THE PLANT ECOLOGY OF RE-VEGETATED PEAT CUTTINGS IN OMBROTROPHIC MIRES, WITH SPECIAL REFERENCE TO THORNE MOORS, S. YORKSHIRE

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SUMMARY

1. The plant ecology of re-vegetated peat cuttings in ombrotrophic mires was investigated to elucidate factors having a major influence on the vegetation, with the aim of formulating management guidelines for the rehabilitation of such areas for nature conservation.

2. Most of the investigations were carried out at Thorne Moors, a cut-over derelict raised bog near Doncaster, S. Yorkshire.

3. The vegetation of the wide range of abandoned peat cuttings present at this site is described. Particular attention was paid to re-vegetated peat cuttings within an area comprising a series of cuttings, baulks and canals abandoned about 1920, now a proposed National Nature Reserve. Successional, hydrological and chemical factors and processes important in determining the distribution of vegetation were investigated.

4. Stratigraphical investigations show that some species which recolonized the abandoned peat cuttings (e.g. *Sphagnum imbricatum* and *S. magellanicum*) have disappeared from the site since 1920. They have been replaced by species which were not major components of the undisturbed mire (e.g. *Sphagnum recurvum* and *S. fimbriatum*).

5. The distribution of the vegetation in peat cuttings principally reflects the height of the water table. Hydrological studies have also shown that the methods used to maintain the water table in the proposed National Nature Reserve (dams in ditches and drains and peat baulks), a virtually isolated peatland block, are effective. The peat of the baulks appears to have an extremely low hydraulic conductivity which may be a result of drainage.

6. The chemical characteristics of the peat waters suggest weakly minerotrophic rather than ombrotrophic conditions. This is attributed to various sources of nutrient enrichment as well as to the effects of peat drainage. The vegetation reflects this enrichment.

7. The concentration of bisulphite in the rainwater may explain the disappearance of *Sphagnum imbricatum* and *S. magellanicum* from Thorne Moors, the current low diversity of *Sphagnum* species and the dominance of *S. recurvum* at the site. However, there is no evidence that the growth of *Sphagnum* species introduced onto Thorne Moors was substantially affected by bisulphite in the rain.

8. The abundance of *Sphagnum recurvum* is consistent with the chemical composition of the peat waters in cuttings and with its wide tolerance as regards the height of the water table.

9. Many cuttings are dominated by *Eriophorum vaginatum*. This species, which can withstand a wide range of water table conditions, probably became established when the water table was somewhat lower than at present.

10. The dominance of *Juncus effusus* in some cuttings may be associated with water flow and is sustained by flooding with nutrient-rich water and nutrients provided by Black-headed gulls. *Juncus effusus* became established when the water table was relatively low.

11. *Betula pubescens* achieved its present dominance when the water table was somewhat lower than at present. This species is now becoming moribund and is dying in flooded peat cuttings.

12. The composition of the vegetation relates to the time which has elapsed since the peat cuttings were abandoned.

13. On the basis of the present findings and also of observations on other derelict sites, guidelines for the management of cut-over peatlands are presented. The importance of maintaining a *constant* water table somewhat above the cut-over surface is emphasized. Attention is also drawn to the importance of water quality and a source of colonizing species as well as to the need to create conditions suitable for the colonization of *Sphagnum* spp.

14. Guidelines for the management of Thorne Moors are formulated.

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Species nomenclature follows Clapham, Tutin & Warburg (1981) for vascular plants, Smith (1978) for mosses and Paton (1965) for liverworts.

CHAPTER 1

INTRODUCTION

1.1 THE NATURE OF THE INVESTIGATION

Ombrotrophic mires (i.e. mires irrigated directly and exclusively by rainwater) support various and specialized plant communities. These have drastically declined over the last 200 years as a result of agricultural reclamation, afforestation and commercial peat extraction (Tansley 1939; Godwin 1981; Goode 1981). Lowland raised bogs, particularly, have been destroyed or severely modified by peat cutting (Ratcliffe 1977; Goode 1981). However, although many of the cut-over peatlands which remain have lost their former importance as intact raised mires, many support a wide variety of semi-natural habitats, and may provide the potential, through appropriate management, for rehabilitation of communities of ombrotrophic mires. Indeed some cut-over sites, including Shapwick Heath in Somerset, Moorthwaite Moss in Cumbria and Thorne Moors (or Waste), S. Yorkshire have been conserved partly because of their potential for the regeneration of mire communities (Ratcliffe 1977).

Little information is available on the plant ecology of re-vegetated peat cuttings and, therefore, the management strategies required for the recreation of peatland communities (Barker & Gibson 1922; White 1930; Giller 1982). The objective of the present study was to investigate the plant ecology of re-vegetated peat cuttings in ombrotrophic mires and to assess the major ecological differences between intact and cut-over peatlands. It was hoped to formulate guidelines for the management of cut-over peatlands on the basis of these findings.

Most of the investigations were carried out at Thorne Moors, S. Yorkshire, because of the considerable range of abandoned peat cuttings present at this site. These are of various ages and contain a wide variety of vegetation types; the water table, nutrient status of the water and the residual peat depth also vary. In addition, part of the site is a proposed National Nature Reserve (pNNR). To make the investigation more comprehensive, cut-over areas were also examined on other peatland sites. These included: Danes Moss, Cheshire; several Cumbrian peatlands; Fenn's and Whixall Moss, Clwyd/Shropshire; and Shapwick Heath, Somerset.

