable literature on the technical and scientific aspects of both irrigation and drainage. It is a different matter in respect of where and when irrigation and drainage schemes have actually been carried out. A satisfactory amount of information is available in respect of irrigation schemes based on retention of water by dams for irrigation purposes, but data on the amounts of water used in such modern methods as sprinkler irrigation are hard to come by. In respect of drainage, the availability of information on when and where it has been carried out is very limited, even though major schemes of surface drainage of alluvial lands - such as those of the Netherlands and the Fenlands of England - are well documented. As regards schemes for drainage of heavy soils by either surface or sub-surface methods, less information has been assembled. The objective is of course to lower the water-table in the soil and it has been amply demonstrated that well designed field drainage lowers the water-table in periods when it would otherwise remain close to the surface. Thus its cumulative effects on agriculture and on plant communities have been profound.

It would be desirable to quantify the areas where agricultural drainage of any type has taken place. This however is not yet practicable, but an attempt is made here to map the amount and distribution of field under-drainage. Even this is difficult because of the difficulty in discovering statistical data. Only in a few cases are they included in national censuses of agriculture, Götz (1970) having reported only nine. In Europe the present writer has found such data included in national censuses only in Finland, France, Norway and Sweden, and there not always every year. In Belgium they were included only once, in the 1951 census, and that referred only to what had been carried out in the previous five years.

In most western and northern European countries substantial government grants are now available for agricultural drainage and because of this, statistics are compiled annually of grants paid and estimated areas drained with the aid of them. These data are not always published but can be obtained in, for instance, the United Kingdom and the Republic of Ireland, from the Agricultural Departments of Central Government. In Denmark, where grants are not made, data are available only through an unofficial sample census conducted by the Danish Farmers' Union.

As can be expected from the above, the assembling of the data is very tedious and it cannot be put into a form which allows precise

comparability from one country to another; this report attempts to get as close an approximation as possible.

Figures were produced by Nosenko and Zon (1976) for certain European countries from which a map was produced as shown in Figure II.1. This has several shortcomings, the two chief ones being (i) that it does not distinguish sub-surface from surface drainage, and (ii) the sources are not clearly stated.

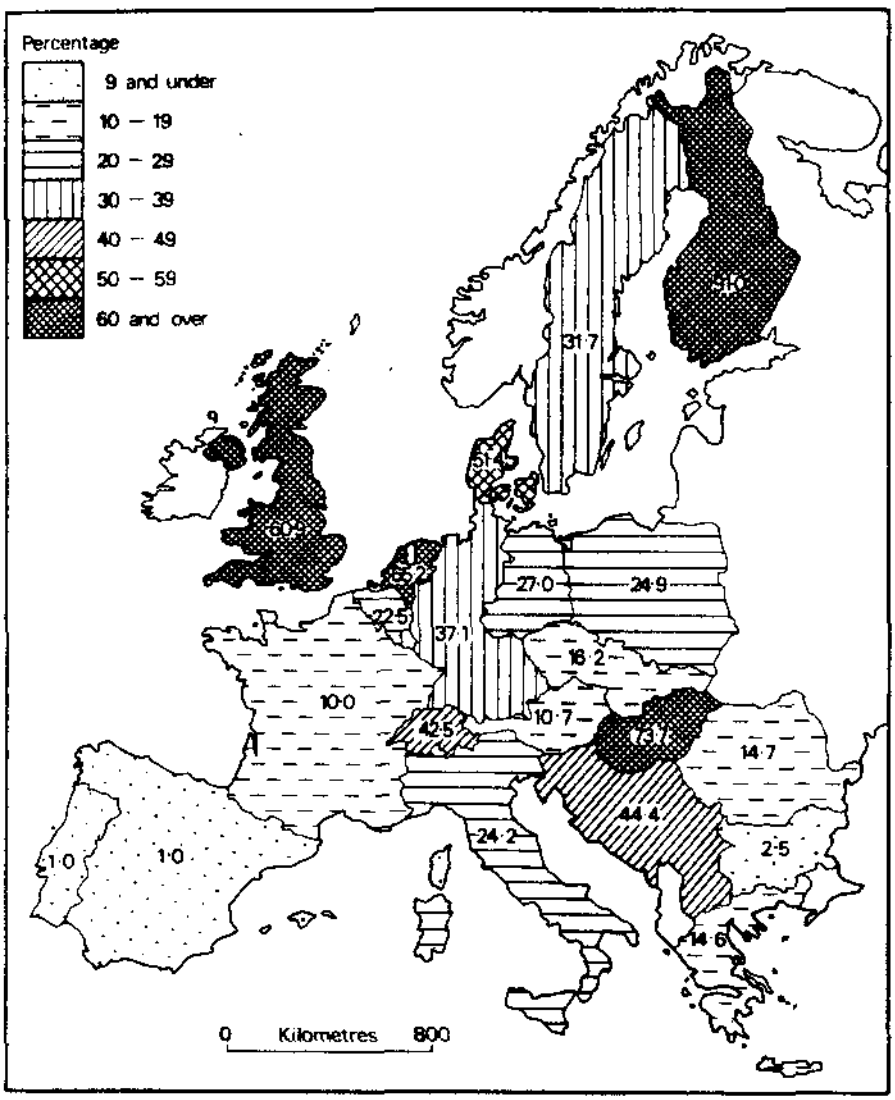

FIGURE II.1 **Percentage of agricultural land drained in Europe** *(after Nosenko & Zon, 1976).*
No data from countries unshaded.

An enquiry was also conducted under the auspices of the C.I.G.R. (Commission Internationale du Génie Rurale), and the results of this were compiled and published in 1972 (Musy, 1972). A map based on estimates submitted by various countries is shown as Figure II.2. It corresponds in a very general way with Figure II.1, but in every case shows lower percentages, with a particularly large discrepancy in the case of Switzerland. Only to a limited extent can the discrepancies be explained by the somewhat earlier date of the C.I.G.R. enquiry.

An annotated cartographical review has been made first of the position in individual countries, followed by an attempt at assessing the current position in these countries taken together. Other types of land drainage are discussed in conclusion.

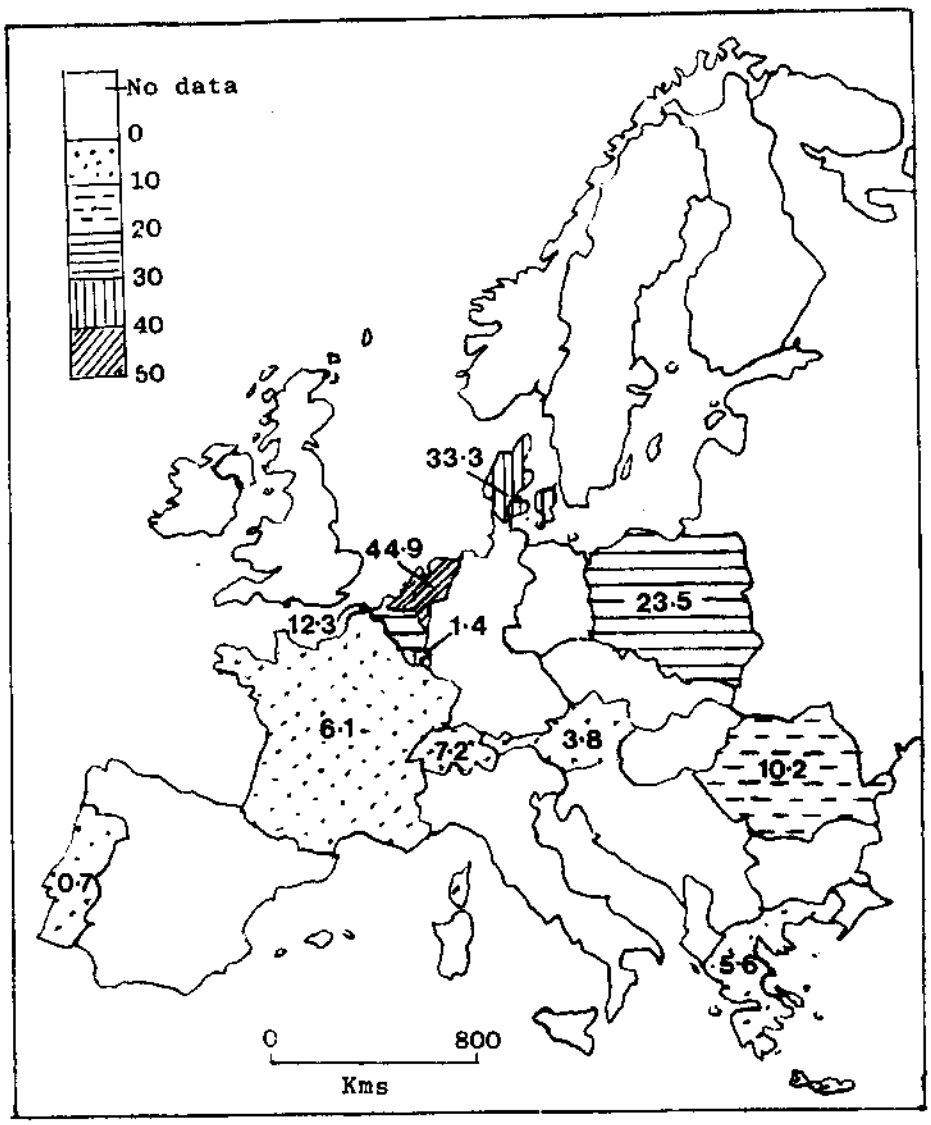

FIGURE II.2 **Percentage of agricultural land drained in Europe** *(after Musy, 1972).*
No data from countries unshaded.

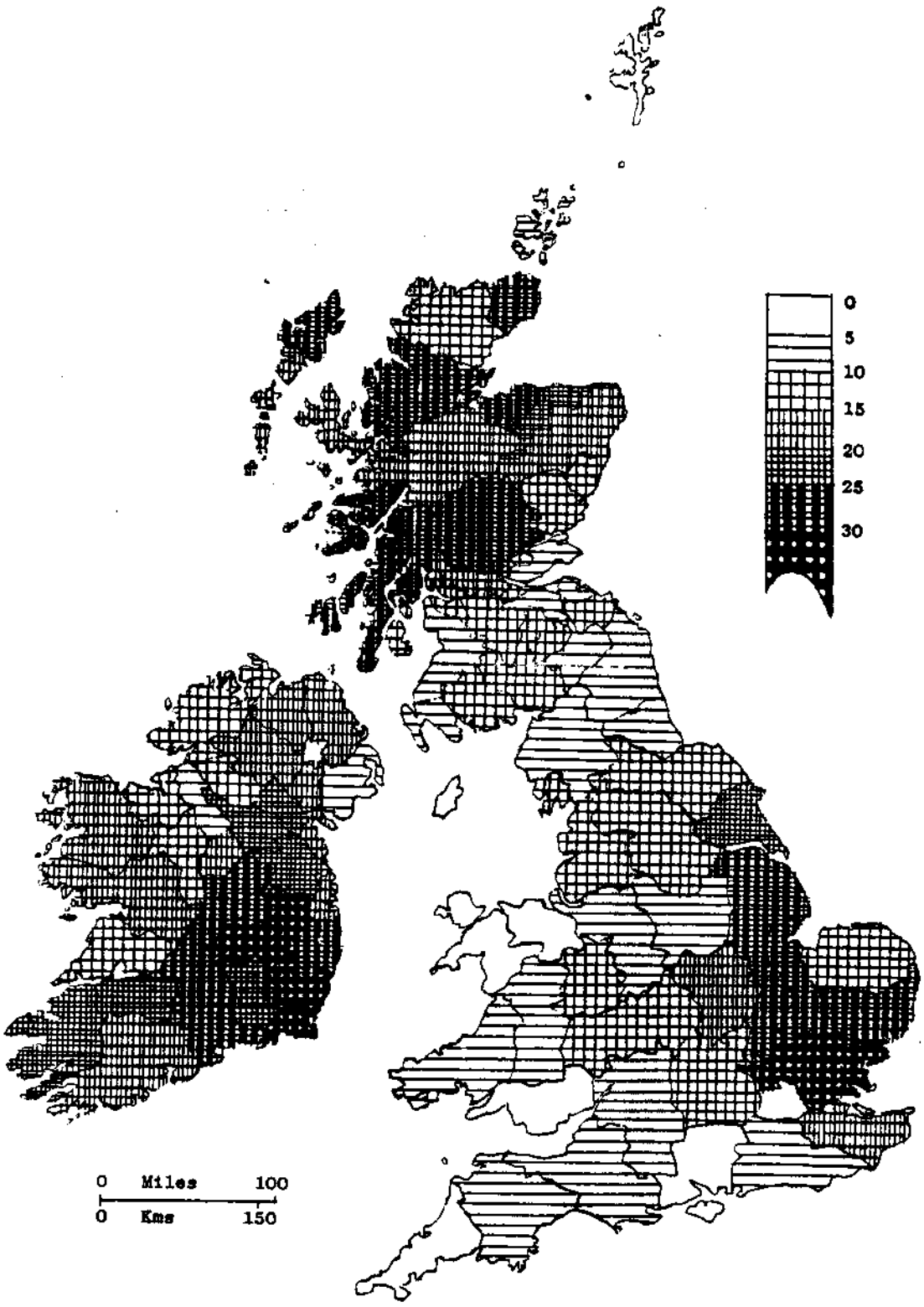

FIGURE II.3 Extent of field under-drainage in the British Isles, 1949-1976, expressed as percentage of area under crops and grass.

THE BRITISH ISLES

In the British Isles virtually none of the available statistical data has been published but much information is held by the Agricultural Departments of central government. For the most part it is available only for the years since the present types of grant-in-aid were established, i.e. since the period of World War II.

Very much under-drainage was however carried out in the mid-nineteenth century in all parts of the British Isles and no systematic statistics are available for this - much of which is still effective. Indeed for the period before 1940, the only figures existing are for Scotland (as a whole) back to 1921, and these do not separate field drainage from arterial drainage until 1958. Figures are available for England and Wales of the extent of under-drainage carried out since 1940. For the British Isles as a whole it was possible to map the extent of under-drainage from 1949 onwards. Figure II.3 (from Section I) shows the regional distribution more or less accurately, but almost certainly somewhat under-estimates the amount in England, Wales, and Scotland, as compared with Ireland. In Scotland the map is a bit misleading, unless one bears in mind that the high percentage under-drained in the north-west concerns only a small total area of agricultural land.

In the current system of approval of grants, inspectors in England and Wales, and in Scotland, now enter on the forms information on past under-drainage (substantially, this was pre-1940 drainage), and this, as explained by Green (1979) enables a rough estimate to be made of the total percentage of agricultural land under-drained in the nineteenth and twentieth centuries. This estimate is displayed in Figure II.4 for England, Wales and southern Scotland. To estimate the total percentage, likewise, for Ireland, one can only add an arbitrary percentage to what is mapped in Figure II.3, assuming similar nineteenth century drainage activity to that in Great Britain.

Very much more can be mapped for the 1970s, one particularly important aspect being the proportion of land which has received secondary treatment, by moling or subsoiling. This and other features are discussed in papers by the writer (cf. Green, 1976, 1977), and in the annual reports of the Field Drainage Experimental Unit. Apropos of secondary treatment, it is now considered that pipe-drainage is not properly effective in most soils without it.

In the British Isles generally, climate is the predominant factor determining the intensity of drainage activity. In all parts, except those with particularly free-draining soils (notably those underlain by the Chalk and some of the Jurassic limestones in the south and east of England), the soil surface is liable to be water-logged during the periods, especially autumn and early winter, when it is required to have agricultural machinery on the land. In Great Britain in the nineteenth century, hilly land was under-drained almost as much as flat or gently

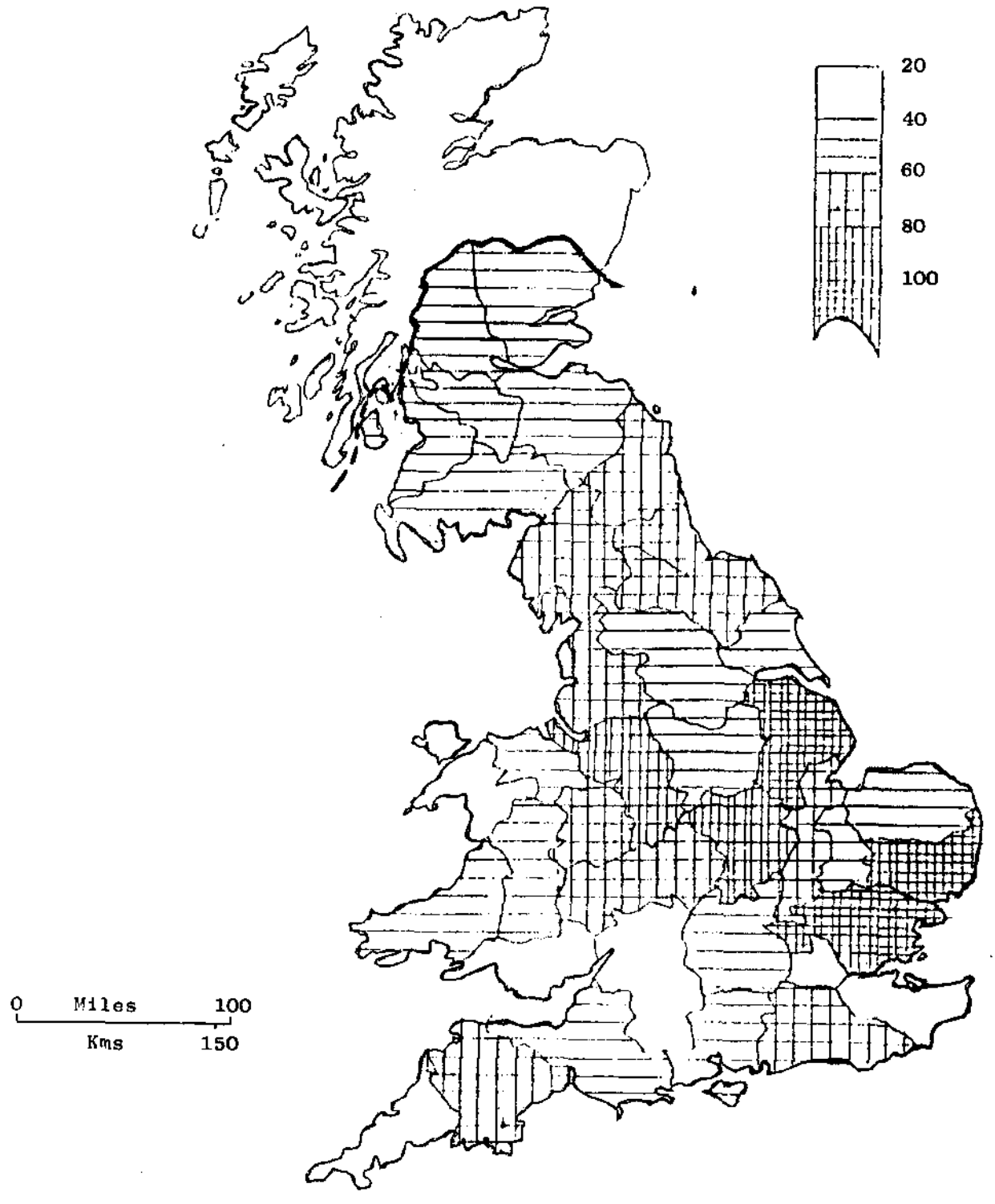

FIGURE II.4 The estimated total percentages of land under crops and grass (current area), underdrained up to 1977, by MAFF and DAFS Divisional areas. NB (a) Data inadequate north of heavy line, (b) some land has been underdrained more than once, hence percentages more than 100% in certain areas.

undulating lowlands, whereas since 1940 the greatest activity has been in the extensive arable areas of the east.

In the case of flat riverine and deltaic land, which has been progressively protected from inundation by various kinds of surface drainage, under-drainage has not always been necessary, especially where the land is used for pasture. In very recent years the change to arable and also to more intensive pastoral use has led to under-drainage in such "polder-lands" as Romney Marsh and the Somerset levels.

In these areas which are climatically wettest, such as the west of Scotland, the proportion of agricultural land drained is high, but of course the total area involved is not great.

In Ireland, both climate and topography demand under-drainage, and the distribution of effort has thus been fairly uniform over the whole island, but with a perceptible maximum in the more favoured arable areas in the south-east (as in England and for essentially similar reasons).

The annual course of under-drainage since 1949 is shown in Figure II.5.