1.2 RESEARCH APPROACH

The plant ecology of re-vegetated peat cuttings and the ecological differences between intact and cut-over peatlands were studied by investigating the factors and processes influencing the distribution of the vegetation (Chapter 3). The factors which appear to be most important in determining the distribution of vegetation types both within and between mire systems are hydrology (Lopatin 1949; Ivanov 1953; Ingram 1967; Goode 1970), chemistry (Sjörs 1950; Gorham 1956a, b; Gorham & Pearsall 1956) and successional status (Tansley 1939; Walker 1970). Individual investigations were therefore carried out into the hydrology (Chapter 5), chemistry (Chapter 6) and stratigraphy (Chapter 4) in a wide variety of peat cuttings. In view of the likely importance of bisulphite pollution in influencing re-vegetation by *Sphagnum* spp. (Ferguson, Lee & Bell 1978), the effect of such pollution on certain *Sphagnum* spp. has also been investigated (Chapter 7). Results of these studies are presented after a consideration of the land use history of Thorne Moors (Chapter 2). On the basis of these findings, factors affecting the main floristic features of the re-vegetated peat cuttings (relevant to the management of peatlands) are discussed (Chapter 8). Observations on other cut-over peatlands visited during the course of this study are included (Chapter 9); these are followed by suggested guidelines for the management of cut-over peatlands (Chapter 10) and guidelines for the management of Thorne Moors (Chapter 11).

The investigations at Thorne Moors were mostly completed before 2 June 1982 when a severe fire burnt much of the site. The management guidelines (Chapter 11), however, take the effects of this fire into account.

1.3 DETAILS OF THE MAIN STUDY AREA

1.3.1 The situation of Thorne Moors

Thorne Moors (or Waste*) peatland is a cut-over raised bog situated 18 km north-east of Doncaster and 5 km south of Goole (Nat. Grid Ref. SE 720155; Vice-County 63); the S. Yorkshire/ Humberside boundary passes through the site (Figs. 1.1 and 1.2). Together with the adjoining site of Crowle Waste (situated to the east of the Swinefleet Warping Drain; cf. Figs. 1.1 and 1.2; not studied during the present investigation) this peatland covers an area of 2630 ha. Most of the site is underlain by Bunter Sandstone; to the east of Will Pitts(Fig. 1.2), however, this is overlain by Keuper Marl. Drift deposits of clay and silt cover the underlying bedrock below the peat (Cory 1972). To the south and east The Moors are bordered by the alluvium of the former main channel of the River Don (Fig. 1.1; 2.3). This separates the site from Hatfield Moors, another cut-over raised bog (Smith 1958; not studied in the present investigation). Thorne Moors are otherwise surrounded by warpland, i.e. land (mainly reclaimed for agriculture) on which river-borne sediment has been allowed to settle (2.5). The present surface of Thorne Moors lies at c. 2 m O.D. The average annual rainfall is 568 mm

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* The site is subsequently referred to as 'Thorne Moors' or 'The Moors' in accordance with the wishes of local naturalists; this is because the name 'Waste' tends to be used to make a case for developing the area (Chapter 2; 3.2).

Fig. 1.1 The location of Thorne and Hatfield Moors.
Scale 1:250,000 or 4 cm to 10 km.

(Appendix 3), typical for lowland eastern Britain.

1.3.2 Site description

The raised bog at Thorne formed c. 3000 years ago during the Bronze Age (zones VIIb and VIII; Pigott 1956; Turner 1962, 1965; Buckland & Kenward 1973; Buckland 1979; 4.1). The site has been almost entirely cut-over for peat (Chapter 2) and no areas of undisturbed mire remain. At present the peatland is owned and worked by Fisons Ltd. (Fig. 1.2; 2.6; this ownership, however, has recently been questioned; Bunting *et al.* 1969; Skidmore 1970).

Owing to the peat cutting methods used, a wide variety of semi-natural habitats have developed on Thorne Moors (Peacock 1920, 1921; excursions of the Yorkshire Naturalists' Union 1907-1970 (3.2); Bunting *et al.* 1969) and in the early 1970's the Nature Conservancy Council declared this peatland a Site of Special Scientific Interest. Of particular interest is the Dutch Canal System (Fig. 1.2), a series of re-vegetated cuttings, baulks and canals originally worked by a Dutch peat cutting company and abandoned around 1920 (Chapter 2). The canals contain an extremely diverse flora consisting of some elements of the original raised mire as well as species characteristic of fen conditions (Skidmore 1970; Rogers 1971; Rogers & Bellamy 1972; Chapter 3). Most of the Dutch Canal System has been protected since 1978 under Section 15 of the Countryside Act (1968), which allows for certain management work and scientific recording to be undertaken; in addition, Fisons Ltd. have agreed to consult