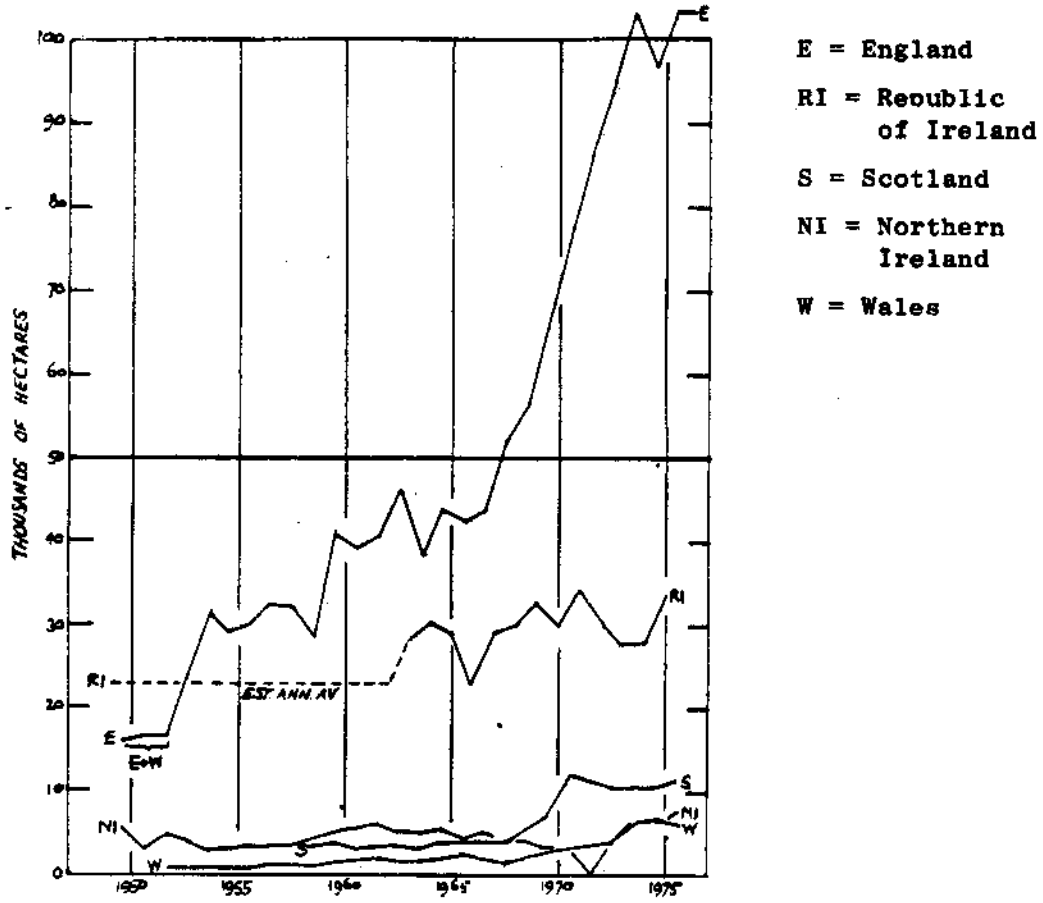

FIGURE II.5 Under-drainage, annually, in different parts of the British Isles.

NORWAY

Statistical data on agricultural drainage were available for Norway as *a whole from* 1921, *and* for counties (Fylker) from 1939. They are published by the Norwegian Central Bureau of Statistics.

There is a terminological problem, in that the word "grøfting" can refer to ditches or to under-drainage (or both together), according to the context. It is believed that the areal figures for "grøfting av tidligare dyrke jord" refer mainly to field under-drainage, and the following maps of field drainage assume this.

Agricultural land is still being broken in, but if one takes the 1969 agricultural area, the proportion drained from 1921 onwards comes to 27 per cent. Fluctuations in the annual amount drained, mainly with the aid of government grants and loans, are shown in the graph (Figure II.6). The 27 per cent must under-estimate, by an unknown amount, the total undertaken in Norway. But, since a high proportion of any under-drainage undertaken before 1921 would have needed renewal, the under-estimate may not be serious. At any rate, the percentage compares well with that for neighbouring Sweden, where the data refer to all under-drainage work which has taken place.

Figure II.7 is roughly comparable to the map prepared for the British Isles for the period 1949 to 1976 (the amount under-drained in the U.K. between 1939 and 1949 was small). Maps prepared for the years 1958, 1968 and 1975 show no great difference from the average distribution pattern. The drainage effort in the year 1975 is shown in Figure II.8. One similarity to the position in Britain is quite clear, namely the concentration of drainage work in the drier lowlands, especially around Oslo and Trondheim fjords. A smaller proportion of the agricultural area has been drained on the west coast (from Rogaland to More and Romsdal) than in the west of Scotland, but agricultural land there is well limed.

I am greatly indebted to Dr K. Bjor, of Norges Institutt for Skogsforskning, Ås, for extraction of data.

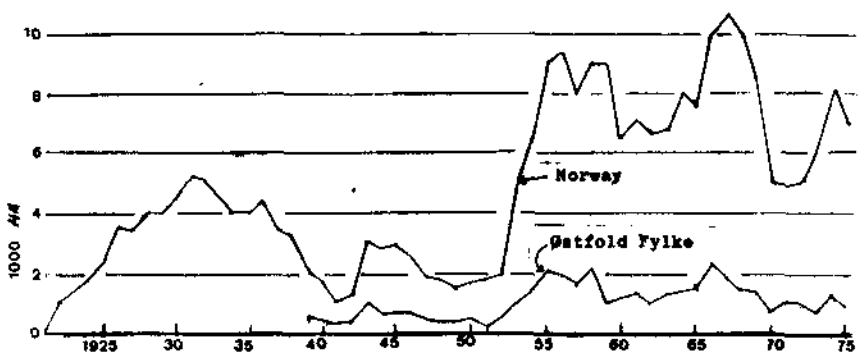

FIGURE II.6 **Area, in hectares, under-drained annually, in Norway as a *whole, and also Østfold Fylke*.**

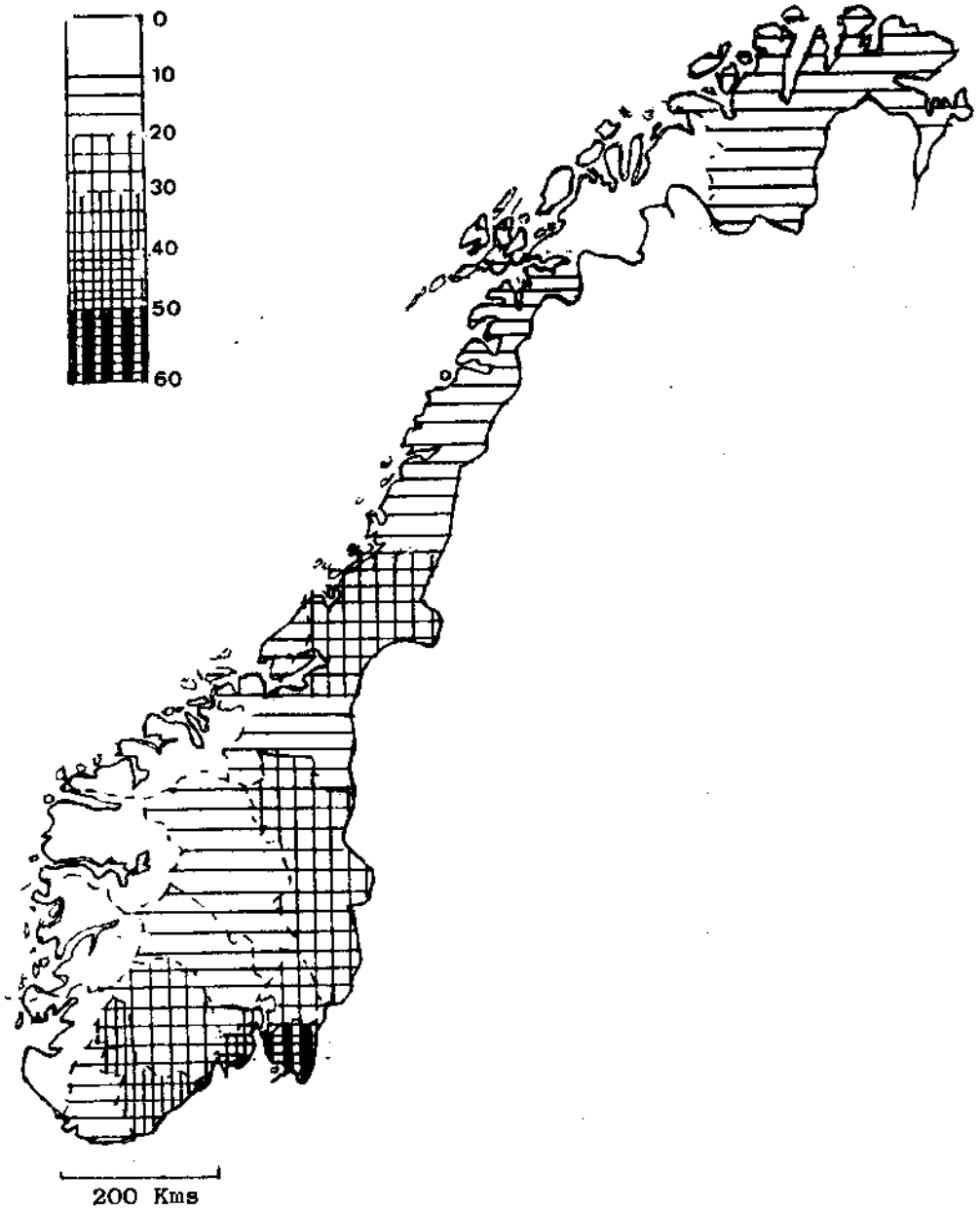

FIGURE II.7 Percentage of (1969) agricultural area which was drained 1939 to 1975. NB The area drained 1921 to 1938, in the whole of Norway, was 16% of that drained 1939 to 1975.

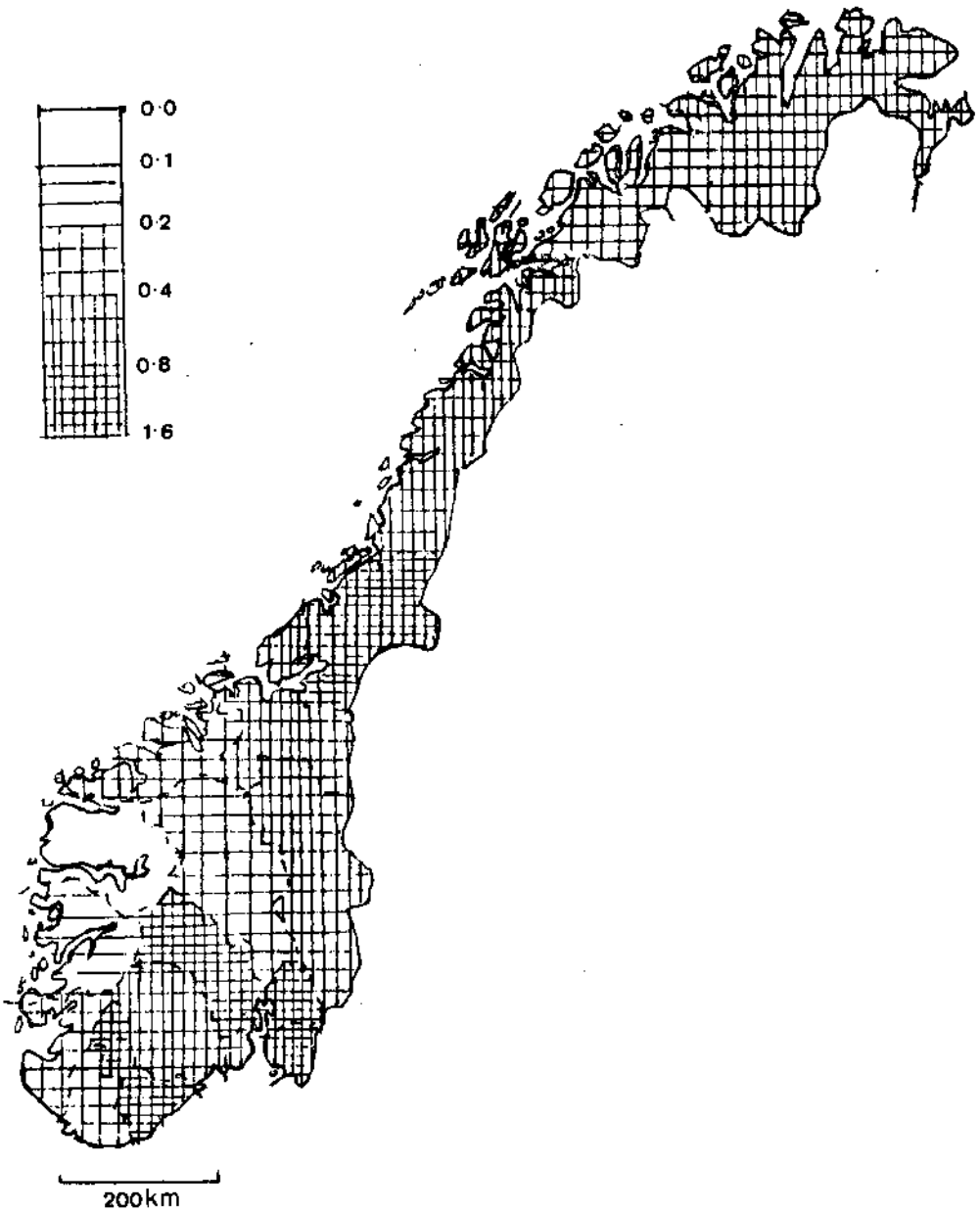

FIGURE II.8 Percentage of agricultural land drained during the year 1975.

SWEDEN

The Swedish statistics come mainly from periodical Censuses of Agriculture. In the years when drainage information was covered it was reported how much land had been under-drained, at any time, and usually also whether it was by pipe, stone, or other material. As shown by a special investigation, carried out in 1973 by the Central Statistical Bureau, in conjunction with the agricultural authorities, there has been some margin of error in the areas reported; in particular, the total amount reported as drained went down slightly between 1927 and 1932, and between 1937 and 1944 (see Figure II.9). However, for Sweden as a whole, it is fairly clear that the amount of under-drainage undertaken annually did not change greatly between 1927 and 1951, but has shown a slight increase since then.

The 1973 position, based on the data published in the Yearbook of Agricultural Statistics, is shown in Figure II.10A, and II.10B, based on data in the same Yearbook, shows the proportion drained before and after 1930. In the Census of Agriculture 1951, areas under-drained are given for the 'natural agricultural districts' as well as for counties (Läner), and so a more detailed map (see Figure II.11A and B) was possible for the area under-drained up to that year.

Correlation of under-drainage with the distrubution of deglaciation deposits is clear. It has been undertaken most, and earliest, on the central and coastal lowland areas, which were longest below sea-level, and particularly on the level plains with moraine clay deposits, as in Scania, central Östergötland, around western parts of Lakes Mälar and Hjalmar, and on the islands of Öland and Gotland. Only later did the somewhat similar areas around Lake Väner catch up.

I have to thank Prof. T. Hägerstrand, Lund University, for assistance in extraction of data.

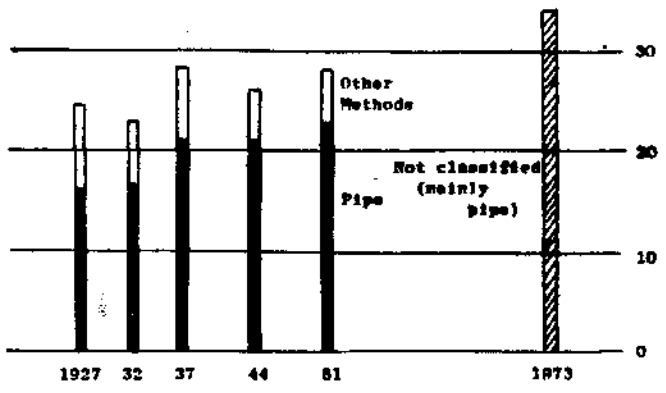

FIGURE II.9 Total percentage of agricultural area reported as having been under-drained at various times.

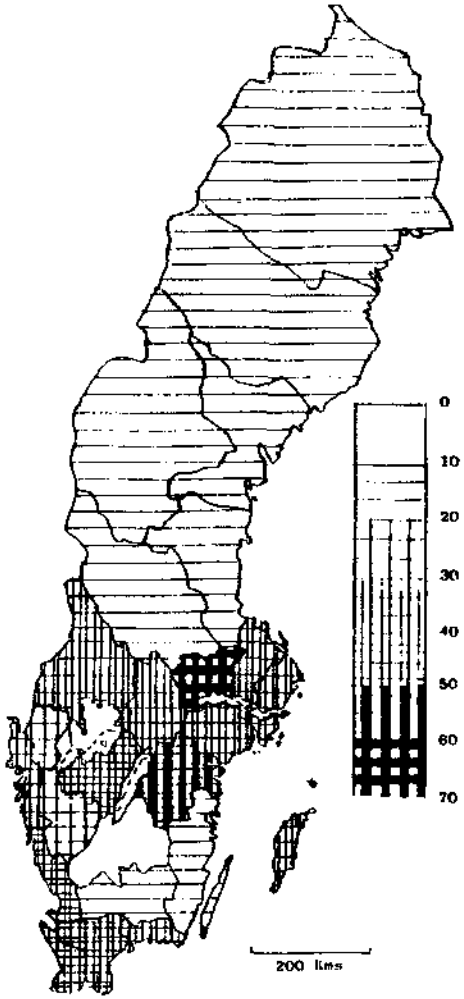

FIGURE II.10A Percentage of agricultural area under-drained in Sweden to 1973.

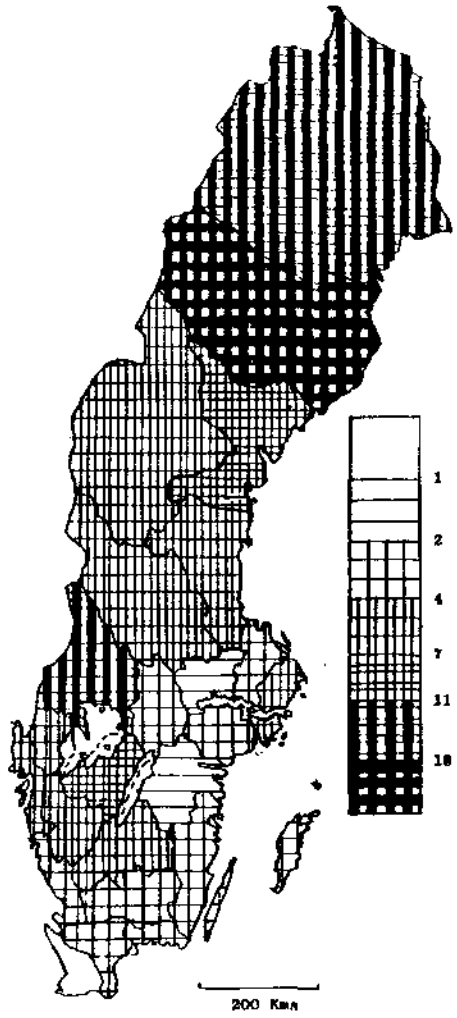

FIGURE II.10B Percentage of agriultural area under-drained in Sweden, in 1930 or later, divided by the percentage under-drained before 1930.

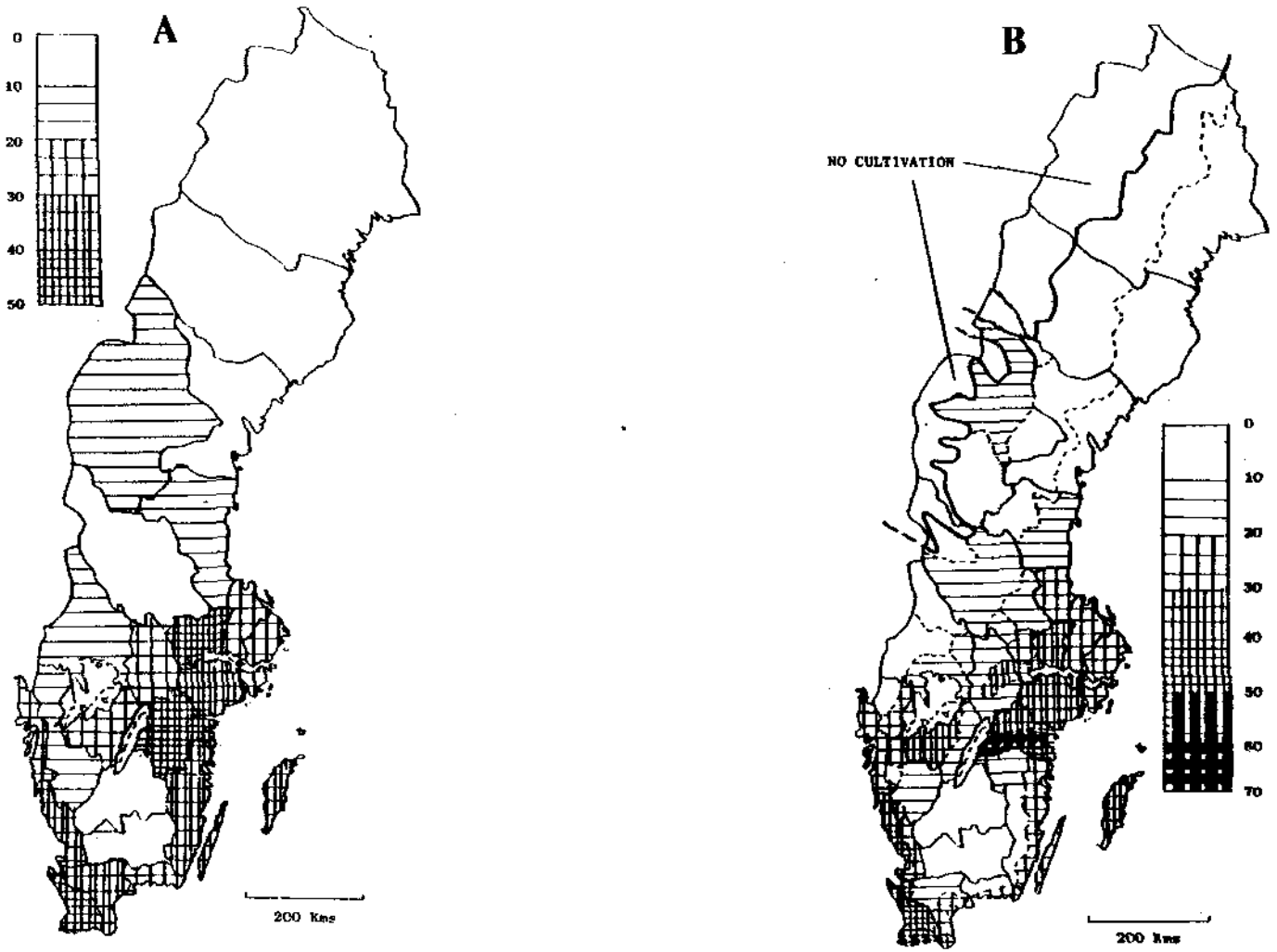

FIGURE II.11 Percentage of agricultural area in Sweden under-drained, to 1951:
A by Länner, B by agricultural districts.

DENMARK

The map of Denmark (Figure II.12) is compiled from the results of a sample survey conducted during 1972 and 1973 by the Danish Farmers' Union. Approximately one per cent of the farmers (farming about one per cent of the agricultural land) in each county were interviewed. This enabled a table to be compiled of the percentages of the agricultural land drained in four periods: (i) before 1920, (ii) 1921 to 1932, (iii) 1933 to 1950, and (iv) 1951 to 1972. The percentage under-drained by 1972 is shown on the map. In the earliest of the four periods, drainage effort was concentrated in the islands; at the end of the second period, more than half the 1972 total had been accomplished in all the islands except Funen county. North Slesvig caught up during the third period.

There is a general, although not perfect, correlation of drainage effort with districts containing the highest proportions of clay soils. Rainfall does not vary substantially across Denmark, but it is evident that the least drainage has taken place in the more exposed parts of the country, i.e. west and north Jutland, which in general have lighter soil. On the whole, the distribution and the intensity of under-drainage in Denmark are more similar to the British Isles than they are in any other country.

I am indebted to the Danish Heath Society, of Viborg, for extraction of the data from the Farmers' Union Survey.

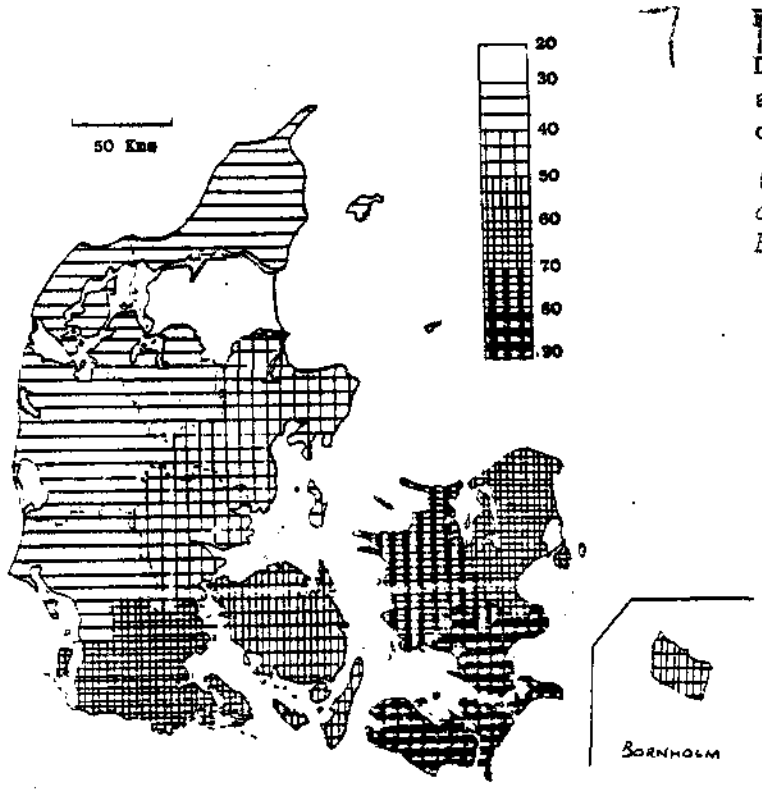

FIGURE II.12

Denmark: Percentage of agricultural land under-drained drained, to 1972.

(From sample survey conducted by the Danish Farmers' Union.)

FINLAND

Finland is a special case - reflected in the fact that field drainage is, uniquely among European countries, almost always referred to by writers on its agriculture (cf. Smeds, 1960). The reason lies first in its northern position - it is the most northerly developed country in the world which gives particular features to its climate, and secondly, in its having considerable spreads of nearly level clayland.

The climate imposes the necessity of removing water from the soil as rapidly as possible after the spring thaw, and also after the harvest, to enable some work on the land to be carried out before the winter freeze-up. It is estimated that over ninety per cent of the agricultural land is therefore artificially drained. Under the Finnish conditions it is not surprising that this has been in the past mostly surface drainage. Since some kind of drainage is absolutely essential it was easier to undertake surface drainage since it is cheaper and can be renewed frequently. The drainage channels use up some land which could be tilled and it was recognised that this loss of land could be reduced if pipe-drainage was more extensively used, as it has been since about 1960.

Pipe-drainage is concentrated in the south and south-west of the country including the coastal areas of Ostrobothnia on more than 60% of the cultivated land in some districts (see Fig. 13). It is helped by state grants and the material used is still mainly ceramic. As in the case of Sweden, the highest proportion of the under-drainage in northern communes has been done in very recent years.

I am indebted to the Finnish Field Drainage Centre (Salaojakeskus) for data up to 1977.

ESTONIA

It is known that the first installation of under-drainage took place in Estonia in the 1850s. But statistical information was available only for the years 1971 to 1977, when it averaged about 30,000 ha per year. It is however estimated by the Estonian authorities that, in total, 46 per cent of the agricultural area of the country has been under-drained to date.

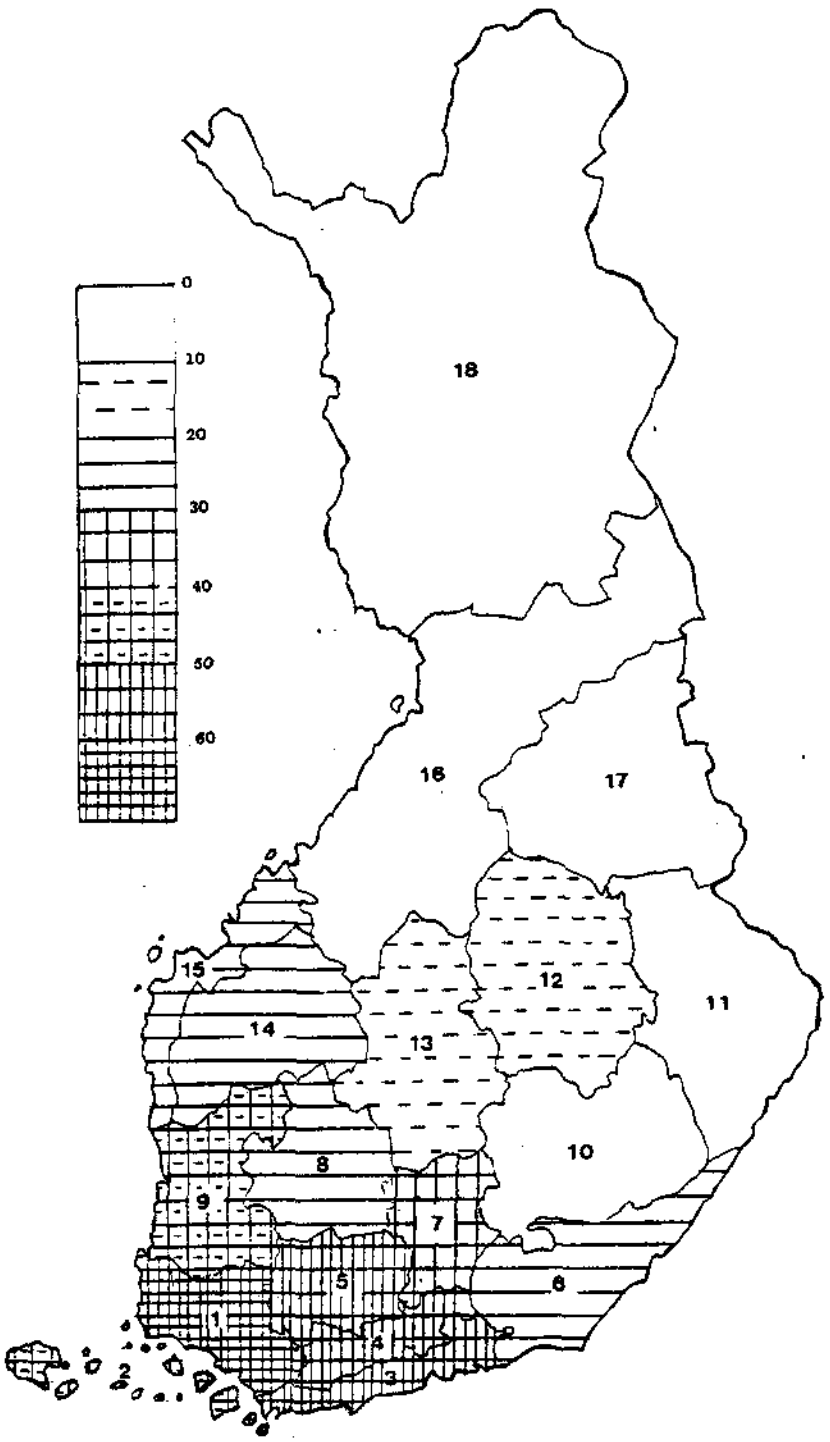

FIGURE II.13 Finland: Percentage of total arable land under-drained to 1977, by Agricultural Society areas. The numbers refer to these areas (see table in Appendix).

BELGIUM

Figures for Belgium as a whole were available for the years 1945 to 1975 (Figure II.14), but statistics by regions were available only from the Agricultural Census of 1951, which gave the figures for 1945 to 1950. Similar information has not appeared in any other agricultural census. From 1945 to 1968, the annual average amount of under-drainage fluctuated around 1500 ha, but it shot up to 6000 ha in 1969 (after a wet winter), and has now settled down to about 3000 ha per year.

The distribution of drainage activity in the 1945-50 period (Figure II.15) shows an overwhelming concentration in the polder-land of Flanders, and corresponds to the predominance on similar land in the neighbouring Netherlands and the Département du Nord in France.

It is worth observing that only 51 per cent of the land area of Belgium is in agricultural use.

If one accepts Nosenko and Zon's figure of 22.5 as the percentage of agricultural land drained in Belgium, and that the regional distribution of drainage effort has been fairly constant, one can use the maps drawn for 1945-50 to make an estimate of the distribution of the total amount of under-drainage in Belgium. The average for the country for the five years was 0.64 per cent. If the keys to the maps are altered by multiplying by $\frac{22.5}{0.64}$ (= 35.1), this may be assumed to be largely, though not entirely, under-drainage. The total percentage for West Flanders is somewhat over 100, the most likely explanation for this being that an unrepresentatively large amount of work was done between 1945 and 1950, but also some land could have been drained more than once.

I am indebted to J-P Goethuys, of Tielt-Winge, for obtaining data.

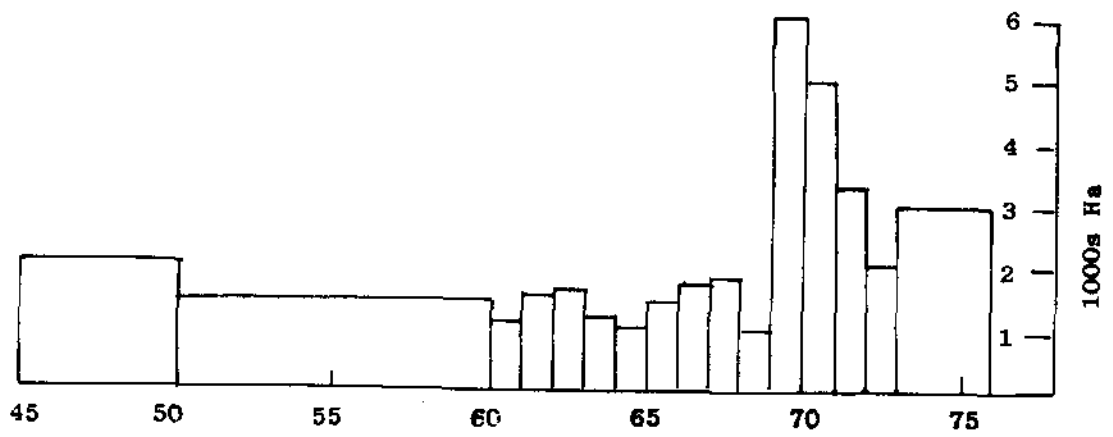

FIGURE II.14 Belgium: area under-drained annually

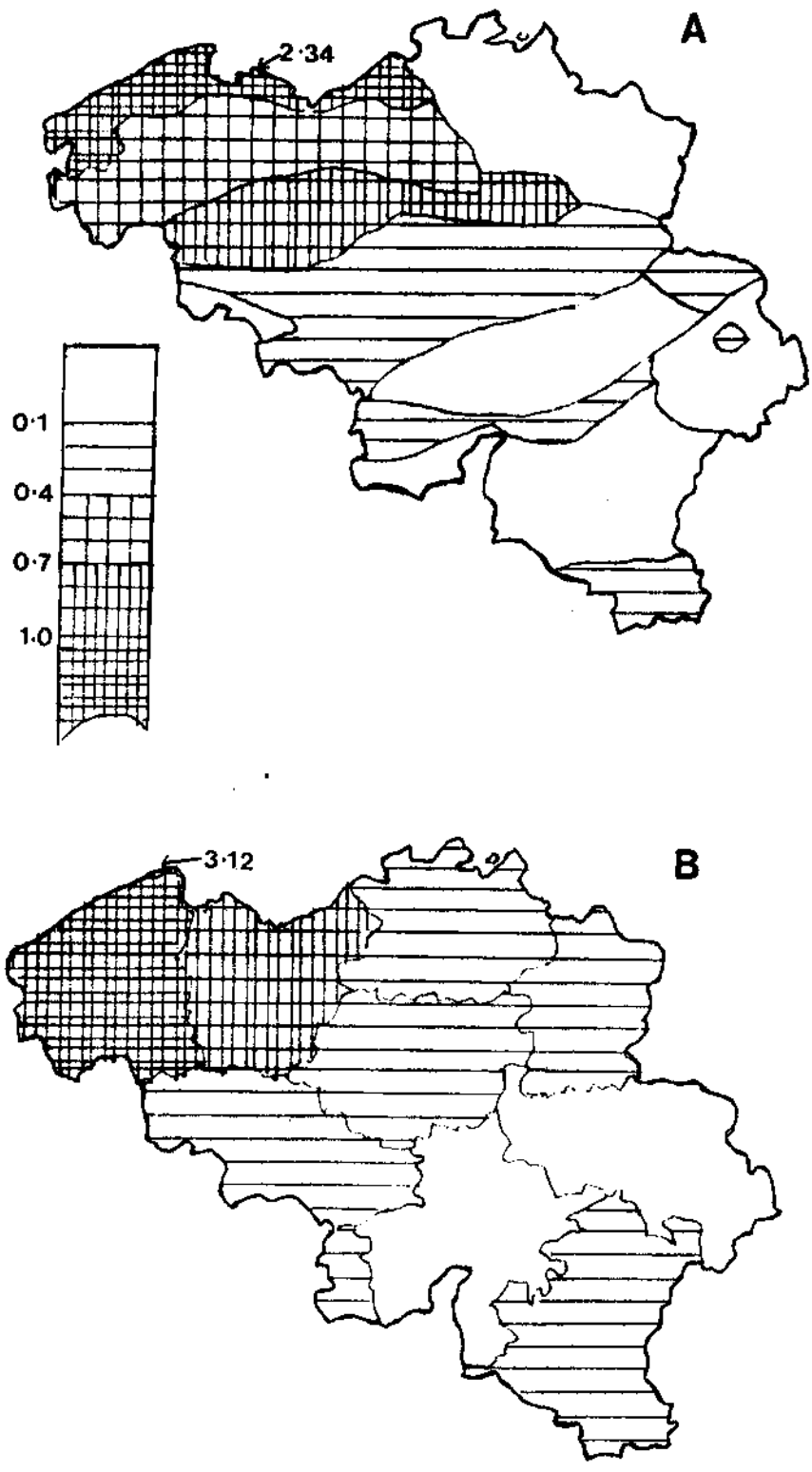

FIGURE II.15 Belgium, under-drainage 1945-50: (a) as percentage of total land area, by agricultural regions, (b) as percentage of agricultural area, by Provinces

THE NETHERLANDS

The map in Figure II.16 is reproduced from that given in 'General Information on Subsurface Drainage in the Netherlands' by T. E. J. van Zeijts, (1978) and is based on the 1977 inventory of Water Management in the Netherlands. It shows, as in Belgium and the immediately adjoining part of France, an overwhelming concentration of under-drainage on the polderlands of marine clays. A map prepared for the same Inventory of land still needing new or renewed under-drainage shows that this, likewise, is concentrated in the same area.

Figure II.17 from the same source shows (a) the fairly steady annual under-drainage effort since 1958, and (b) the rapid rise of the use of corrugated plastic pipes since 1967 - as for instance in France. It also indicates that the usual density of the drains is 1 km of piping for 1.3 ha.

There is of course much surface drainage in the Netherlands, and it is evident that this, aided by pumping, is sufficient to regulate the water-table in the generally permeable soils.

Dr J. Wesseling of the Institute voor Cultuurtechniek en Waterhuishouding, Wageningen, kindly directed me to data sources.

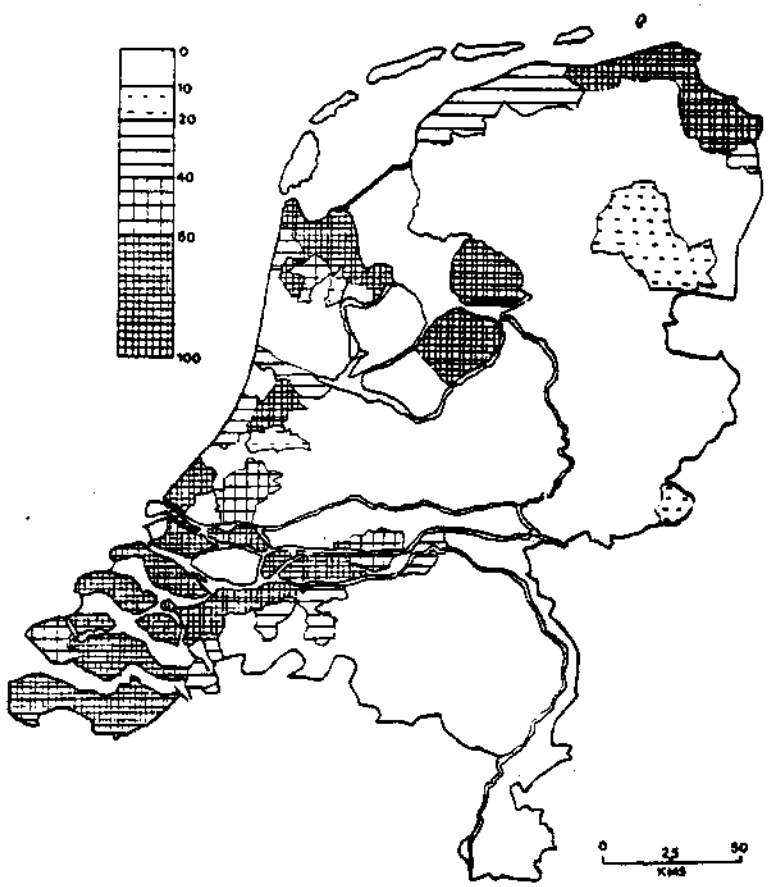

FIGURE II.16

Netherlands: Percentage of agricultural land under-drained, to 1977

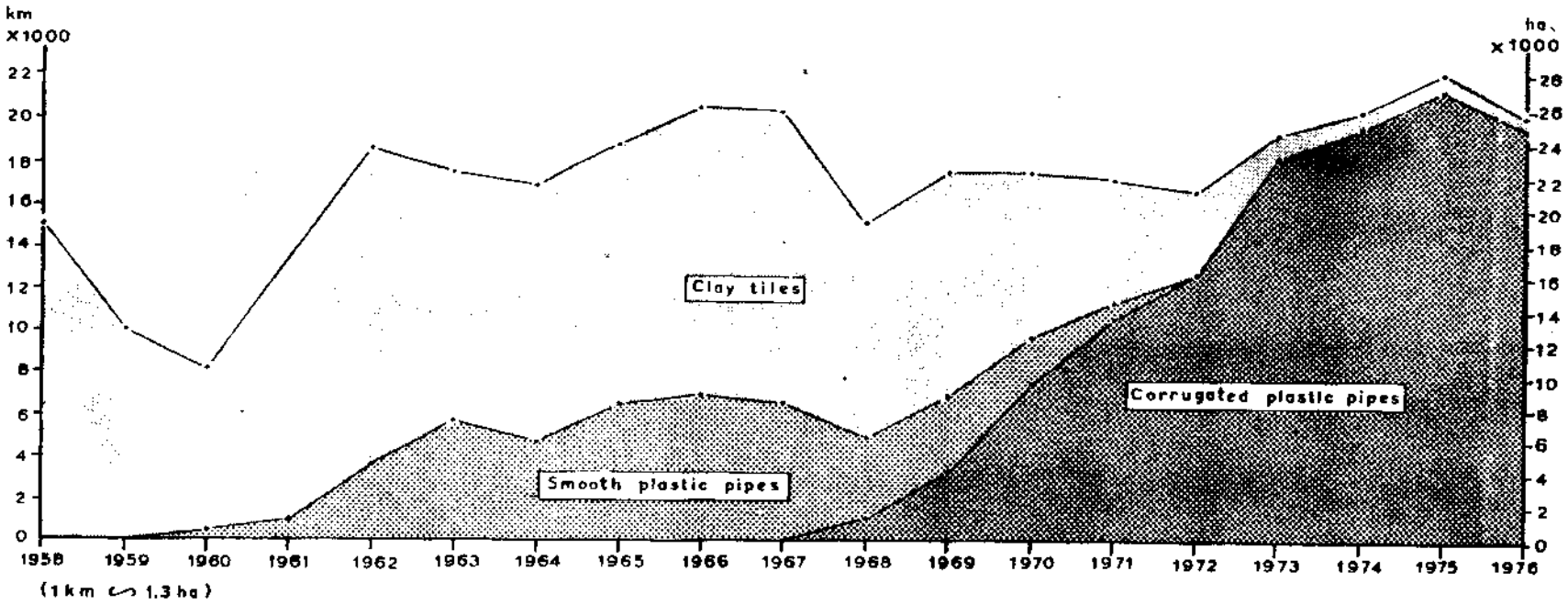

FIGURE II.17 Annual figures for the use of various types of drainage pipes in the Netherlands

GERMANY (WEST)

Details of the regional distribution of under-drainage in West Germany were not available, and even the total area drained can only be estimated. Figures are available of the amount spent, in each year since 1955, by drainage associations (Verbändungsdränungen), and these are shown in Figure II.18. This reveals a peak in 1968, and a nearly fifty per cent decrease since then. But there is also privately undertaken drainage, which is believed by 1970 to have been between 20 per cent and 30 per cent of that undertaken by associations. Figures are also available of the production of PVC drainage pipes which, as in the Netherlands, have almost completely replaced ceramic tiles and these show a doubling of production between 1970 and 1976. At most, 15 per cent are exported. Thus it must be presumed that privately undertaken drainage has increased considerably since 1970.