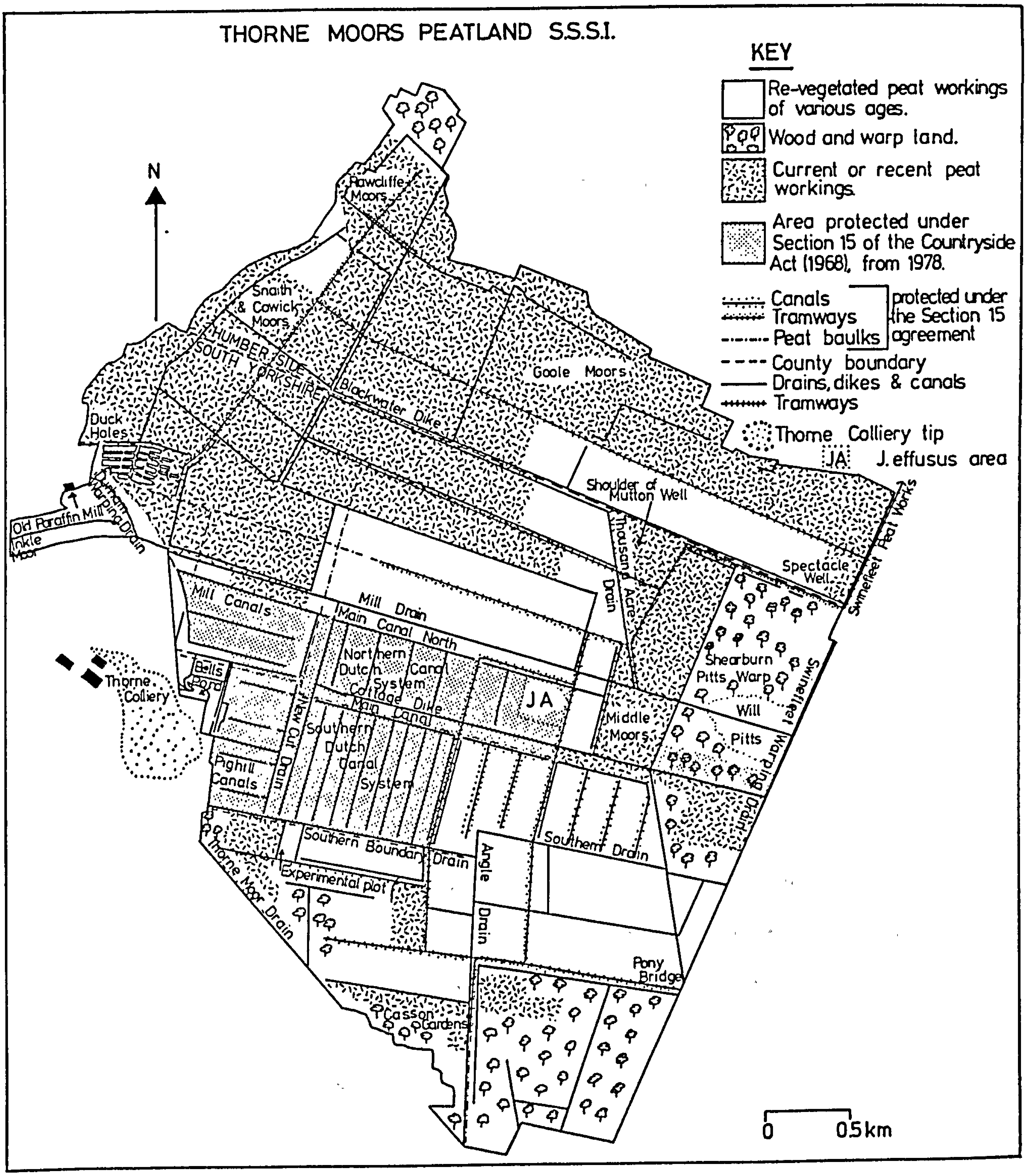

THORNE MOORS PEATLAND S.S.S.I.
KEY
Re-vegetated peat workings of various ages.
Wood and warp land.
Current or recent peat workings.
Area protected under Section 15 of the Countryside Act (1968), from 1978.
Canals
Tramways
Peat baulks
protected under the Section 15 agreement
County boundary
Drains, dikes & canals
Tramways
Thorne Colliery tip
JA J. effusus area
N
Rawcliffe Moors
Snaith & Cowick Moors
HUMBERSIDE
SOUTH YORKSHIRE
Blackwater Dike
Goole Moors
Duck Holes
Old Paraffin Mill
Inkle Moor
Shoulder of Mutton Well
Thousand Acre
Drain
Spectacle Well
Swinefleet Peat Works
Mill Canals
Mill Drain
Main Canal North
Northern Dutch Canal System
Cottage Dike
Main Canal
JA
Shearburn Pitts Warp Will Pitts
Swinefleet Warping Drain
Thorne Colliery
Bells Pond
Middle Moors
New Cut Drain
Southern Dutch Canal System
Pighill Canals
Southern Boundary Drain
Southern Drain
Angle Drain
Experimental plot
Thorne Moor Drain
Pony Bridge
Casson Gardens
0 0.5km

Fig. 1.2

the NCC over peat extraction (and related activities), the removal of tramways and baulks and the chemical spraying of tramways (Fig. 1.2). Part of the Southern Dutch Canal System is also a proposed National Nature Reserve (pNNR ; cf. Figs. 1.2 and 1.3; 1.3.4; 2.7). Individual canals, tramways (Chapter 2; 3.3) and peat baulks as well as an area of unreclaimed warpland (which has reverted to fen; 3.3) are protected under the Section 15 Agreement and the warpland is, in addition, a further pNNR (Fig. 1.2). The peat baulks and tramways are being retained because, on completion of cutting activities, it is hoped that some cut-over areas will be re-flooded (Goode 1973; 11.6).