Assuming an average 12-metre spacing of drains, Eggelsmann (1978) concluded that, in the most recent years, about 60,000 ha have been under-drained per annum, which is negligibly less than the amount estimated for the period 1962-69. This means about 0.42 per cent of the agricultural area each year, and although a figure cannot be given for the total area under-drained in West Germany, the rough total of the percentage area of agricultural land drained at any time would seem likely to be not seriously out of accord with Nosenko and Zon's figure.

An estimate made of the area needing under-drainage (whether it had in fact been drained or not) gives 4.4 million ha, which is 31 per cent of the agricultural land area, but for the north-west of the country it reached 60 per cent. This suggests a continuity of pattern with the neighbouring parts of Denmark and the Netherlands.

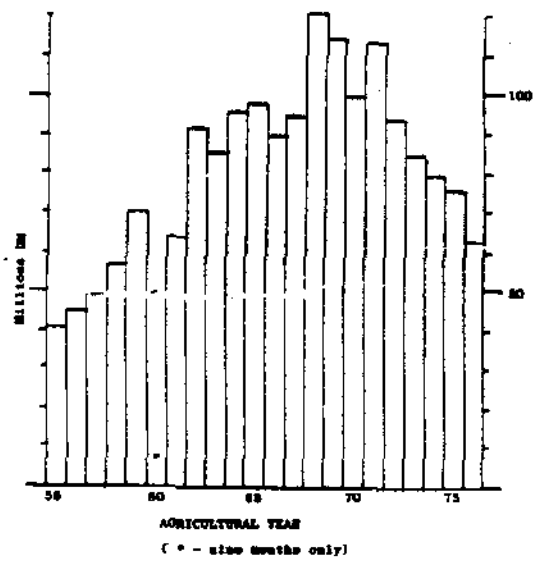

FIGURE II.18 Germany, Federal Republic: Annual expenditure on under-drainage by Drainage Associations (Verbänden), in Deutschmarks

GERMANY (EAST)

According to Olbertz (1966), about 2.4 million ha were considered to require drainage. Of that area, about 1.3 million ha had been drained, 0.9 million ha of which was considered to have been effectively carried out, although some (possibly a third) was no longer fully operative; sometimes the outfalls were not in satisfactory condition.

If one takes the total area 'under crops and grass' as 10,820,000 ha, the percentage under-drained (at any time) is about 12 per cent. Since 1966, it would appear that about 40,000 ha have been under-drained annually; this would make the present percentage about 16. Nosenko and Zon give 27 per cent; since the 10,820,000 ha given above probably includes some land which would not, in the British sense, be included under 'crops and grass', 16 per cent is very likely too low a figure, and so a compromise figure of 20 per cent has been used for Figure II.25A.

No regional statistics were given, but Olbertz states that most of the land which required drainage, and where most drainage had been carried out, was in the north of the country.

CZECHOSLOVAKIA

Nosenko and Zon (1976) quote 16.1 as the percentage of cultivated land which has been under-drained in Czechoslovakia. Figures supplied from Prague in 1977 give the following percentages of under-drainage:

(a) 7.18 per cent of total land surface
(b) 12.12 per cent of agricultural land including pasture
(c) 13.75 per cent of agricultural land excluding pasture.

In fact, the difference between (b) and (c) is mainly accounted for by central and eastern Slovakia. At any rate, all the above percentages are somewhat less than that quoted by Nosenko and Zon.

Figure II.19 prepared from the latest available statistics, shows the distribution of under-drainage as a percentage of the agricultural area, including pasture. The most obvious features of the distribution are:

(i) the generally small percentages of under-drained land in Slovakia compared with Bohemia and Moravia;

(ii) a correlation of most of the higher percentage areas with areas of relatively low elevation and low relief, in Bohemia and Moravia;

(iii) a general correlation with areas of low rainfall, as found to be the case in north-western European countries.

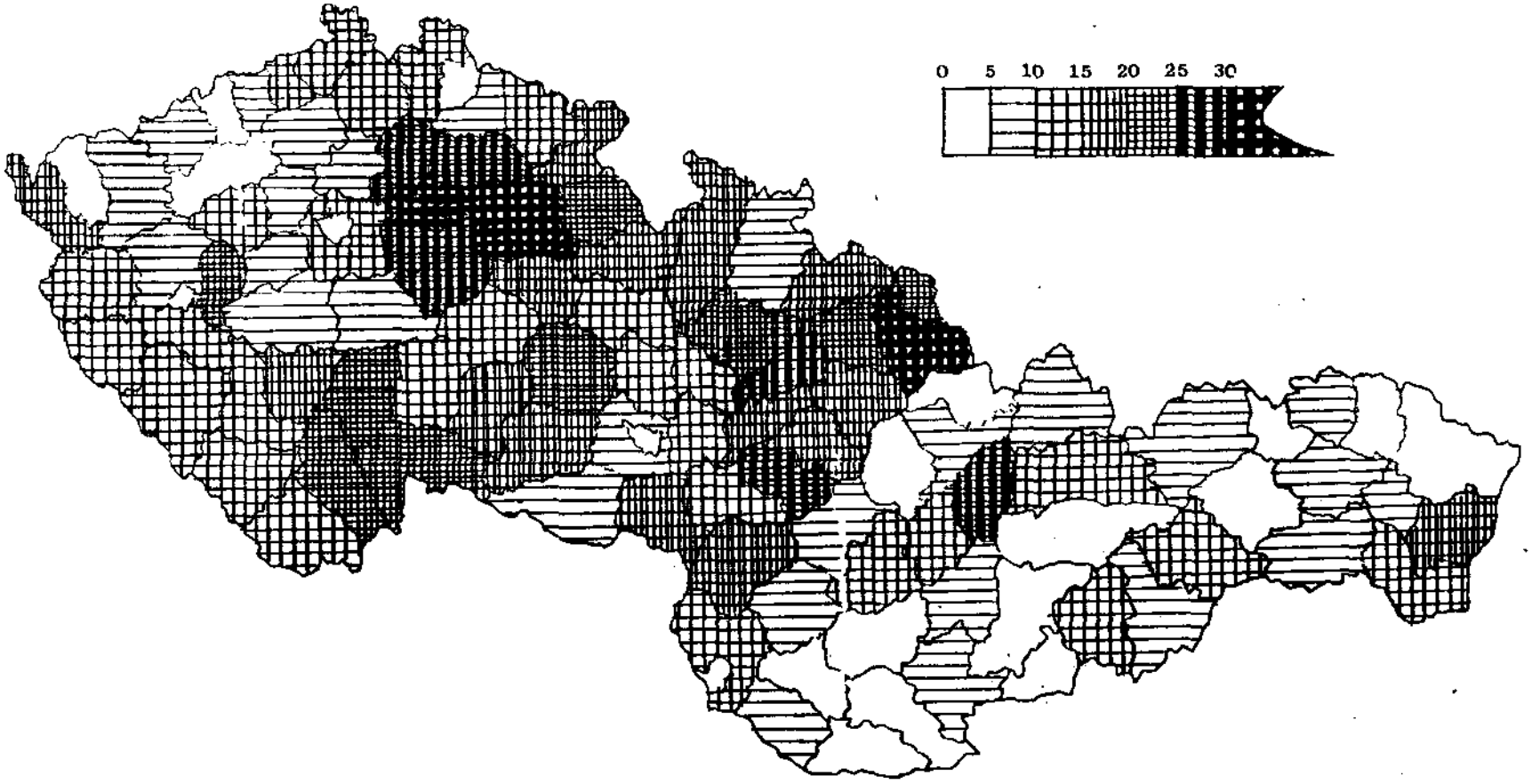

FIGURE II.19 Czechoslovakia: Percentage of cultivated land (including pasture) under-drained, to 1976, by okra

AUSTRIA

Statistics were available for Austria only in respect of (i) the agricultural area drained in each province in the fifteen year period 1945 to 1960, and (ii) the total agricultural area drained in the whole country during the period 1945 to 1975. It is not known what proportion of this was sub-surface drainage but this proportion is likely to be high. The amount is seen to be higher since 1960 than in the previous fifteen years. Figure II.20 shows the distribution by provinces for the period 1945 to 1960.

If the distribution of drainage effort by provinces has always been approximately the same, the percentages shown on the map might be multiplied by a factor of something like five, to give an estimation of the total area effectively drained. This would accord tolerably well with the percentages in the adjoining parts of Czechoslovakia, and with Nosenko and Zon's figure of 10.7 per cent.

In this area of summer maximum rainfall, the areas where the amount of drainage is greatest would appear to be determined by the amount of land of high agricultural potential, but particularly where such land - because of slightly higher rainfall or somewhat poorer natural drainage - most needs drainage. The drained area is relatively low in the flat south-eastern province of Burgenland, where drought rather than excessive wetness is the chief constraint on agricultural success.

I am indebted for the provincial figures (see Appendix) to Dr Franz Blümel, of the Bundesanstalt für Kulturtechnik und Bodenwasserhaushalt.

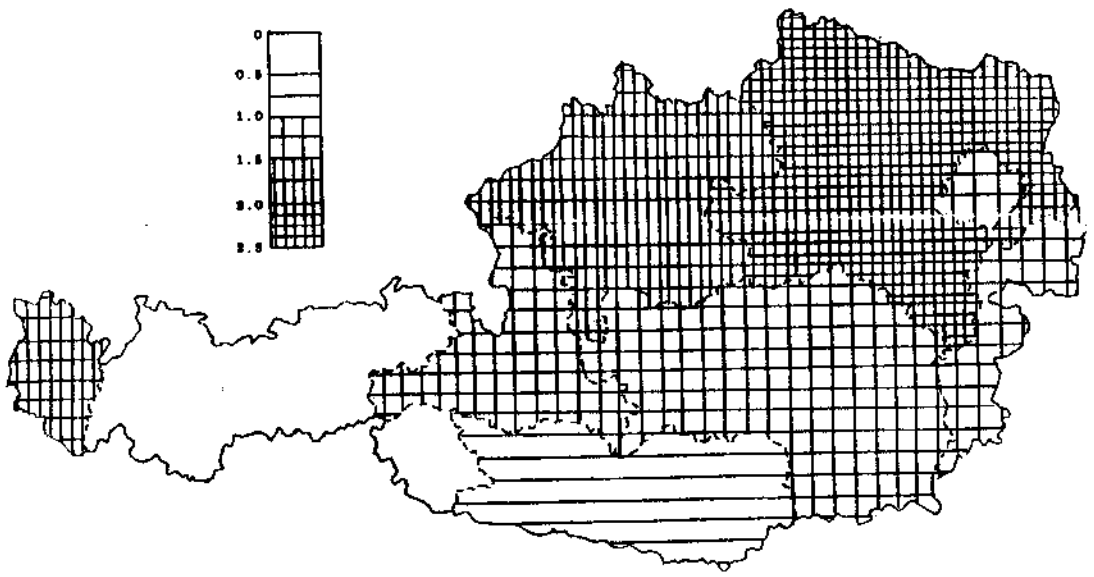

FIGURE II.20 Austria: Percentage of agricultural land under-drained during the years 1946-1960

SWITZERLAND

Figures were available for Switzerland only for the area drained (presumed to be mainly under-drained) in the whole country, from 1885 onwards. These figures give a total of 167,063 hectares. This amounts to 15.9 per cent of the total agricultural area or 63.4 per cent of the arable area (Swiss agriculture has concentrated on pastoral farming much more than neighbouring Austria). The data are presented in graphical form in Figure II.21, and in tabular form in the Appendix.

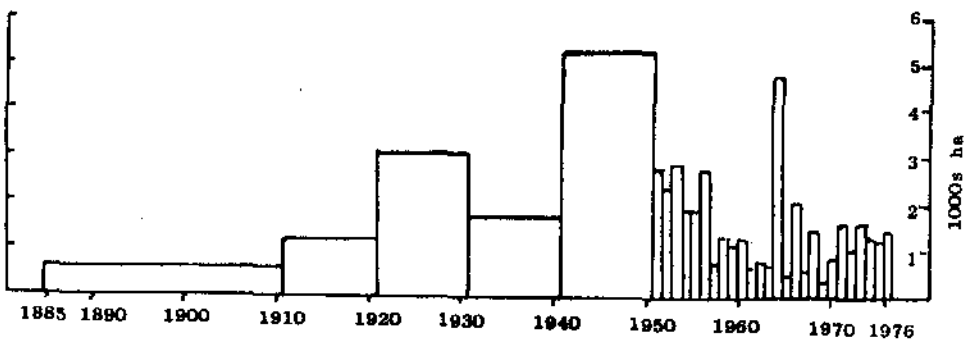

FIGURE II.21 Switzerland: Annual amounts of under-drainage

FRANCE

In the case of France, the position up to 1970 is portrayed in Figure II.22, based on the statistical data in the Census of Agriculture 1970-71. This shows a regional distribution of drainage activity generally similar to that given by Phillips and Clout (1970) for the third quarter of the nineteenth century.

It seems fairly clear that there was a peak effort about that time, corresponding approximately with the peak of effort in Britain. But whereas it is estimated that at least 5 million hectares were under-drained in Britain in the mid-nineteenth century, the figure for France seems unlikely to have been more than about ½ million hectares; only about 0.35 per cent of the agricultural area of France was under-drained between 1852 and 1862. Figures published in 1967 by the French Ministry of Agriculture show that the scale of under-drainage effort in the present century was minimal, until the 1960s, when, for the first time, it climbed up to the level of the 1860s, which was about 15,000 ha annually (Figure II.23). The annual effort accelerated greatly up to 1975 and has then levelled off (latest figures available from the Syndicat National Professionnel des Entrepreneurs de Travaux de Drainage), having reached 40,000 ha, or 0.12 per cent of the agricultural area of France. In England and Wales the current upsurge of effort began earlier - in the late 1940s - but also shows a marked acceleration since about 1967.

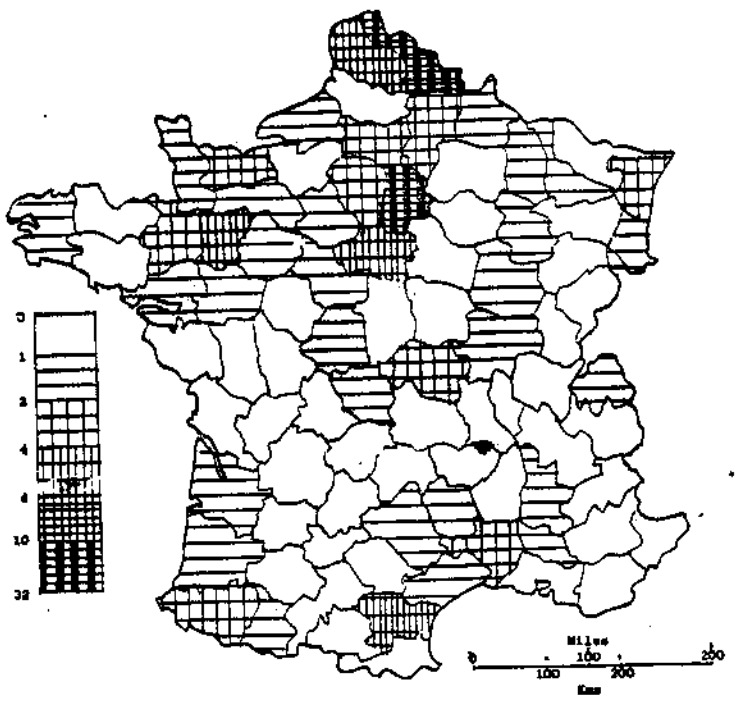

FIGURE II.22 **France: Percentage of area under crops and grass (Superficie agricultural utile) reported as drained, Census of Agriculture, 1970/71**

The regional distribution of the current under-drainage activity in France is shown in Figure II.24. There is rather greater concentration in certain areas than in the earlier periods; Normandy, Maine and the Vendée are relatively less active now, and in the Midi the chief effort has shifted to the extreme south-west.

Some correspondence can be traced, as Phillips and Clout pointed out for the nineteenth century, between areas drained and predominance of clay land. But, as they also pointed out, the structure and type of farming have provided the more important constraints. Small size, and fragmentation of holdings have inhibited under-drainage work right up to the present day. It is also relevant to say that the greater amount of agricultural land, in relation to population, than in neighbouring countries, has meant less pressure to increase the productivity of the land. As regards type of farming, the larger scale cereal growing farms have throughout been prominent in drainage work.

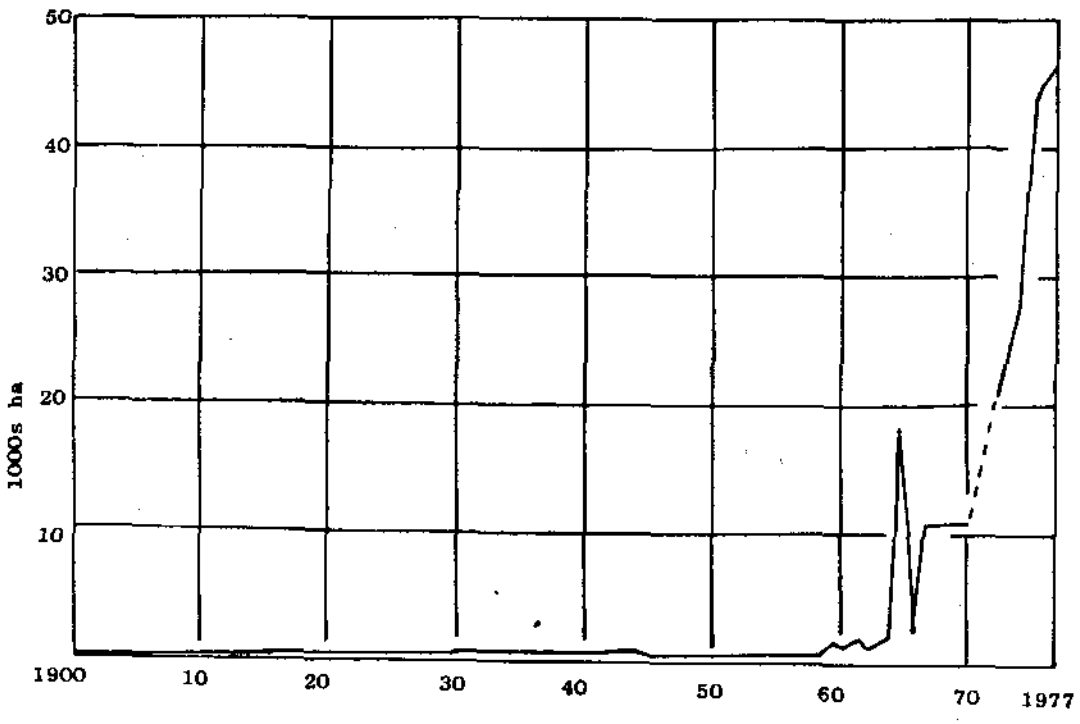

FIGURE II.23 Areas under-drained in France, years since 1900

France is clearly backward in field under-drainage, with less of its agricultural land under-drained than any other country in western, northern or central Europe (except for Spain and Portugal, in most of which the climate is such that it is not needed). One should however recall that France has not been backward in regulation of rivers, streams and ditches; surface drainage work is referred to again at the end of this report.