1.3.3 The drainage system of Thorne Moors

The pNNR in the Southern Dutch Canal System is actively managed for nature conservation (1.3.4) and, therefore, hydrologically 'sealed' by means of peat baulks and dams in ditches and drains (Figs. 1.3 and 2.2). This area receives no run-off from elsewhere as it is situated above the level of its surroundings (6.5). Most of the remainder of the area protected under the Section 15 Agreement is also hydrologically sealed. Otherwise, The Moors are drained as follows (Fig. 1.2): The eastern extension of Main Canal North (now a drain; 2.7) flows into Mill Drain which, with the eastern reaches of Cottage Dike and Southern Drain, receive water from the eastern parts of the peatland and discharge into the Swinefleet Warping Drain. Northern parts of The Moors are drained by Blackwater Dike; this drain also flows into the Swinefleet

Warping Drain which eventually discharges into the River Ouse near Goole, 7 km north of the site (Fig. 1.1). The western reaches of Southern Drain and water from the north of Angle Drain flow into the Southern Boundary Drain; this flows westwards into Thorne Moor Drain. Thorne Moor Drain also receives drainage water from the drain at the base of the colliery tip (2.9; 6.5) and the southern reaches of Angle Drain; it eventually discharges into the River Trent at Keadby (Fig. 1.1; 2.3). This drainage pattern is modified from time to time by Fisons Ltd. (2.8). No feeder drains flow onto The Moors.

1.3.4 The proposed National Nature Reserve (pNNR) in the Southern Dutch Canal System

The pNNR, 81 ha in area, comprises parallel series of alternate peat cuttings and peat baulks separated by canals, originally used to transport peat from the area (Fig. 1.3; 2.7). Owing to the presence of dense birch scrub (Chapter 3), accurate levels were not determined across the area; there appears, however, to be a slight rise in height to the south and west of the pNNR.

The primary aim of management in the pNNR is to encourage the development of communities characteristic of ombrotrophic mires (Goode 1973; Bonner 1978). At present, management activities include: maintenance of dams in ditches and drains, monitoring of the water table, scrub clearance, recording of flora and fauna and fire watching; these are undertaken by a full-time NCC warden.

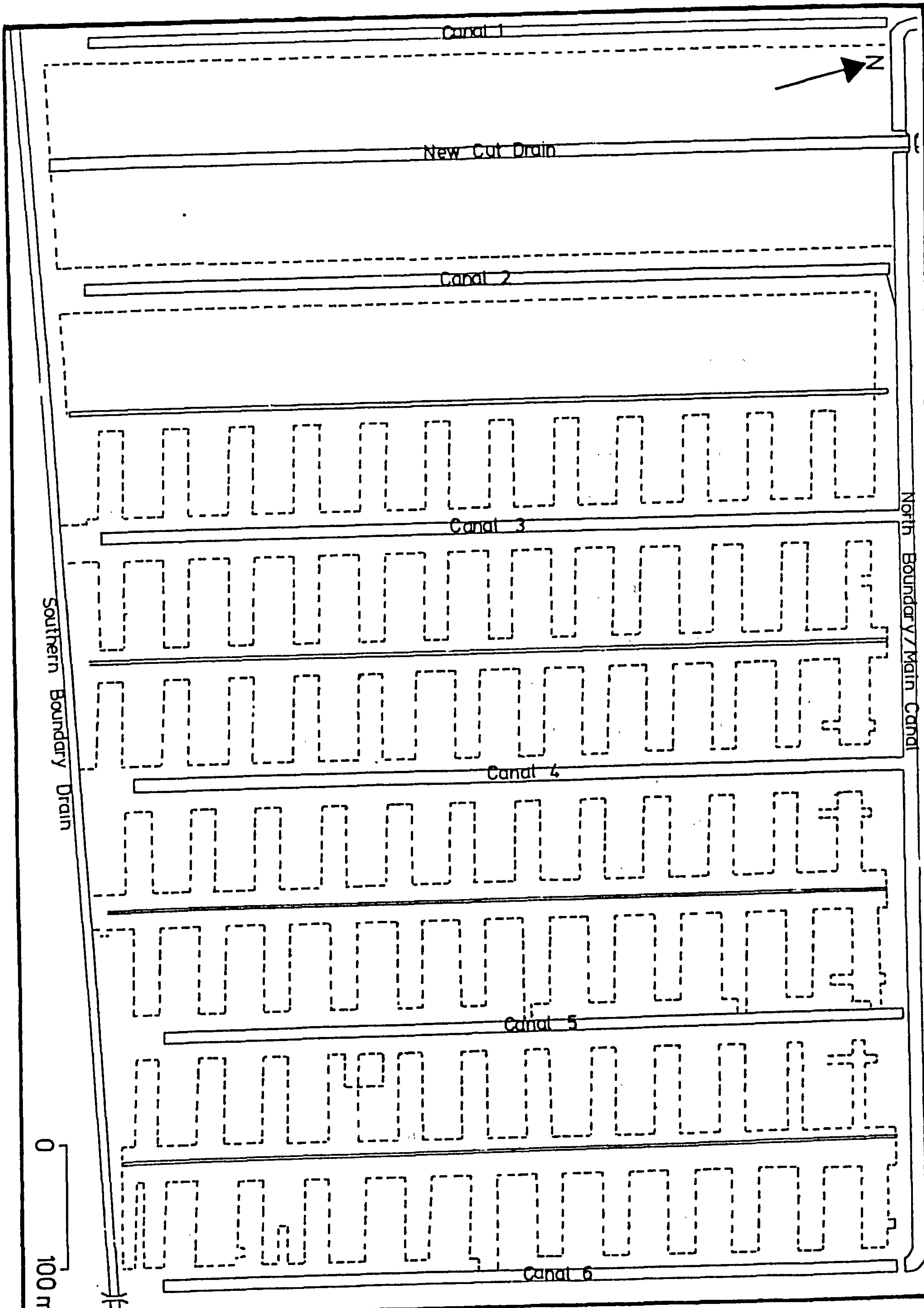


Fig. 1.3 Thorne Moors proposed National Nature Reserve (pNNR)

1.3.5 Study sites

1.3.5.1 Study sites within the pNNR

Most of the investigations were carried out in the pNNR. Within this area, sample sites were located in peat cuttings, on peat baulks and in canals along transects across the length and breadth of the pNNR (Fig. 3.1; 3.4.2; Fig. 8.1).

One cutting in the centre of the pNNR was investigated particularly thoroughly; this cutting (4/5W5, Fig. 3.1) was considered to be of particular interest owing to its central location and diverse vegetation (3.4). To prevent disturbance to the long term investigations carried out in this cutting, damaging activities (e.g. peat boring) were restricted primarily to an adjacent peat cutting, also relatively species-rich (4/5W4, Fig. 3.1). Some species-rich cuttings were avoided completely to prevent undue damage by trampling.

1.3.5.2 Other peat cutting study sites

A *Juncus effusus* swamp adjacent to and south of Main Canal North (JA on Figs. 1.2 and 2.2; 2.7; 3.3.2) was selected as a major study site. A tramway borders this cutting on its eastern side; in the south and west it is bordered by parts of the Northern Dutch Canal System (Fig. 1.2; 2.7). The complete dominance of *Juncus effusus* in this cutting and the possibility that water flows through this area from surrounding cuttings were considered to be of particular interest (cf. Rogers 1971).

The Experimental Plot (EP; Figs 1.2 and 2.2; 2.8; 3.3.2) is an area of c. 2.5 ha offered for research by Fisons Ltd.; this was selected for particular study as an example of a shallow peat cutting abandoned relatively recently. This cutting rises gently to the north where it is bordered by the Southern Boundary Drain; it is surrounded by peat baulks on the other three sides. All borders were 'hydrologically sealed' in 1979 (Lindsay 1979).

CHAPTER 2

THE LAND-USE HISTORY OF THORNE MOORS

2.1 INTRODUCTION

Thorne Moors was once part of a vast, low-lying wetland complex of bog and fen situated around the head of the Humber. This region, which stretches north to York, west to Selby and Snaith and south, between the Don and Trent, to Gainsborough is known as the Humberhead Levels (Wilcox 1933; Figs. 2.1 and 1.1).

The southern part of the Humberhead Levels is known as Hatfield Chase, a Royal hunting forest at the time of James I. This area, in which Thorne Moors is situated, is roughly rectangular in shape. It is bordered by the River Ouse in the north, the River Trent in the east and the River Idle in the south (Fig. 1.1). The Isle of Axholme lies in the south east of Hatfield Chase; this 'hillock' is formed of Keuper Marl and has a maximum elevation of 39 m.

The land use history of Thorne Moors is mainly concerned with the reclamation of a vast raised bog through drainage, peat cutting and warping. Much reclamation occurred in the seventeenth, eighteenth and nineteenth centuries. In 1874, however, Thorne Moors was still 'a shaking bog, trembling in waves when you jumped on its 'scurf' or 'floral blanket'' (Peacock 1920). Although the total peatland area has remained approximately the same (Skidmore 1970), commercial peat winning activities have radically altered the nature of the raised bog at Thorne.