Mr J. Devillers of the French Ministry of Agriculture, greatly assisted me in finding the statistical data.

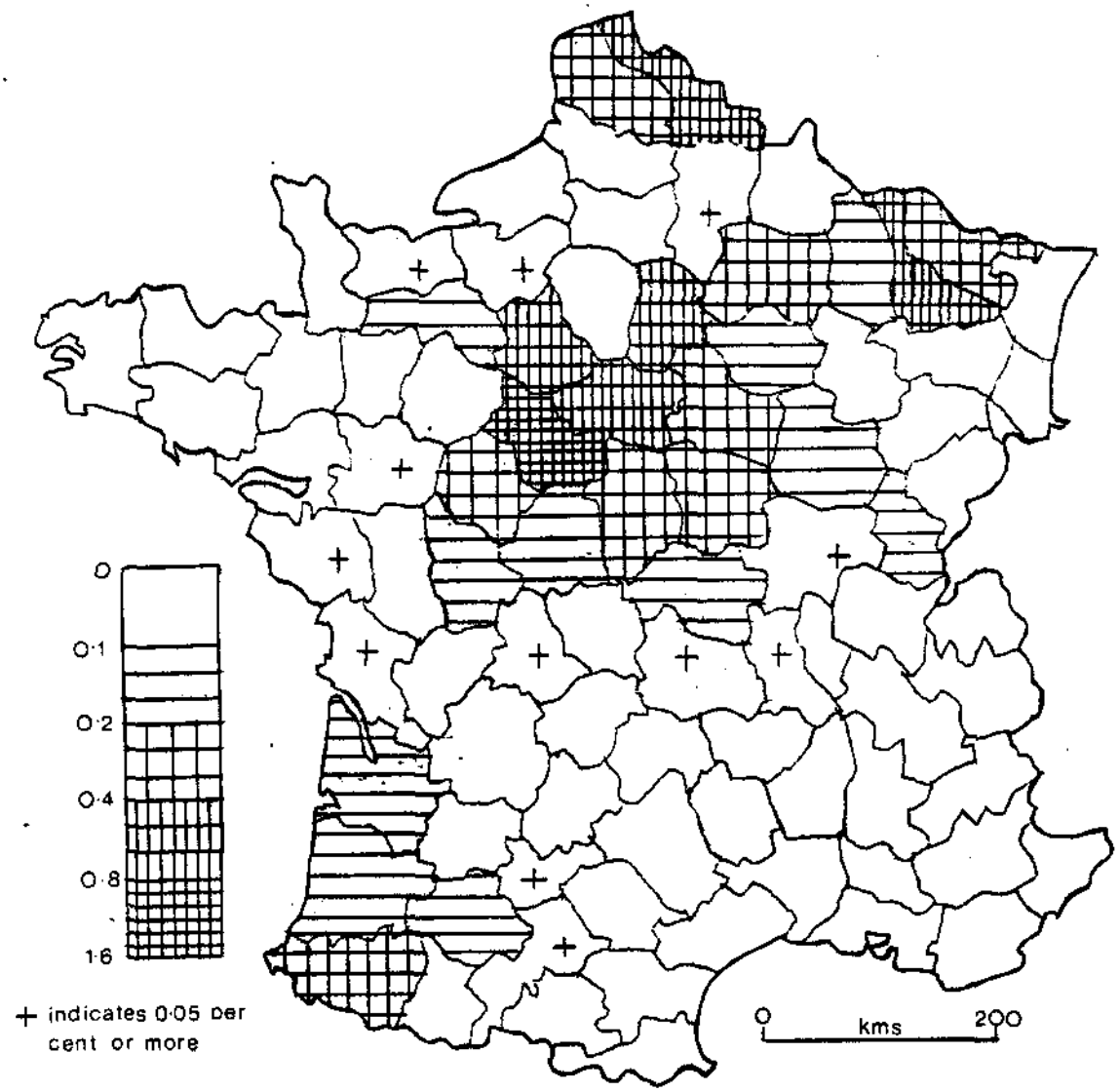

FIGURE II.24 **Percentage of area under crops and grass (Superficie agricultural utile) under-drained in 1974-75 - average of these two years**

General

An attempt has been made to combine the maps for individual countries to give a picture of the total percentage of agricultural land drained up to the mid-1970s. The limitations of this map (Figure II.25A and B) will be apparent from what has been said above.

In the cases of Czechoslovakia, Denmark, France, the Netherlands and Sweden, the statistics available were for total area under-drained, up to varying years in the 1970s. In the case of Norway the area must be under-estimated somewhat because the statistics available were from 1939 onwards. In the case of Belgium, as described in the note on that country, an estimate was made based primarily on the known area under-drained over the period 1945-50; likewise for Austria, estimates of the total were made from data covering only 15 years.

The construction of the map for Great Britain has been explained in Section I (and see Green, 1979a]. The available data for Ireland (both Northern Ireland and the Republic] are for 1949 onwards. It has been explained in Section I that these probably overstated the amount, but it is certain that this overstatement is more than counter-balanced by the non-availability of data for earlier periods.

Whatever its shortcomings, the final map, considered together with Nosenko and Zon's, and Musy's, figures, does permit of some descriptive generalisations concerning under-drainage. The greatest intensity is in the British Isles and the areas around the North Sea, with evidence that it extends to the Baltic coastal areas in general, as it certainly does to eastern Sweden and southern Finland. In this part of northern Europe one common factor is a climate which favours waterlogging of soils at certain times of the year. But the nature of the soil is also an important factor, and in Scandinavia and the British Isles under-drainage is most prevalent on clay lands, many of which are deglaciation deposits, and some of which - notably in Ireland - are also areas of natural climatic bog.

It is however not entirely clear why, in the Low Countries, under-drainage is almost confined to reclaimed polder-and. The Netherlands generally, of course, are very extensively drained by various surface methods, and waterlogging is not a paramount problem in such periods as ploughing time. The slightly greater warmth and continentality in rain-fall regime as compared with the British Isles can go some way towards explaining this, as also the very small amount of under-drainage in the hillier terrain of inland Belgium. The small area of polder-land in the immediately neighbouring part of France causes the Département du Nord easily to hold the record for under-drainage in France. But the strik-ing thing about France is the enormous contrast between the two sides of the English Channel, where both terrain and climate are closely similar. This can be accounted for only by non-physical factors, in particular the organisation of farmland. Under-drainage is in general, whatever the physical conditions, correlated with consolidation of

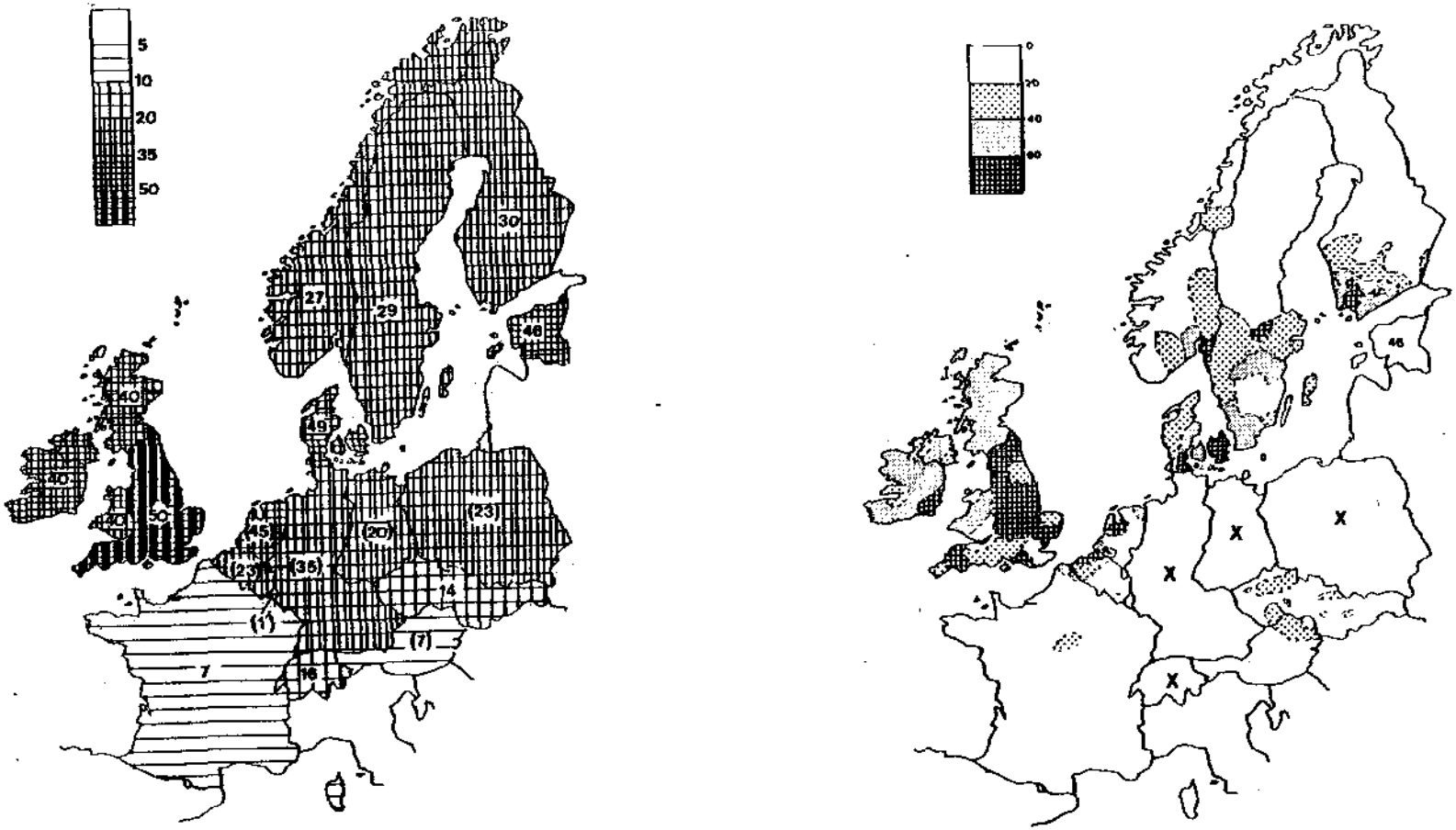

FIGURE II.25 Total percentage of agricultural land under-drained, estimated from present survey
(A) by countries (b) by regions X = no regional data

farm holdings. There is now very little fragmentation of farm holdings on the northern side of the Channel, but in France it still inhibits schemes for under-drainage, and the greatest current under-drainage activity there is in the consolidated farms of the Paris Basin.

Having established that Nosenko and Zon's data are not greatly inaccurate in respect of the countries now examined in more detail, one may assume that their figures have general validity for the remaining countries. And one may venture some general comments on them.

It is generally desired to eliminate waterlogging at two main times of the year - the time of preparation of the fields (ploughing and sowing), and during critical parts of the growing period (which vary from crop to crop). In the truly Mediterranean lands waterlogging is not a common feature; short-lived floods following heavy downpour are another matter, and receive other palliatives than field under-drainage. It is therefore not surprising that only small percentages of agricultural land are drained in the Iberian peninsula, southern Italy, and the southern Balkans.

In Hungary the large percentage given by Nosenko and Zon is primarily surface drainage on the Danubian lowlands, where in recent years there has been considerable extension of channels which can be used alternately for irrigation and for drainage purposes. In Yugoslavia the relatively high percentage is doubtless mainly accounted for by the Danubian lowland area, adjoining Hungary. In northern Italy also the need will have been mainly to drain marshy land, subject to lateral water flow.

In areas with a summer maximum rainfall, field under-drainage will be most needed where soils are heavy, slopes are gentle, and evaporation rates relatively low. This would appear to be the case, for example, in Switzerland and Austria.

It would be unwise to comment, without further information, on the remaining countries in east central Europe, but with the North Sea countries in mind on the one hand and mountainous central Europe on the other, one can expect considerably regional variation according to soil type, topography, the seasonal evaporation/rainfall ratio, and the organisation of farm holdings.

Other types of land drainage

As pointed out at the beginning of this report, it is, except for certain specialised purposes, as much desirable to quantify the areas of land drainage by other methods as by agricultural under-drainage.

To complete the picture of artificial alterations of the drainage pattern, which have affected the flow of water downstream to the sea, and incidentally altered aquatic habitats, it will be necessary to quantify the following catena of artificial modifications:

(i) field under-drainage

(ii) minor surface channels

(a) for agricultural field drainage
(b) to drain hill land to improve rough grazing
(c) for forestry purposes
(d) for building and other purposes

(iii) improvement of natural stream channels, and construction of ditches to supplement them

(iv) major works on rivers and on sea-defences to accommodate satisfactorily water outflowing from the above.

Using the analogy of a road network, this catena concerns additions and modifications to the general system, but there are various important by-passes, exemplified by (a) construction of reservoirs, from which water is extracted for domestic, industrial and agricultural use, of which much returns to the system at a lower level, (b) urban and industrial drainage and sewage disposal, which modify in a generally similar way. A few examples only can here be given of the magnitude of the areas involved in other than field under-drainage:

In the case of Scotland, a notably wet country, there is much drainage of hill land by ditching. In recent years approximately equal amounts (about 25,000 ha) have been drained annually (a) to improve rough grazing, and (b) for afforestation (Green, 1974 and 1979b). In the case of Norway, statistical records of forestry drainage (kindly supplied by Dr K. Bjor of Norges Institutt for Skogsforskning, Ås) are available annually for the years since 1950. These show two peaks, of about 180,000 ha a year on each occasion, about 1932-34 and in 1959. In the 1970s it has been about 35,000 ha a year, compared with 6,000 ha of agricultural field drainage. One can only surmise that the ratio would be somewhat similar in Sweden, and less in the other countries under consideration. An interesting feature of Norwegian forestry drainage practice is that there has been an intensification from about 250 metres per hectare in the early 1950s to about 650 in the 1970s.

In the case of France some statistical data are available on surface drainage of the arterial type. In British parlance arterial drainage is divided into major works and minor works, the former being not specifically for agricultural purposes, while the latter are primarily so. Figure II.26 in effect shows the distribution of minor works in France up to 1966 (the proportion of under-drainage included being extremely small). For France there is also available a map (Figure II.27) showing the length of water-courses, 'non-domaniaux' which has been regulated up to 1966.

Recently, Marshall, Wade and Clare (1978), whose main interest was the length of surface drainage channels in land approximately at sea-level (mainly deltaic and estuarine areas), estimated the ares of such land in England and Wales, where drainage had been improved by artificial surface channels. They made it about 800,000 ha, to which should be added a relatively small area inland and above sea-level. In total it

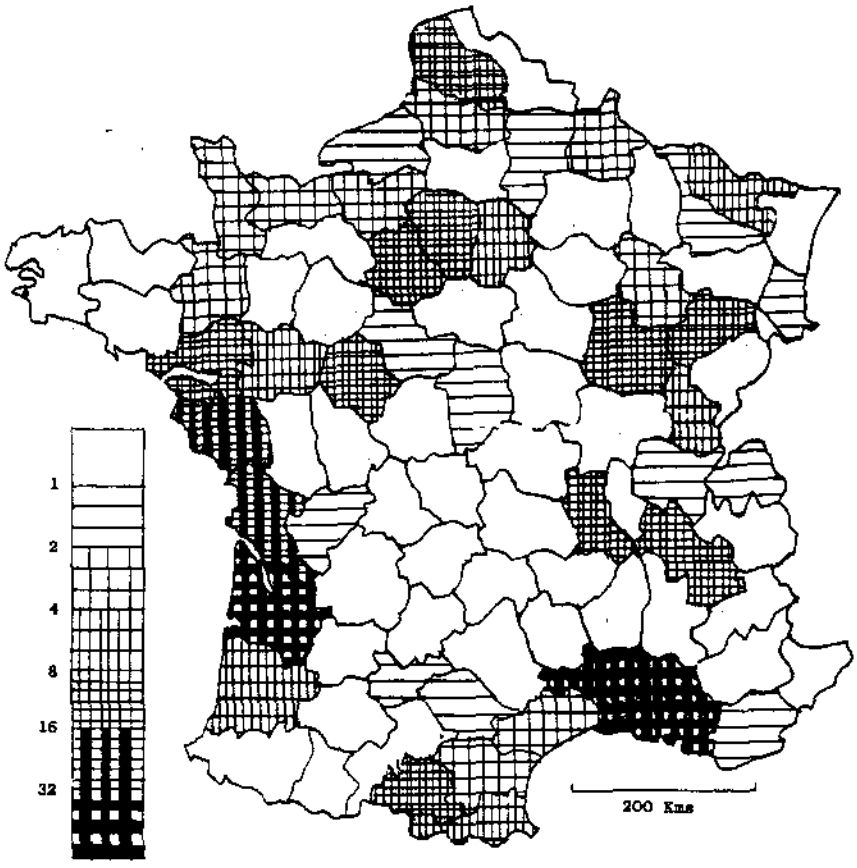

FIGURE II.26 France: Percentage of agricultural land area of each Department drained by all methods, by''ouvrages collectifs' to the end of 1966

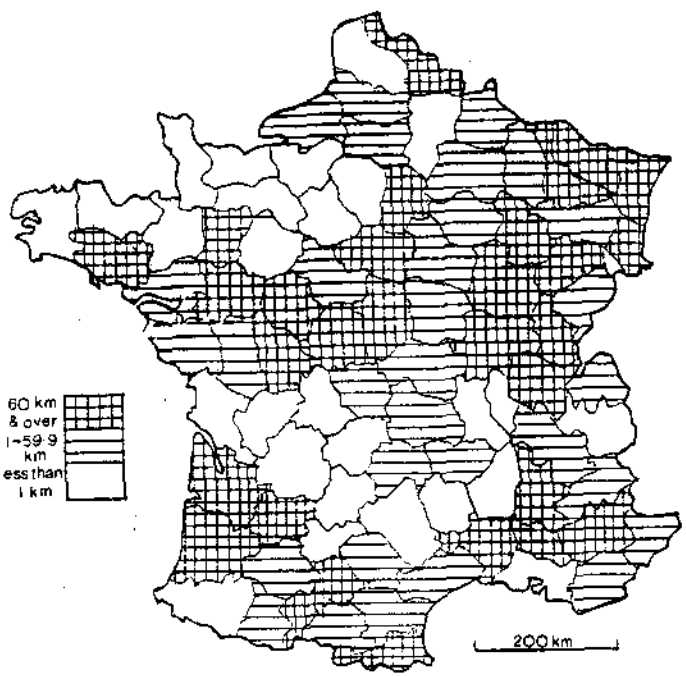

FIGURE II.27

France: Classification of Departments by lengths of watercourses 'non-domaniaux' regulated, to end of 1966

amounts to about a tenth of the area which has been under-drained in England and Wales, although in some land - notably the Fen District - surface drainage and under-drainage have both been undertaken.

Finally, reference may appropriately be made to some other forms of land treatment which affect water flow in one way or another. The first is application of lime, which not only counters acidity, but breaks down the soil and renders it more permeable. The two attached maps of Norway (Figures II.28A and B) show in particular that much land, not under-drained, is nevertheless well limed. Liming in Great Britain (cf. Green, 1976) is widespread, and comparison of Figure II.29 with Figure I.1 in Section I of this report, shows that, as in Norway, lack of under-drainage in certain areas is partly compensated for by liming; the same is true in Ireland.

A second is the grading of land and clearing it of scrub and boulders for agricultural use. There has, in the 1970s, been an upsurge of this in Norway, with the aid of heavy machinery (see Figure II.30). This clearly affects water flow, through major disturbance of the soil and its surface cover.