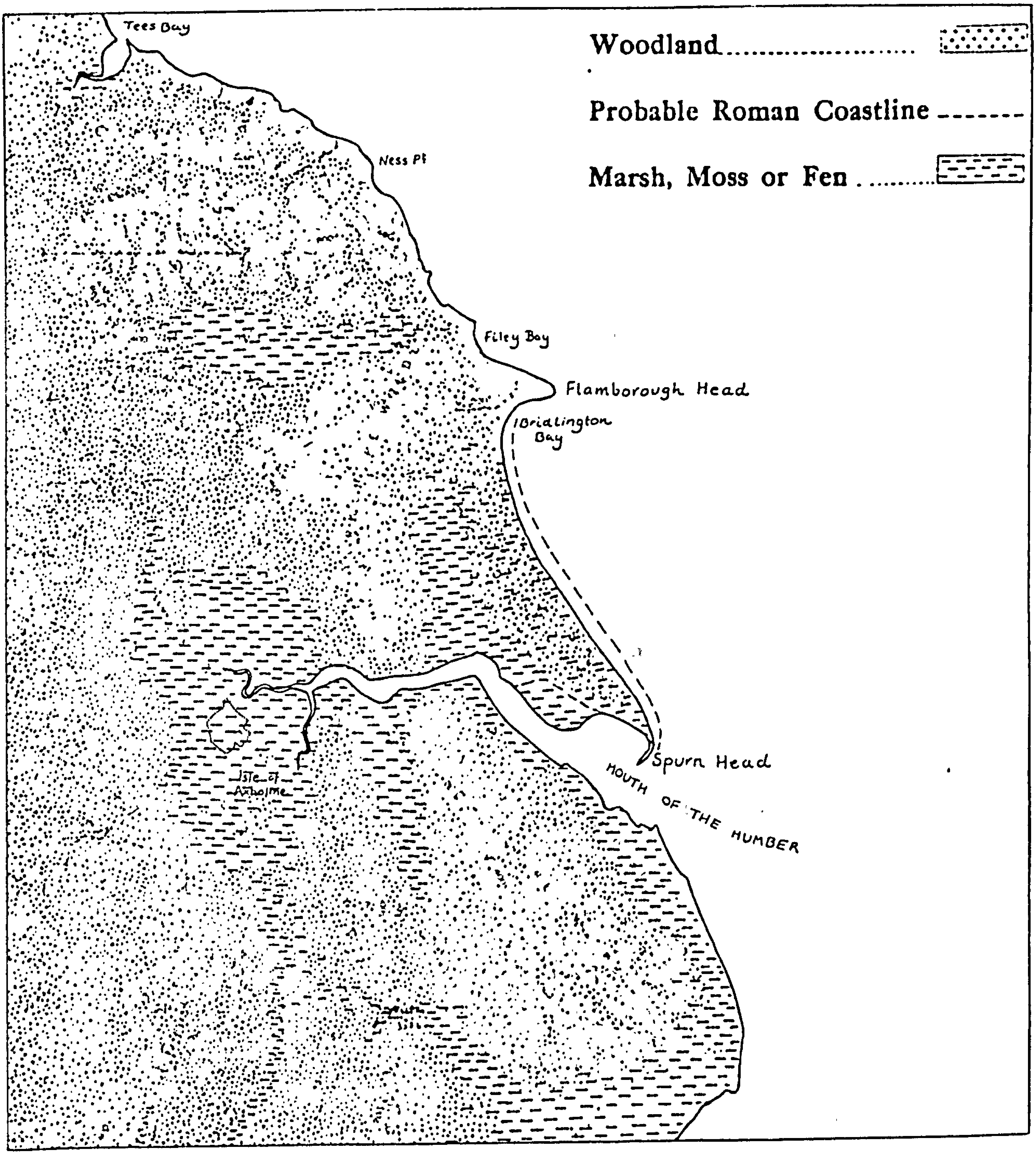


Fig. 2.1 The Humberhead Levels and surrounding areas in Prehistoric times (after Wilcox 1933). The present extent of Thorne Moors is indicated by a dotted line.

2.2 EARLY OBSERVATIONS ON THE HISTORY OF THE HUMBERHEAD LEVELS

The first paper devoted to a consideration of fossil material and its origin in the Humberhead Levels was by de la Pryme (1701), who noted the occurrence of 'pitch trees', oak, birch, yew, 'wirethorn', willow, ash and hazel beneath the peat. He observed that, although the formation of the peat bogs was attributed by some to Noah's flood, the 'real truth is that ... they have been produced from trees falling upon Springs and Rivers and obstructing their courses; they ... were made by ye Romans cutting down ... ye Woods in ye Low grounds and Levels ... in the first century A.D.' (Tomlinson 1882). This theory was subsequently quoted and elaborated by other historians including Stonehouse (1839), Casson (1869), Tomlinson (1882) and Bunker (1898, 1905). Indeed, in spite of recent work which indicates that the wood at the base of the peat at Thorne Moors dates from the Bronze Age (Turner 1962, 1965; Buckland 1979), the destruction of a vast forest by the Romans is still considered by some to mark the initiation of peat formation at Thorne Moors (Goodchild 1971).

It is clear that the inhabitants of Hatfield Chase knew of the existence of the remains of a forest below the peat from the time of the seventeenth century drainage (Stonehouse 1839; 2.3); some even gained a living by retrieving tree trunks from the peat (Bunker 1898). As it is possible that the forest remains were observed even earlier, caution is needed in the interpretation of the observation by Roger de Mowbray, Lord of Axholme, in 1100 A.D. that 'the whole of the Levels twixt Don and

Trent *were* covered in a great old decaying forest of oaks and firs'. This phrase, quoted by Peacock (1920, 1921), Skidmore (1970) and Rogers & Bellamy (1972) as indicating conditions in 1100 A.D. may have referred either to conditions at this time or to the previous existence of a forest in the Humberhead Levels.

Other historical records of woodland in areas of the Humberhead Levels are also somewhat difficult to interpret. This is because it was apparently assumed that woodlands present in the area were relicts of the forest which originally covered the whole region, and were, therefore, still gradually disappearing owing to the continuation of the process which destroyed the original forest. For example, the statement quoted by Skidmore (1970) and Rogers & Bellamy (1972) (the source of which is not identified) that 'during Elizabeth I's reign the last standing pines, remnants of the great old forest of pine and oaks which covered the whole of the Humberhead Levels long before, sank into the morass' gives the impression that the Humberhead Levels became significantly wetter during the last few hundred years. De la Pryme's suggestion (1704) that 'pitch trees called firr' lasted into the eleventh century and finally disappeared just before the drainage (seventeenth century) also gives this impression; however, a relatively recent rise in water table may not, necessarily, have taken place (cf. Buckland 1979).

2.3 THE DRAINAGE OF THE HUMBERHEAD LEVELS

2.3.1 The rivers of the Humberhead Levels (Cory 1972; Severn Trent Water Authority 1979; Fig. 1.1)

Before the reclamation of the Humberhead Levels three major rivers and their tributary streams meandered across the region: the Rivers Don, Torne and Idle. They flowed in unstable river channels which may have become divided from time to time.