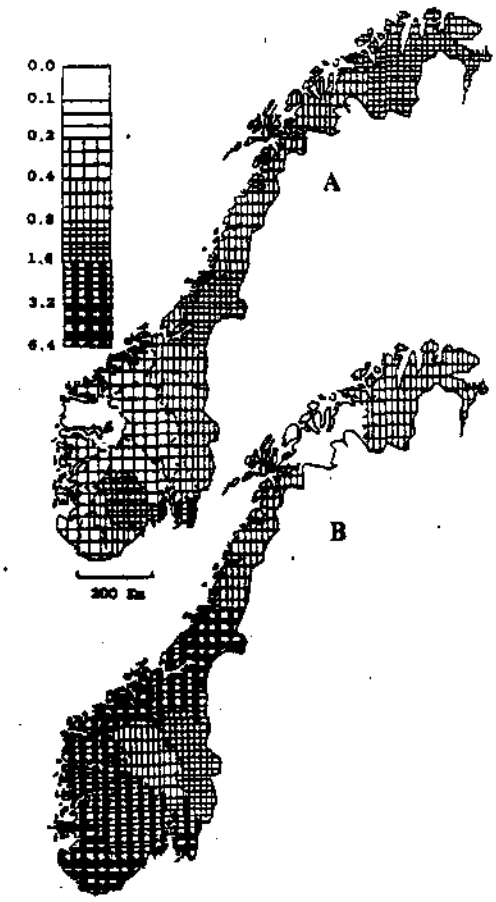

FIGURE II.28 Norway: Percentage of agricultural area (A) drained, (B) limed, in the year 1958

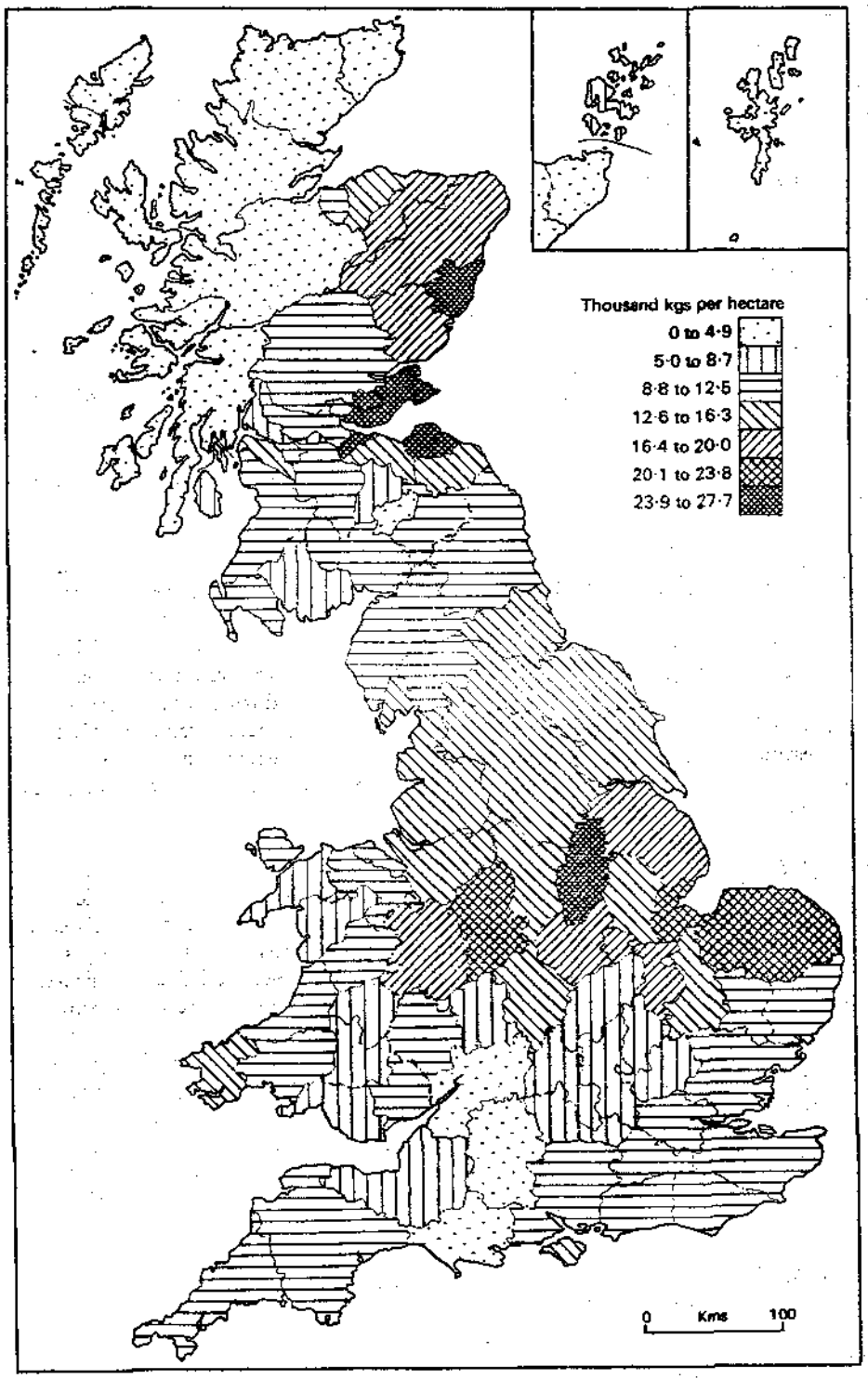

FIGURE II.29 Great Britain: Liming (Kgs of CaO equivalent) per hectare of crops, grass and rough pasture in the year 1973 (*Green, 1976*)

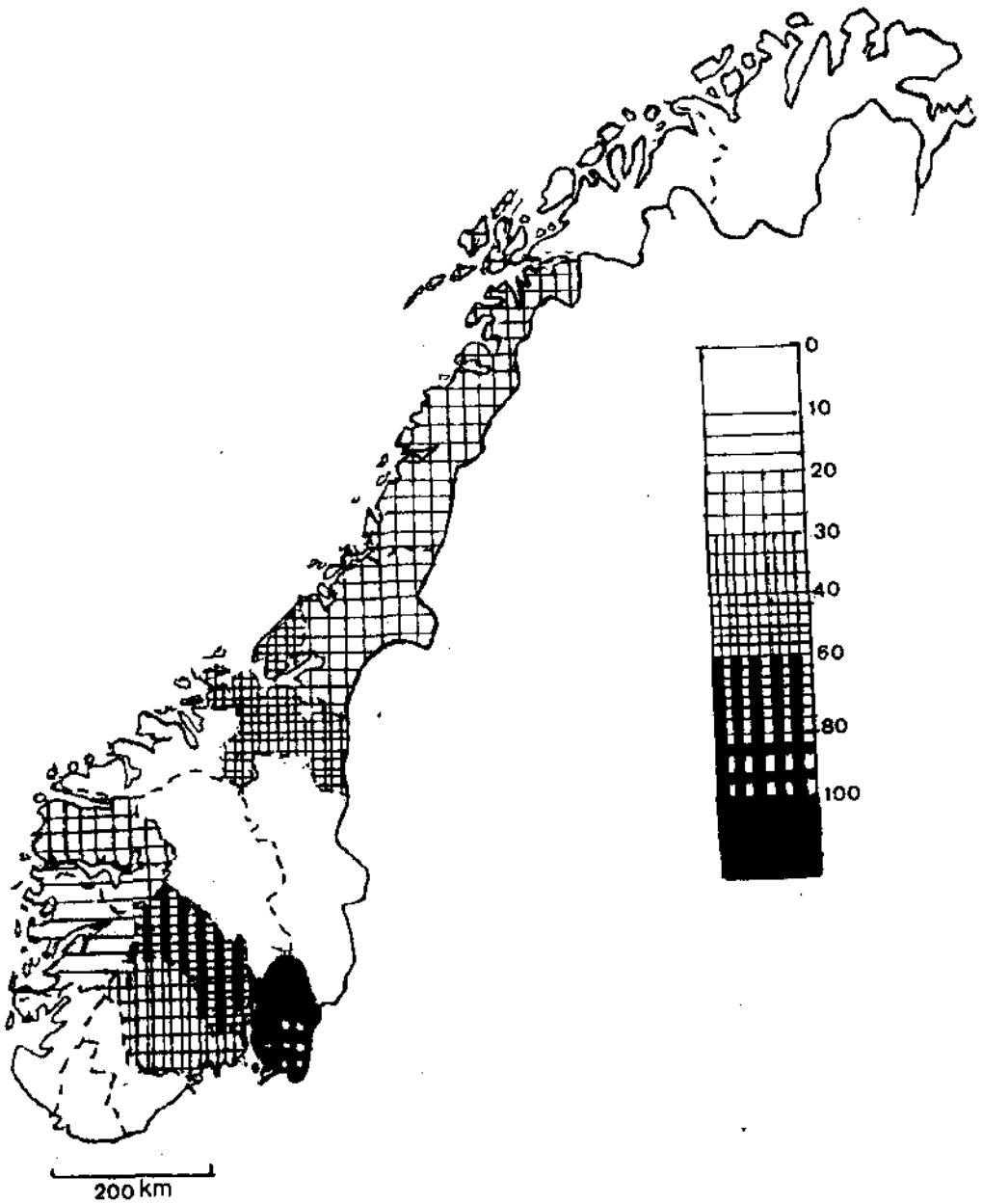

FIGURE II.30 Area graded as percentage of area drained, during the year 1975, in Norway

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SECTION III

LARGE SCALE MAPPING OF DRAINAGE DATA IN BRITAIN

Almost all the maps presented in Sections I and II of this report are by administrative areas or by agricultural regions. An alternative method is to employ computer mapping by grid squares, as is now done by the Field Drainage Experimental Unit (M.A.F.F.), and an example is reproduced as Figure III.1. This example incidentally shows where moling was carried out in a recent typical period. Response to rainfall of the run-off out of tile drains is more rapid when moling or other secondary treatment has been done.

The grid mapping can usefully be converted to a isopleth system, as in the example illustrated in Figure III.2 (Green, 1976). But for detailed correlation of areas under-drained with such things as soil series, slope, land utilisation, or farm units, smaller land divisions need to be used.

The current data in England and Wales is coded, by parishes as well as by grid references and, for years and areas for which print-outs have been made, it is possible to construct maps such as illustrated in Figure III.3 and III4-9. Finally, it is possible, although extremely laborious, to map individual fields, by reference to manuscript six-inch (or 1/10,000) maps maintained in most Divisional offices of A.D.A.S. (Agricultural Development and Advisory Service). These are subject to confidentiality constraints, and so the example shown in Figure III.4 must not be identified here more closely than being of the catchment area of a stream in Cambridgeshire (Huntingdon District), with soils developed mainly on Boulder Clay.

The smaller scale mapping referred to above (Figures III.1 and 2) enables certain correlations to be seen which are not apparent on maps by administrative areas. For instance, the considerable amount of recent under-drainage following the line of the Oxford Clay outcrop from Peterborough to near Swindon is clear from Figure III.2. Using parish data (Figures III.3 and III.4-9), the correlation with physical conditions is even clearer. Figure III.3, using parish data, shows in more detail the correlation with geological outcrops including, in the north, the western end of the Oxford Clay formation.

A print-out by parishes, specially provided by the F.D.E.U. for the six years 1971/72 to 1976/77 for Cardiganshire, Montgomeryshire, and Radnorshire, enabled data to be plotted, as in Figures III.4 to 9. From the county data, based on grants awarded, it had become clear that mid-Wales was an area of exceptional increase in under-drainage activity in the seventies, 1972/73 subsequently proving to have been the peak year. Land under-drainage during the recent six years is shown, in Figure III.5, as a percentage of the total land area in the

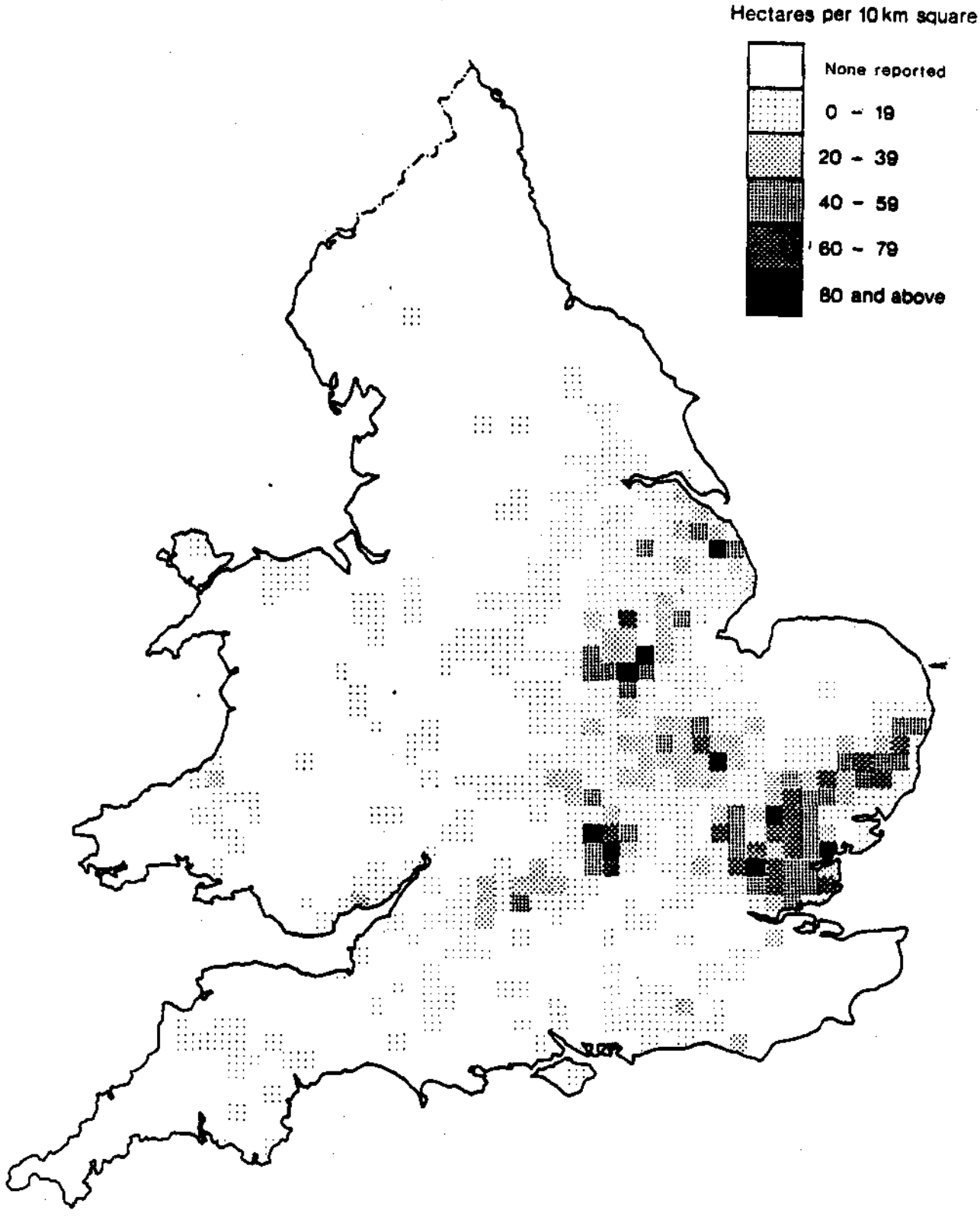

FIGURE III.1 **Secondary treatment, England & Wales: Hectares per 10 km^2 moled or subsoiled, 1/4/73 - 31/3/76** *(map prepared by the Field Drainage Experimental Unit, MAFF)*

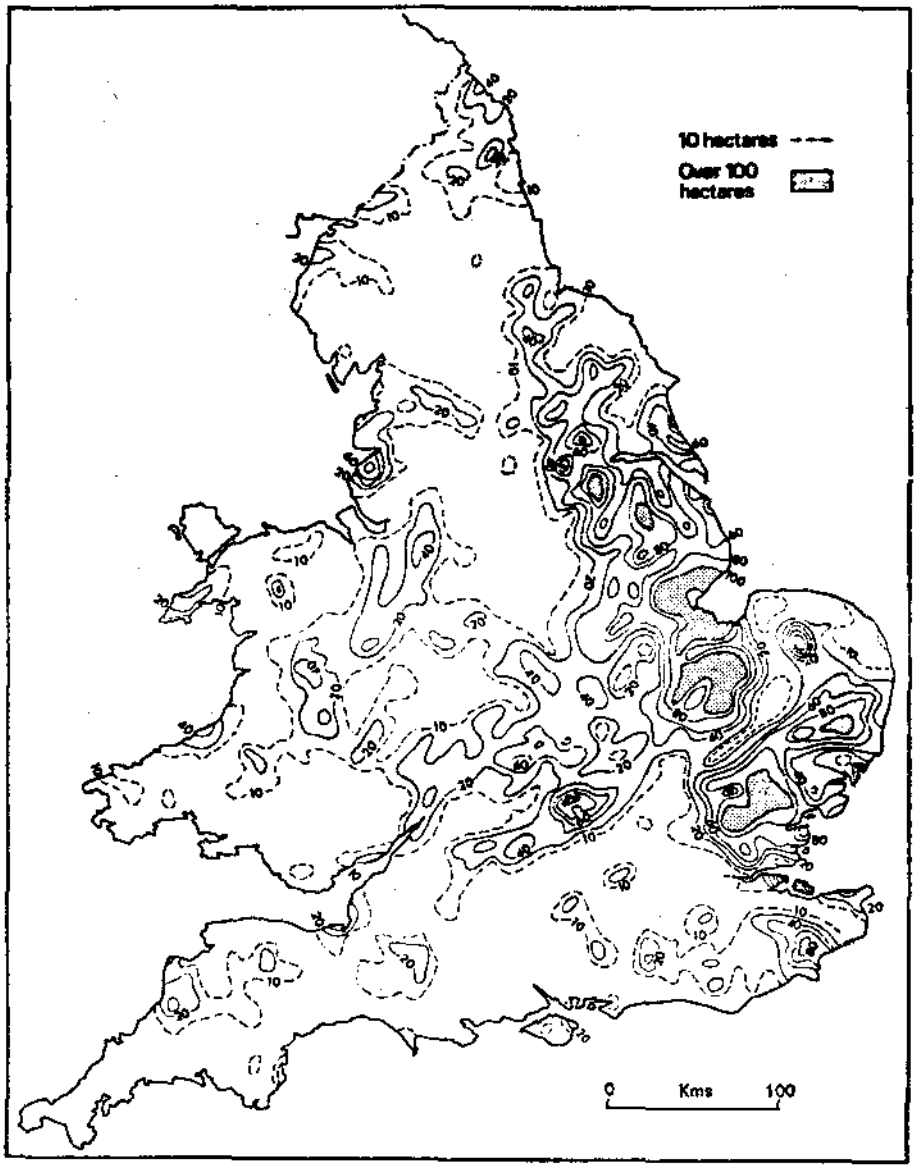

FIGURE III.2 Area under-drained, in ha per 100 km^2, 1/4/71-31/3/74; isopleths at 20 ha intervals, with addition of 10 ha isopleth *(from Green, 1976)*

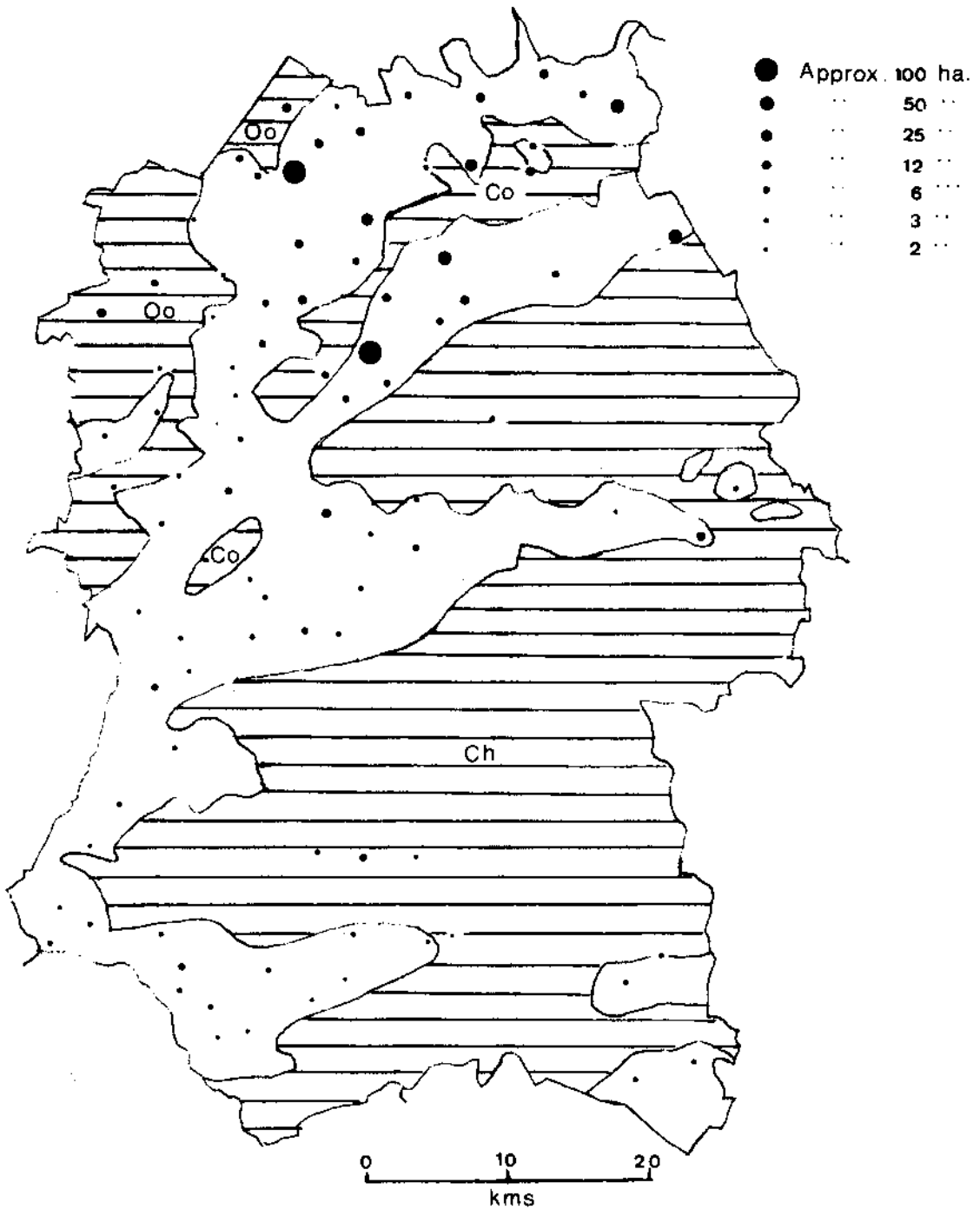

FIGURE III.3 Wiltshire, England: Hectares under-drained, 1/4/71-31/3/74, by parishes. (Symbols placed approximately in centres of parishes.)