The River Don entered Hatfield Chase west of Thorne. It then divided into two parts: a northerly branch joined the River Aire and an easterly branch flowed eastwards between Thorne and Hatfield Moors to meet the River Idle at Sandtoft. From Sandtoft, the Don, with the added waters of the Idle (north course), followed a wavering channel to enter the Trent near Adlingfleet.

In the southern part of the Chase the River Idle split into two parts; one part flowed eastwards towards the Trent north of Misterton; the other extended northwards to join the River Torne east of Wroot and the River Don at Sandtoft.

2.3.2 Drainage operations before the seventeenth century

The Romans may have been the first to attempt the drainage of the Humberhead Levels. They apparently built banks to keep out the sea and dykes to drain submerged land (Tomlinson 1882).

During the mediaeval period the course of the northerly branch of the River Don was altered (Buckland 1973) and doubtless small areas of land were recovered from marsh during the Middle Ages (Cory 1972).

2.3.3 The seventeenth century drainage (Stonehouse 1839; Cory 1972; Fig. 1.1)

2.3.3.1 The agreement between Charles I and Vermuyden

The first major marshland reclamation in Britain was undertaken in Hatfield Chase in 1626 by a syndicate of Dutchmen (known as 'Participants') led by Cornelius Vermuyden. An agreement between Charles I and Vermuyden provided for the distribution of 77,000 acres (31,000 hectares) of marshland in three parts: a third each to the Participants, to the Crown and to the Tenants of Axholme. Also included in the area was 3,000 acres (1,210 hectares) reserved for flooding.

2.3.3.2 Drainage operations carried out by Vermuyden: 1626-1629

Vermuyden's plan for the drainage of Hatfield Chase was based on the principles of first intercepting incoming rivers and then constructing straight internal watercourses to suitable outfalls. Briefly, the southern branch of the Don was blocked near Thorne so that the whole of this river discharged along an enlarged channel into the Aire. At the same time the Idle was stopped in the south of Hatfield Chase and diverted eastwards into the Trent and the Torne was confined to a new channel which discharged into the Trent at Althorpe. In addition to these major diversions many straight drains were also cut to deal with the meres and meanderings of many watercourses.

2.3.3.3 Drainage operations after 1629

The three-year drainage project fell far short of complete success. The discharge of the Don into the Aire and the Torne into the Trent proved to be too great for the channels designed to convey these rivers; this resulted in the flooding of large areas, some of which had been previously dry. Remedial work was enforced upon the Dutch Participants; this included the raising of the Don banks and, in 1635, the cutting of the Dutch River in order to provide a satisfactory outfall for the Don into the Ouse at Goole.

2.3.4 Eighteenth and nineteenth century drainage operations (Cory 1972; Rogers 1971; Fig. 1.1)

In the latter part of the eighteenth century, drainage operations included the widening and deepening of outfalls into the tidal River Trent and improvements to the New Torne. The construction of the Stainforth and Keadby Canal in 1792, which passes between Thorne and Hatfield Moors, also eased drainage problems in the area.

In 1830 one George Leathers suggested that a northern outfall was necessary for a new tidal drain. He proposed that this watercourse should start west of the new Idle, drain Thorne Moors and follow a straightened version of the old Don's Adlingfleet arm. However, this bold plan was not adopted.

Although wind pumps were used in the drainage of the Fens before 1600, there is no mention of the use of these power sources in Hatfield Chase. The first mentioned mechanical aid to drainage is the steam engine, first used between Epworth and the Trent in 1837. In the latter part of the nineteenth century at least three further steam pumping engines were installed in Hatfield Chase.

2.3.5 Twentieth century drainage operations (Severn Trent Water Authority 1979; Fig. 1.1)

Subsequent to the passing of the Land Drainage Act in 1930 the entire drainage system of Hatfield Chase was reviewed. A detailed levelling survey of the area was carried out and key sites were selected for the location of pumping stations.

At the south-west margin of Thorne Moors the Elmhirst pumping station, located on Thorne Moor Drain (Fig. 1.2), discharges water from this peatland into the North Soak Drain c. 1 km south of The Moors. This drain, which runs parallel to the Stainforth and Keadby canal, eventually discharges into the River Trent at Keadby.

2.4 PEAT CUTTING ON THORNE MOORS BEFORE 1870

2.4.1 Introduction

Turf has probably been removed from turbaries on Thorne Moors since early mediaeval times, the peat being used for building houses as well as for fuel (Tomlinson 1882). The following quotation from the Stovin manuscript (1730; see Jackson 1881) suggests that turf was removed from all margins of this peatland: 'Thorne Waste is of great extent, being twenty-five miles round. It affords turbary to Croul in Lincolnshire, Eastoft, Haldenby, Folkerby, Adlingfleet, Ousefleet, Goule, Hooke, Ayremin, Rawcliff in Marshland, Snaith, Sykehouse, Fishlake, & c., in the county of York'.

The vast region suggested by this passage (cf. Fig. 1.1) may reflect the extent of the peatland area exposed by the seventeenth century drainage (2.3), and may not, necessarily, represent the area covered by the undisturbed ombrotrophic mire. However, its huge size, and the fact that the River Don was navigable to Thorne (through the cutting of the Dutch River, 2.3.3), may have provided the incentive for the development of a turf trade in the seventeenth century.