Oo = Oolite, Co = Corallian, Ch = Chalk, unshaded areas are largely clays

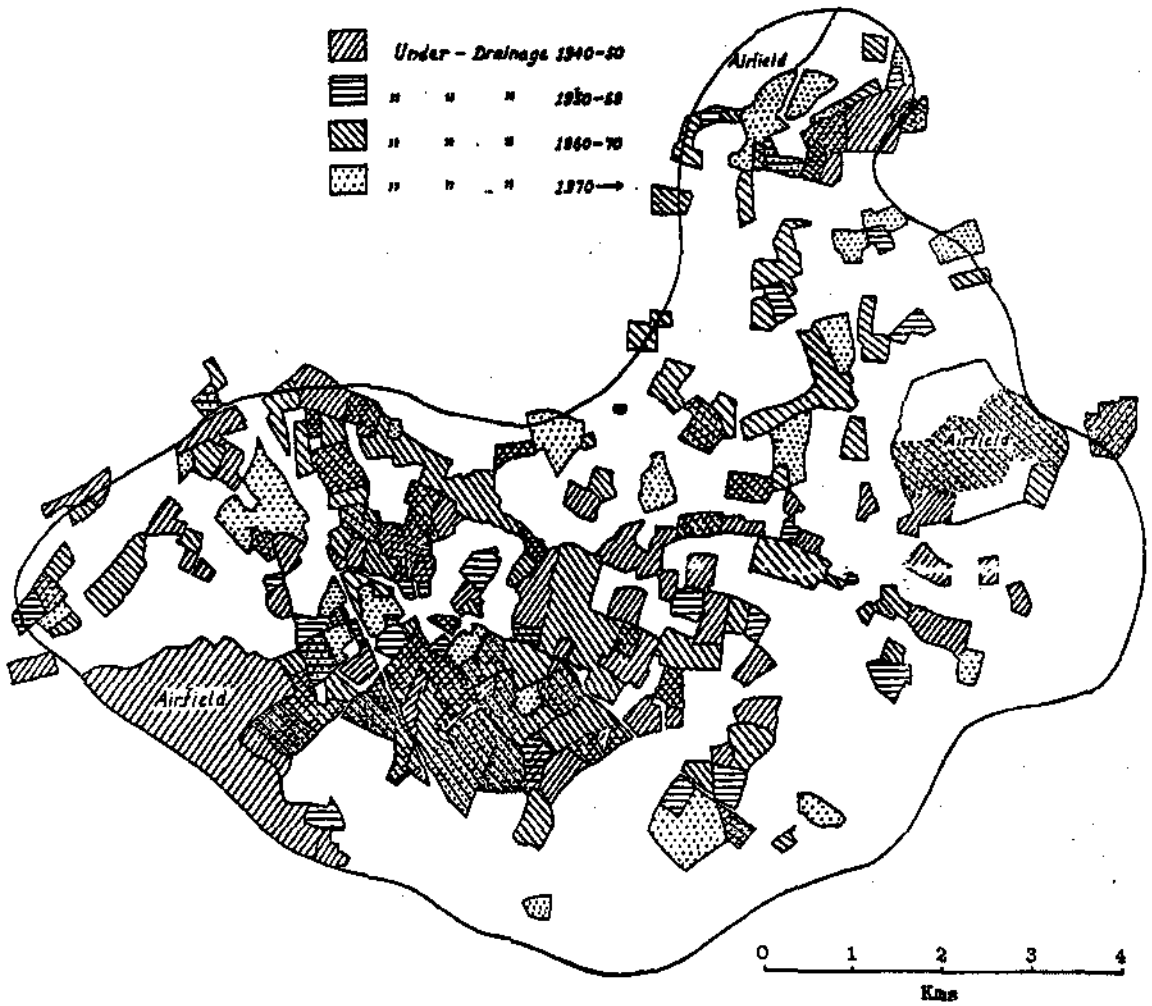

FIGURE III.4 Under-drainage, 1940-1974, in a small catchment area in Cambridgeshire (Huntingdon district), by individual fields

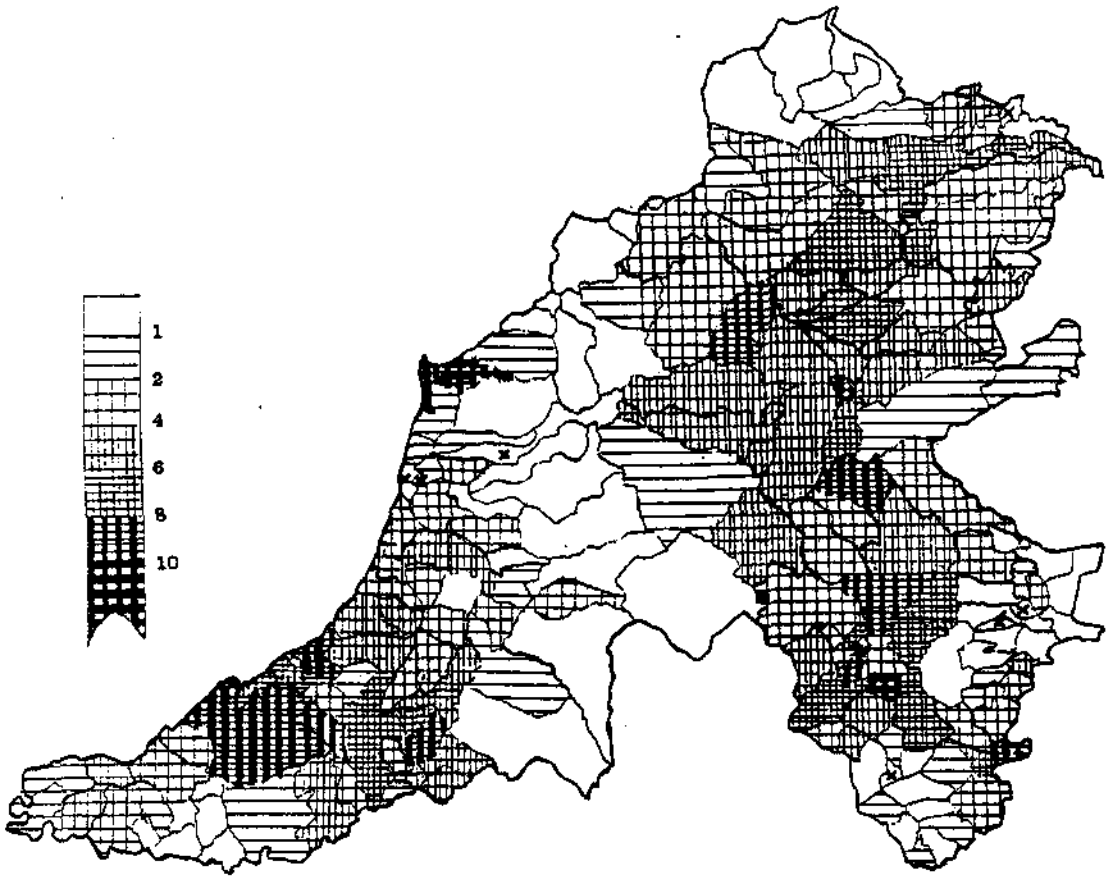

FIGURE III.5 This, and the following four figures, are for the three Welsh counties of Cardiganshire, Montgomeryshire and Radnorshire. This Figure shows land under-drained during the six years 1971/72-1976/77 as percentage of total parish area.
(X indicates no applications for drainage grant.)

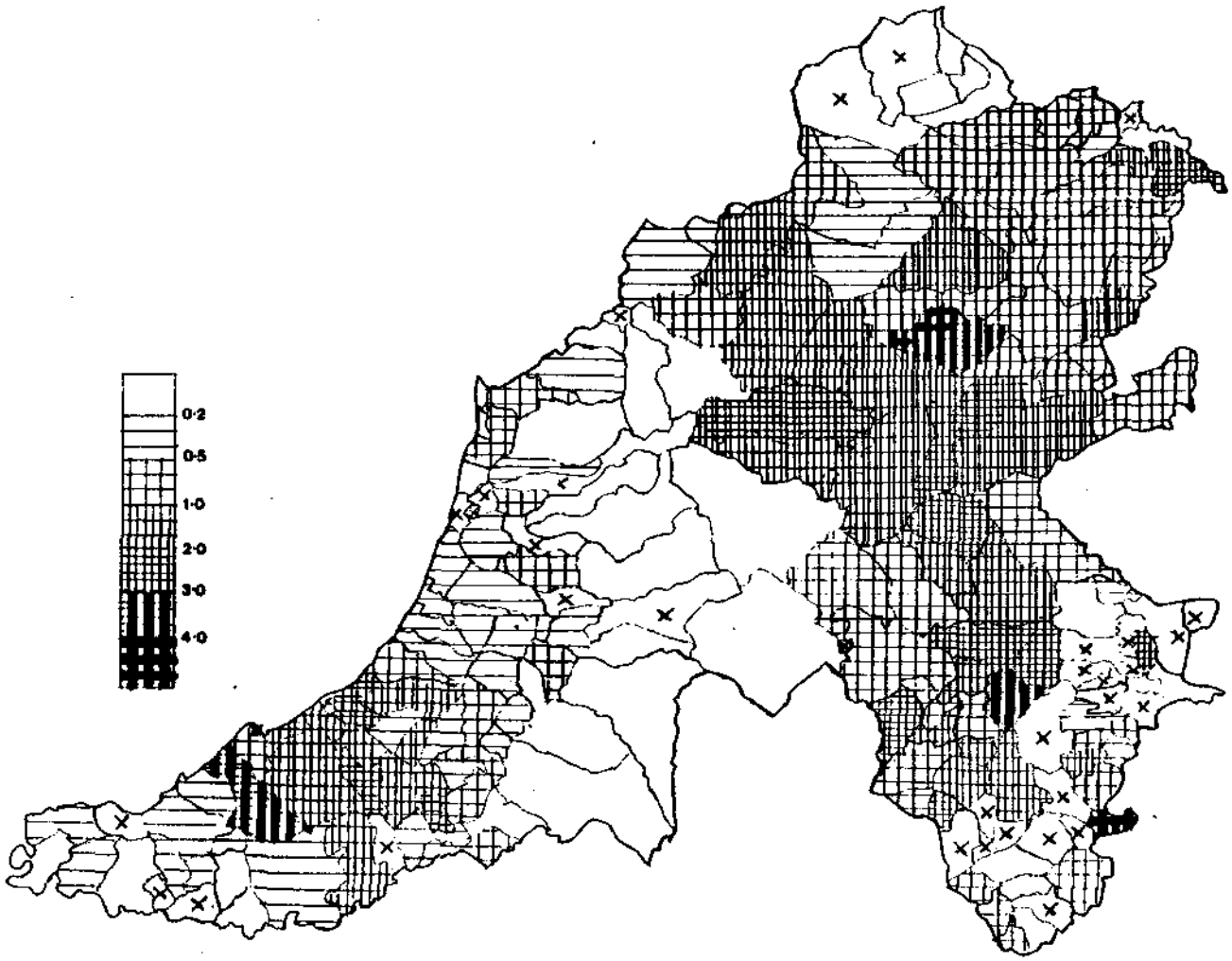

FIGURE III.6 Percentage of total land area under-drained, in each parish, in the peak year 1972/73. (X indicates no under-drainage in this year.)

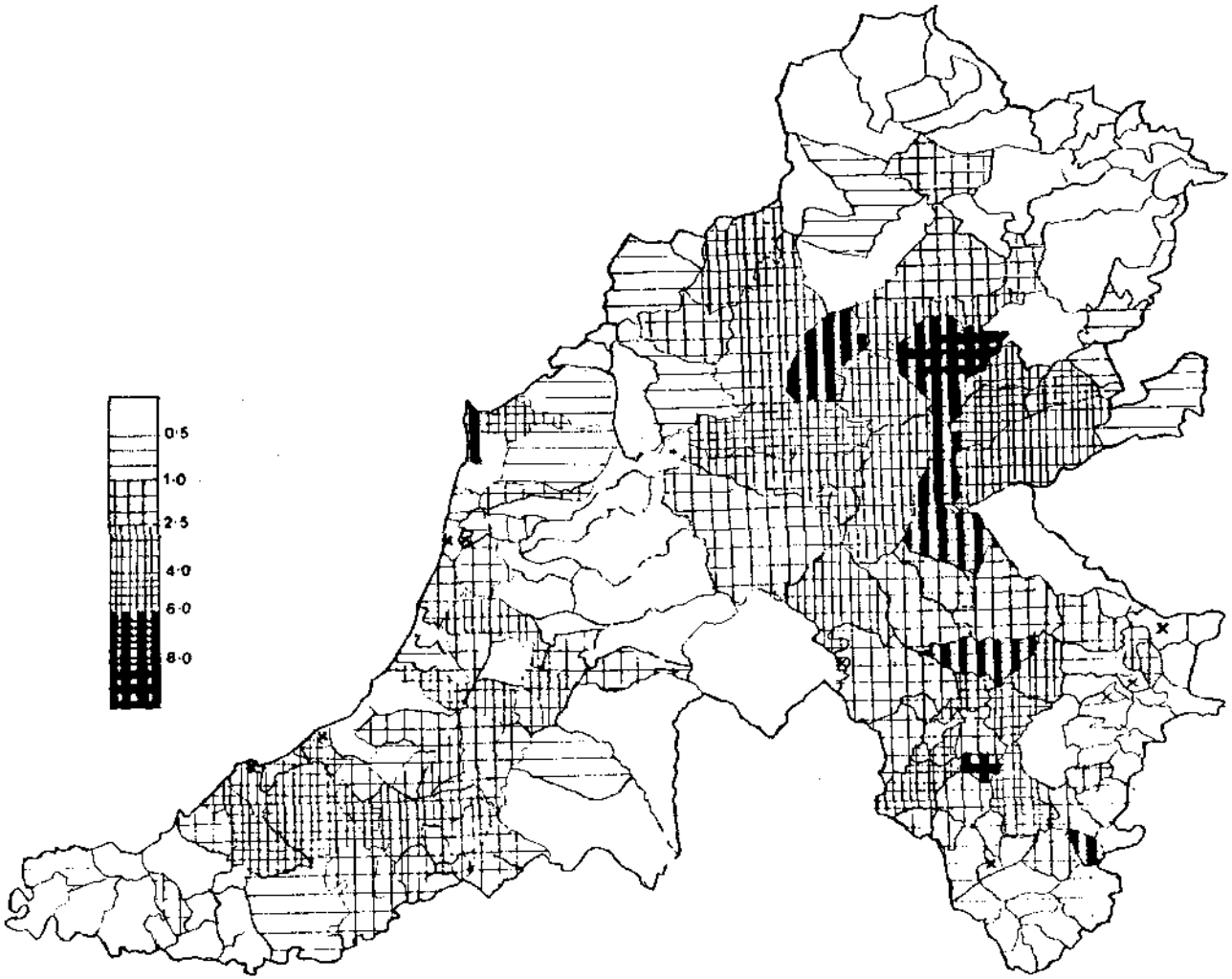

FIGURE III.7 Rough grazing land under-drained, as percentage of total land area of parish, six years 1971/72-1976/77. (X indicates no under-drainage in this period.)

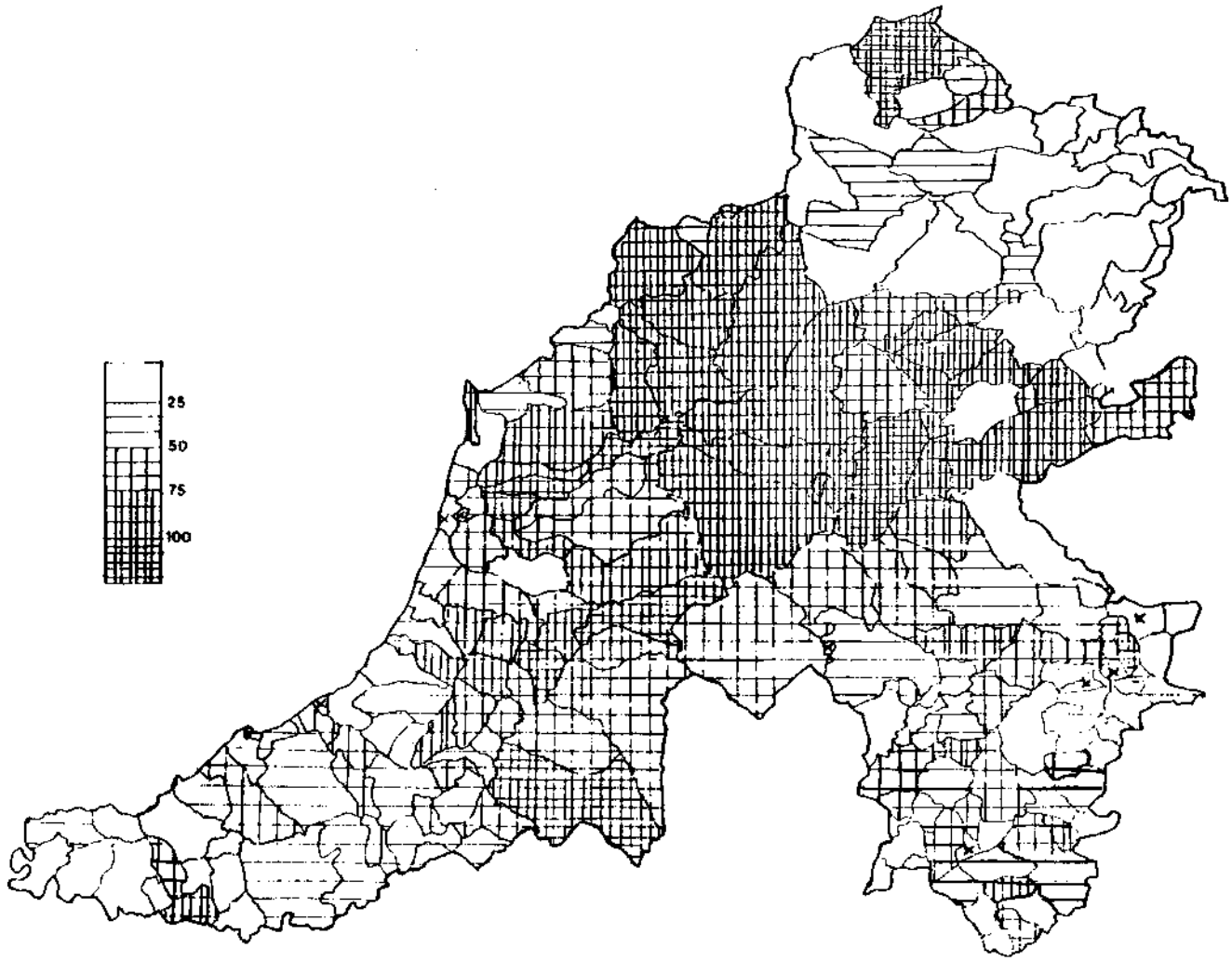

FIGURE III.8 Percentage of land area under-drained, during six year 1971/72-1976/77, which was classified as rough grazing. (X indicates no under-drainage in this period.)

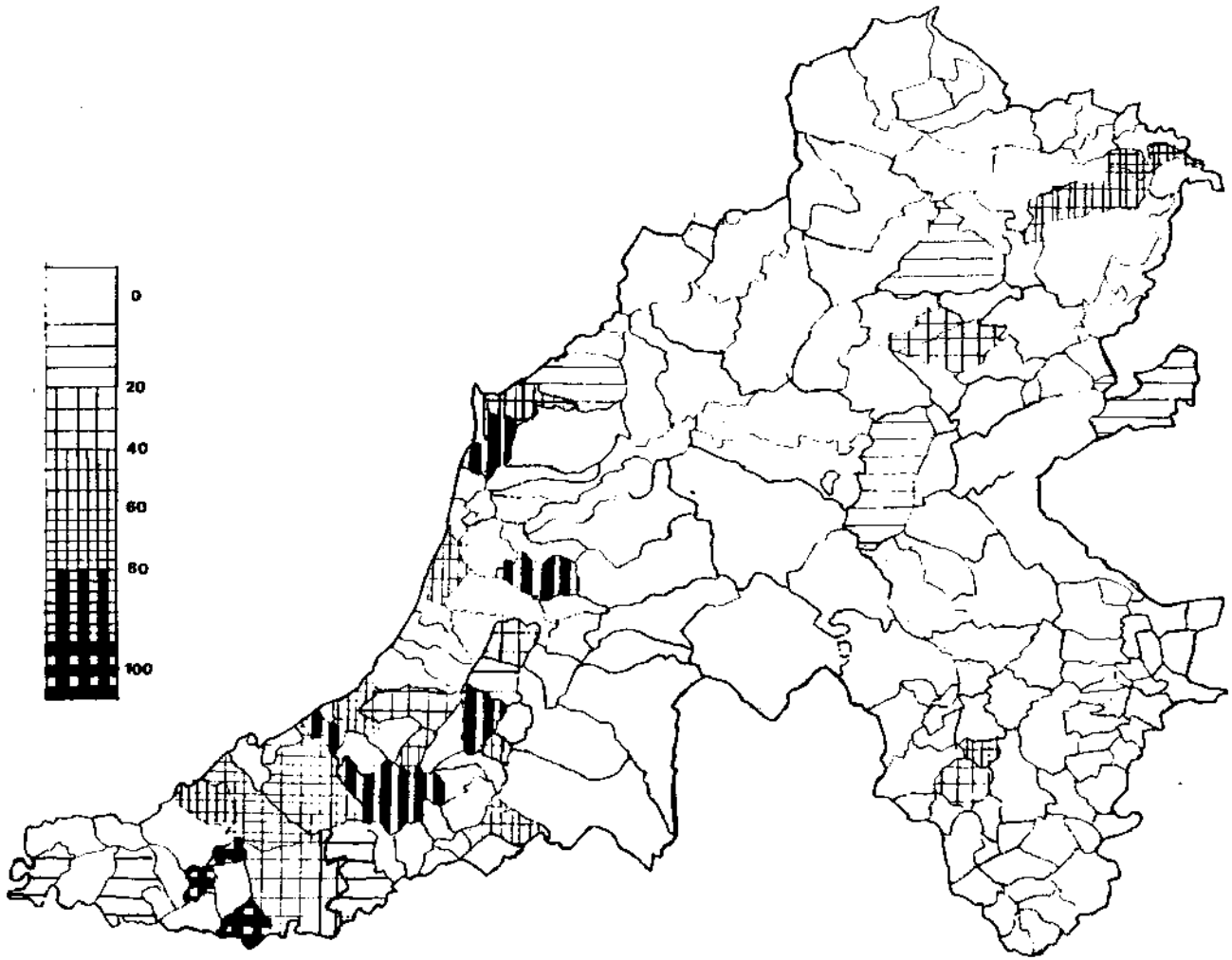

FIGURE III.9 Percentage of the land under-drained in the year 1972/73 which received secondary treatment. (This was all sub-soiling, except in four parishes in south Cardiganshire where there was some moling.)

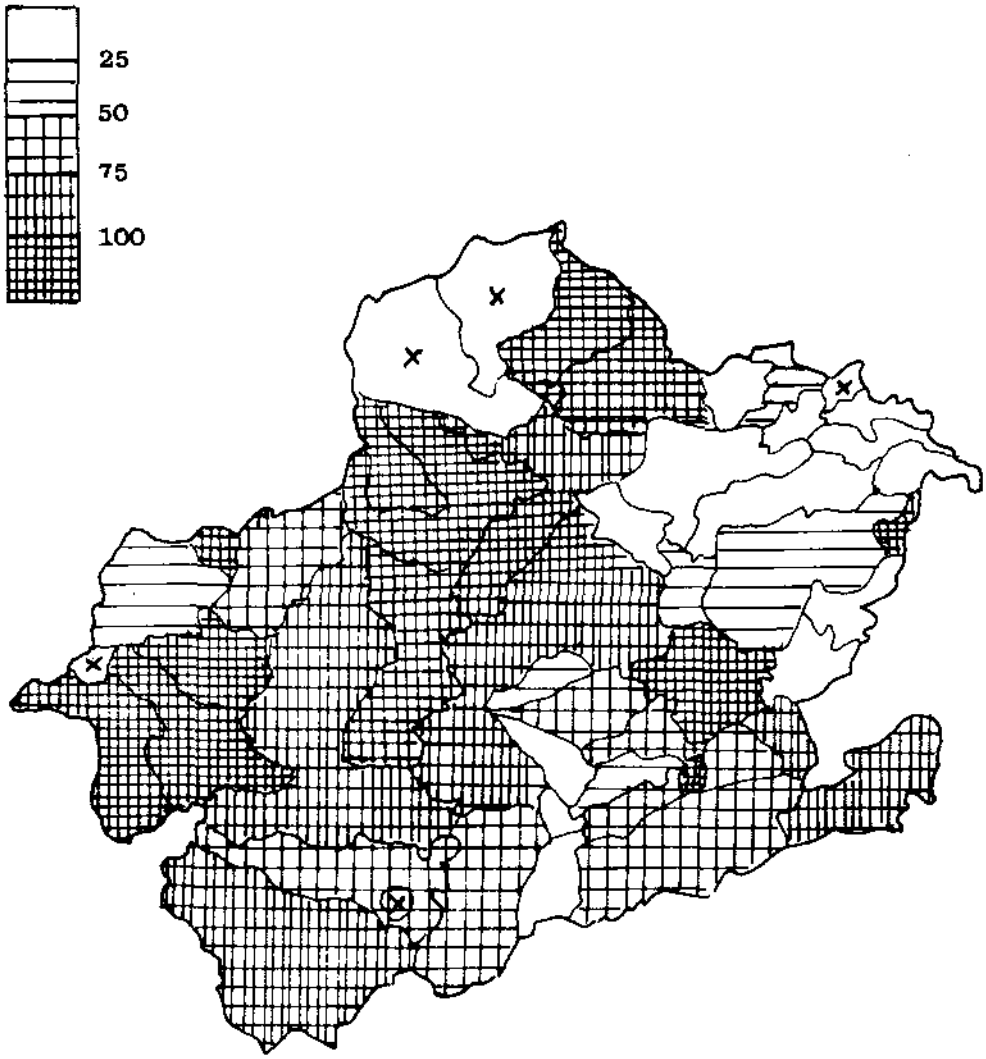

FIGURE III.10 Montgomeryshire: Percentage of applications for under-drainage grants in the year 1972/73, in which pre-1939 drains were reported - as either wholly or partly non-functioning

APPENDIX A

STATISTICAL TABLES

ENGLAND AND WALES. Land under-drained, 1949 to 1976. (From statistics supplied by the Ministry of Agriculture, Fisheries and Food).

M.A.F.F. DIVISIONAL AREA	HECTARES	PERCENTAGE OF AREA UNDER CROPS AND GRASS
Carlisle (Cumberland & Westmorland)	20,100	7.1
Durham (Co. Durham)	11,000	7.6
Alnwick (Northumberland)	23,000	9.6
Northallerton (Yorkshire, North Riding)	40,800	12.9
Preston (Lancashire)	28,600	11.7
Beverley (Yorkshire, East Riding)	56,800	21.9
Harrogate (Yorkshire, West Riding)	42,300	11.1
Nottingham (Derbyshire and Nottinghamshire)	28,600	8.9
Northampton (Leicestershire, Northamptonshire & Rutland)	69,000	17.2
Lincoln (Lincolnshire, Parts of Lindsey and Kesteven)	79,300	36.1
Crewe (Staffordshire and Cheshire)	36,500	9.5
Shrewsbury (Shropshire)	34,000	12.0
Worcester (Worcestershire, Herefordshire and Warwickshire)	56,100	11.2
Huntingdon & March (Soke of Peterborough, Huntingdonshire, Bedfordshire, Isle of Ely, Cambridgeshire & Lincolnshire (Parts of Holland))	135,800	28.4
Chelmsford (Hertfordshire and Essex)	186,400	48.9
Norwich (Norfolk)	59,700	14.8
Bury St. Edmunds (Suffolk, East and West)	109.400	37.0
Maidstone (Kent)	42,000	16.7

M.A.F.F. DIVISIONAL AREA	HECTARES	PERCENTAGE OF AREA UNDER CROPS AND GRASS
Winchester (Hampshire & the Isle of Wight)	10,600	4.3
Oxford (Berkshire, Buckinghamshire, Oxfordshire	61,100	14.9
Guildford (Surrey, East Sussex, West Sussex)	27,200	9.0
Truro (Cornwall)	7,200	2.8
Exeter (Devon)	25,600	5.4
Taunton (Somerset & Dorset)	28,100	5.6
Gloucester (Gloucestershire, Wiltshire)	27,100	5.5
Cardiff (Glamorgan and Monmouthshire)	6,600	4.1
Carmarthen and Lampeter (Cardiganshire, Pembroke and Carmarthenshire)	19,300	5.3
Llandrindod Wells (Brecknock-shire, Montgomeryshire and Radnorshire)	23,100	9.6
Ruthin (Denbighshire and Flintshire)	6,700	4.6
Caernarvon (Anglessey, Caernarvonshire and Merioneth)	6,800	4.7
ENGLAND AND WALES	1,429,300	18.0

NOTE: Changes of boundaries of the M.A.F.E Divisional areas have inevitably led to slight inaccuracies in the totals for the period, particularly in the cases of the Huntingdon and March Divisions, which have had to be combined in the Table. The boundaries shown on the maps are those which existed from 1964 to 1973. Adjustments have been made for earlier boundary changes, but those which followed from the 1973 alterations have been ignored. Because of the inaccuracies due to these causes, the areas have been rounded off to the nearest hundred hectares.

SCOTLAND. Land under-drained, 1949 to 1976. (From statistics supplied by the Department of Agriculture and Fisheries for Scotland).

COUNTY	HECTARES	PERCENTAGE OF AREA UNDER CROPS AND GRASS
Aberdeen	38,905	15.4
Angus	12,869	13.3
Argyll	10,754	29.6
Ayr	9,239	8.2
Banff	14,887	23.4
Berwick	7,587	10.4
Bute	1,153	11.8
Caithness	9,285	26.4
Clackmannan	1,436	26.6
Dumfries	13,149	14.5
Dunbarton	2,100	15.6
East Lothian	3,977	9.5
Fife	3,045	9.9
Inverness	7,542	15.7
Kincardine	6,524	13.6
Kinross	1,736	13.5
Kirkcudbright	6,887	10.9
Lanark	12,163	14.5
Midlothian	3,630	9.2
Moray	7,449	20.2
Nairn	2,657	26.6
Orkney	3,675	8.1
Peebles	4,307	25.1
Perth	28,639	22.9
Renfrew	2,658	11.0
Ross and Cromarty	1,529	28.6
Roxburgh	6,366	9.4
Selkirk	1,338	12.9
Stirling	7,321	18.8
Sutherland	1,317	11.6
West Lothian	2,108	10.8
Wigtown	4,876	8.5
Zetland	351	4.6
TOTAL	255,067	14.6

REPUBLIC OF IRELAND. Land drained and reclaimed under the Land Project Scheme, 1949 to 1976. As explained in the text, this is largely under-drainage. (From *Farm Bulletin*, Feb. 1977: Department of Agriculture and Fisheries, Dublin].

COUNTY	HECTARES	PERCENTAGE OF AREA UNDER CROPS AND GRASS
Carlow	24,004	31
Cavan	36,240	22
Clare	32,288	14
Cork	95,533	17
Donegal	25,198	14
Dublin	11,474	17
Galway	60,827	18
Kerry	51,538	24
Kildare	47,285	32
Kilkenny	40,098	22
Laois	59,000	35
Leitrim	10,821	9
Limerick	53,053	22
Longford	13,746	15
Louth	12,117	17
Mayo	42,318	17
Meath	54,887	25
Monaghan	26,029	25
Offaly	43,222	29
Roscommon	27,664	14
Sligo	13,208	11
Tipperary	10,186	26
Waterford	33,763	26
Westmeath	44,765	29
Wexford	65,365	32
Wicklow	31,117	29
Total	1,034,114	22

NORTHERN IRELAND. Land under-drained, 1949 to 1976. (From statistics supplied by the Department of Agriculture, Belfast].

Antrim	26,260	16
Armagh	13.911	15
Down	14,725	9
Fermanagh	12,983	13
Londonderry	31,201	18
Tyrone	33,113	18
Total	122,259	15

NORWAY. Field drainage - area in hectares, 1939 to 1975.
(Grøfting av tidligare dyrke jord)

FYLKE	AREA	PERCENTAGE OF AGRICULTURAL LAND
Østfold	38,541	51.4
Akershus	23,448	28.8
Hedmark	23,672	24.0
Oppland	10,719	11.8
Buskerud	9,227	18.4
Vestfold	21,740	49.6
Telemark	7,792	27.2
Aust Agder	4,182	33.7
Vest Agder	2,536	12.9
Rogaland	6,850	9.8
Hordaland	2,580	4.8
Sogn and Fjordane	1,192	2.5
More and Romsdal	5,761	9.5
Sør-Trondelag	10,535	15.0
Nord-Trondelag	19,403	25.9
Nordland	9,513	15.2
Troms	2,749	7.9
Finnmark	1,207	11.0
NORWAY	271,047	27.0

SWEDEN. Extent of under-drainage to 1973, hectares. (From Year-book of Agricultural Statistics, 1977).

LÄN	AREA	PERCENTAGE OF AGRICULTURAL LAND
Stockholms	30,433	30.2
Uppsala	55,241	34.4
Södermanlands	49,324	34.2
Östergötlands	109,954	52.7
Jönköpings	10,891	9.9
Kronobergs	8,029	11.6
Kalmar	28,945	19.4
Gotlands	27,812	33.3
Blekinge	14,102	33.6
Kristianstads	64,092	45.4
Malmöhus	138,341	45.4
Hallands	49,420	40.0
Göteborgs and Bohus	26,130	37.9
Älvesborgs	56,217	27.7
Skaraborgs	135,769	49.9
Värmlands	34,689	27.4
Örebro	39,500	33.2
Västmanlands	73,638	61.3
Kopparbergs	8,552	12.7
Gävleborgs	14,705	18.3
Västernorrlands	9,117	13.9
Jämtlands	8,231	17.5
Västerbottens	17,734	19.0
Norrbottens	7,649	15.2
SWEDEN	1,018,515	34.3

DENMARK. Data extracted from National Farmers' Union sample survey.

No.	County	Total agricultural area 1000 ha	Number of farmers interviewed	Percentage of agricultural area	Percentage of drainage				
					before 1920	1921-1932	1933-1950	1951-1972	Total
1	North Jutland north)		69	1.2	2	9	15	10	36
2	- - south)	425	79	1.1	2	3	10	9	24
3	Viborg	278	97	0.9	8	7	14	10	39
4	Ringkøbing	326	114	1.0	3	3	17	11	34
5	Ribe	213	58	0.9	4	5	13	9	31
6	Aarhus	301	113	1.0	8	7	18	12	45
7	Vejle	206	91	1.1	9	12	17	9	47
8	North Schleswig	293	75	1.1	6	6	32	18	62
9	Funen	248	67	0.7	16	8	20	11	55
10	Sealand West	207	50	0.9	36	9	11	22	78
11	Sealand East	133	32	1.0	31	8	15	11	65
12	Storstrøm	248	74	0.9	34	8	28	11	81
13	Bornholm	37	20	1.9	26	6	17	9	58
		2.915	939	1.0	12	7	18	12	49

FINLAND. Area (has) drained by sub-soil pipes to 1977, by Agricultural Society areas (boundaries shown on Figure II.13).

FINLAND

No.	Agricultural Society district	Agricultural area ha	Under-drained area as % of agricultural land	
			1977	TOTAL
1	Varsinais-Suomen	246600	1.3	62.6
2	Finska Hushallnings	30946	0.7	42.8
3	Nylands Svenska	80866	0.8	50.3
4	Uudenmaan	139068	1.3	52.9
5	Hämeen Läänin	159681	1.6	55.8
6	Kymen Läänin	160316	1.1	29.5
7	Itä-Hämeen	71570	1.2	39.6
8	Pirkanmaan	116849	1.3	25.5
9	Satakunnan	188123	1.2	46.8
10	Mikkelin Läänin	107972	0.6	7.6
11	Pohj-Karjalan	122753	0.8	6.9
12	Kuopion Läänin	162344	1.4	11.5
13	Keski-Suomen	112177	1.1	16.3
14	Etelä-Pohjanmaan	276650	1.6	25.2
15	Österbottens-Svenska	115519	0.6	20.7
16	Oulun	278886	0.9	8.2
17	Kainuun	54354	0.5	2.0
18	Lapin Läänin	76539	0.4	3.2
	Total	2501015	1.1	29.5

AUSTRIA. Area drained in period 1945-1960

	hectare
Burgenland	3117
Kärnten	3668
Niederösterreich	24916
Oberösterreich	11831
Salzburg	3665
Steiermark	8362
Vorarlberg	2404
Wien	230
TOTAL	60223

SWITZERLAND. Field drainage, hectares.

		1960	1,252
1885-1910	14.240	1961	580
1911-1920	13,217	1962	736
1921-1930	30.449	1963	657
1931-1940	16,768	1964	4,747
1940	528	1965	439
1941	1,230	1966	2,020
1942	1,896	1967	569
1943	3,840	1968	1,453
1944	5,112	1969	651
1945	5,701		
1946	7,511	1970	792
1947	6,754	1971	1,589
1948	8,861	1972	1,063
1949	8,586	1973	1,626
		1974	1,309
1950	4,049	1975	1,229
1951	2,723	1976	1,433
1952	2,317		
1953	2,827		
1954	1,778		
1955	1,837		
1956	2,704		
1957	725		
1958	1,280		
1959	1,113		

(From various volumes of *Statistisches Jahrbuch der Schweiz*).

FRANCE. Area under-drained, by Départements, 1974 and 1975, in hectares.

(From Enquête nationale sur les travaux de drainage réalisés en France, prepared by the Syndicat National Professionnel des Entrepreneurs de Travaux de Drainage.)

No.	Département	Under-drained in 1974	Under-drained in 1975
01	Ain	150	150
02	Aisne	151	421
03	Allier	213	1,852
04	Alpes (de Ht Provence)	-	-
05	Alpes (Hautes)	-	-
06	Alpes-Maritimes	-	-
07	Ardèche	-	27
08	Ardennes	120	124
09	Ariège	-	-
10	Aube	210	554
11	Aude	60	57
13	Bouches-du-Rhône	-	-
14	Calvados	362	458
15	Cantal	-	-
16	Charente	160	180
17	Charente-Maritime	474	282
18	Cher	1,695	2,087
19	Corrèze	-	-
20	Corse	-	-
21	Côte-d'Or	720	960
22	Côtes-du-Nord	-	-
23	Creuse	140	-
24	Dordogne	80	120
25	Doubs	-	-
26	Drome	-	20
27	Eure	285	294
28	Eure-et-Loir	2,196	2,661
29	Finistère	-	-
30	Gard	-	25
31	Garonne (Haute)	369	229
32	Gers	792	1,052
33	Gironde	155	558
34	Hérault	-	30
35	Ille-et-Vilaine	60	503
36	Indre	682	457
37	Indre-et-Loire	598	1,020
38	Isère	-	-
39	Jura	250	200
40	Landes	277	261
41	Loir-et-Cher	2,381	3,823
42	Loire	250	100
43	Loire (Haute)	-	-
44	Loire-Atlantique	95	80

three counties. Figure III.6 shows the peak year, 1972/73. All but a few small parishes had had some under-drainage during the period. In Montgomeryshire and Radnorshire the activity was more widespread than in Cardiganshire, where it was concentrated on the low coastal plateau in the south; the high intensity in two parishes in the north is exceptional, through Borth Bog having been extensively drained in the years 1973 to 1975. The least amount of under-drainage has in general been in the most elevated parishes in Cardiganshire.

Figures III.7 and 8 show that, especially in Montgomeryshire, a fairly high proportion of the land under-drained was land which was classified, prior to drainage, as Rough Pasture. An important feature of recent years has been the extension of secondary treatment into western counties. This extension is due firstly to realisation that the full benefit of pipe-drainage is not achieved unless secondary treatment is carried out, and secondly to a series of dry years which have facilitated moling or sub-soiling operations. Comparison of Figure III.9 with Figures III.7 and III.8 shows a high correlation between secondary treatment, and areas with a higher land use category (before drainage) than rough grazing.

Some information is provided on earlier under-drainage and from this the map in Figure III.10 was constructed. In the context of studying past drainage, it cannot be assumed that current grant applications represent a truly random sample, but maps such as this at least show that some hill land had been drained before World War II, and that non-functioning early drains were most frequently found in the hilly areas with much land that had reverted to rough pasture.

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No.	Département	Under-drained in 1974	Under-drained in 1975
45	Loiret	1,572	2,265
46	Lot	-	-
47	Lot-et-Garonne	6	325
48	Lozère	-	-
49	Maine-et-Loire	185	565
50	Manche	-	15
51	Marne	1,627	1,473
52	Marne (Haute)	32	92
53	Mayenne	-	-
54	Meurthe-et-Moselle	1,851	2,385
55	Meuse	361	401
56	Morbihan	-	20
57	Moselle	1,481	936
58	Nièvre	520	1,511
59	Nord	1,449	2,900
60	Oise	139	190
61	Orne	820	529
62	Pas-de-Calais	1,451	1,504
63	Puy-de-Dome	380	325
64	Pyrénées-Atlant.	1,350	1,278
65	Pyrénées (Hautes)	57	74
66	Pyrénées Orientales	-	-
67	Rhin (Bas)	-	34
68	Rhin (Haut)	-	-
69	Rhône	-	-
70	Saône (Haute)	-	120
71	Saône-et-Loire	450	645
72	Sarthe	85	209
73	Savoie	-	-
74	Savoie (Haute)	-	-
75	Paris	-	-
76	Seine-Maritime	-	-
77	Seine-et-Marne	1,737	1,587
78	Yvelines	257	302*
79	Sèvres (Deux)	5	50
80	Somme	200	100
81	Tarn	300	-
82	Tarn-et-Garonne	9	342
83	Var	-	-
84	Vaucluse	-	20
85	Vendée	130	500
86	Vienne	299	825
87	Vienne (Haute)	434	55
88	Vosges	-	-
89	Yonne	595	1,861
90	Belfort (territoire de)	included with 78, Yvelines	
91	Essonne		
92	Hauts-de-Seine		
93	Seine-Saint-Denis		
94	Val-de-Marne		
		30,719	42,183
	Not classified by Departments	3,096	2,114
		32,815	44,297

* Including Nos. 91 to 94.

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