2.4.2 The turf trade during the seventeenth and eighteenth centuries (Casson 1869; Goodchild 1971)

One of the few references to the seventeenth century turf trade, which probably developed soon after the drainage, concerns the theft, in 1652, of 'one Catch (open sailing barge) loade of Turves and Wood'. However, by the eighteenth century, it is known that the south-west side of the turf moors at Thorne was being worked for peat from a series of excavations adjoining canals (drains), which ran for short distances westwards and out of the moor. The peat was transported in 30-40 small boats; these were clinker-built, about 28 feet long and 6 feet wide, sharp at both ends and made to work either stem or stern foremost (the drains being too narrow to allow the boats to be turned). Boating Dykes were used to convey the peat; one of these ran from The Moors to the River Don at Thorne and another was cut eastwards to the River Trent, the old River Don no longer being navigable. The peat was apparently shipped to towns on the banks of the Don, Ouse, Trent and Humber.

The turf trade appears to have begun to decline in the 1790's. Firstly the construction of the Stainforth and Keadby Canal (2.3.4) probably resulted in the closure to navigation of part of the Boating Dyke System and meant that dues had to be paid for the carriage of peat; secondly coal began to replace peat as fuel between the Aire and Don valleys.

2.4.3 The turf trade between 1800-1870 (Casson 1869; Goodchild 1971)

In 1815 the Enclosure Commissioners authorized the cutting of a new drain, about 2 miles in length, along the edge of Thorne Moors to the North Soak Drain of the Stainforth and Keadby Canal. However, this drain and the rest of the Boating Dyke System was used only until 1829 when it was decided that 'boating was injurious to the drainage'. At this time there were said to have been only 8 or 9 boats in use 'chiefly confined to the moors'.

After the abandonment of boating all peat was carted either to Thorne town for sale or to the Stainforth and Keadby Canal for shipment.

2.5 THE USE OF WARPING TO RECLAIM LAND IN THE THORNE AREA

2.5.1 The practice of warping (Creyke 1845; Casson 1869)

'Warp' is the term applied to the river borne sediment which by natural or artificial means has settled on land surrounding the Humber estuary and its vicinity. Natural warping has, of course, been utilized by farmers for centuries and in the first half of the nineteenth century extensive areas in the Humberhead Levels were warped artificially.

The warping procedure called for a straight, well reinforced drain connected to the main tidal rivers: Trent, Ouse or Don. At each tide silt laden waters were directed onto strongly embanked areas of land (below sea level) known as warping compartments. Carefully designed drains in the warping compartments allowed the deposit of a uniform depth of silt and the water to be drawn off completely between tides. Occasionally, however, excess water was drained into a 'warping pond'.

Under ideal conditions land was reclamined in one year during which time a depth of 2-3 feet of warp was deposited. For higher land, however, a warping period of 4 or more years was necessary. Many abandoned turbaries were warped in the nineteenth century owing to their location below sea level. Indeed, in some areas it is clear that peat removal was hastened to allow warping to take place.

2.5.2 Warping of the Thorne area (Creyke 1845; Edwards 1851; Casson 1869)

Warping of land around Thorne Moors began in 1821. By 1826 the following areas were covered: 1600 acres at Goole, Swinefleet and Reedness; 800 acres at Eastoft; 250 acres at Crowle Moors.

Areas to the north and east of Thorne Moors were warped by means of the Swinefleet Warping Drain (Fig. 1.2). This drain connected with the River Ouse 7 km from The Moors and still drains the peatland today. Adequate drainage was essential for the cultivation of warplands. The waterlogged Shearburn Pitts Warp to the west of the Swinefleet Warping Drain was never cultivated and today this area has reverted to fen (Fig. 1.2).

In 1848 the 'Thorne Moor Improvement Company' was established to reclaim Thorne Moors in conjunction with plans by the Great Northern Railway Company to lay a railway between Doncaster and Gainsborough (via Thorne, Crowle and Epworth). A scheme to reclaim Thorne Moors by a process of 'dry warping' was drawn up: alluvium from the riverbed of the old Don was to be transported by rail and spread over the peat. However, the plans were abandoned after 'a pressure on the money market' caused the Great Northern Railway Company to refuse to take the railway to Crowle and Epworth.

Subsequent to the failure of this scheme, one of the subscribers to the Improvement Company, Makin Durham, turned his attention to the construction of a new warping drain. The Durham Warping Drain connects the western edge of Thorne Moors to the River Don, approximately 3 miles north of Thorne; excess water from the drain flowed into Bells Pond (Fig. 1.2). This drain, today utilized as a land drain, resulted in the raising of a large tract of swampy ground to 3-5 feet above its original level.

2.6 THE PEAT CUTTING INDUSTRY AT THORNE MOORS SINCE 1870 (Mr S Marshall, employee of Fisons Ltd., personal communication; Goodchild 1973)

The peat cutting industry at Thorne Moors revived around 1870 (Bunting *et al.* 1969), principally because of an increased demand for peat for use as horse and cattle litter.

In 1896, four peat cutting concerns then working on Thorne Moors were amalgamated into the British Peat Moss Litter Company:

1. The Dutch Griendstveen Moss Litter Company (which was only partially taken over) transported peat from the west and centre of Thorne Moors by a system of canals (2.7) to a mill on the western margin of The Moors (the 'Old Paraffin Mill', Fig. 1.2). From here peat was transported out of the area by means of a short branch of the Thorne-Goole railway. This company operated until c. 1920 when the Paraffin Mill was closed.

2. In the south of The Moors the Moss Litter, Charcoal and Manure Company used an internal tramway system to transport peat to Medge Hall mill, c. 1 km south-east of the peatland. Until 1965, when Medge Hall closed, a short branch of the Thorne-Keadby railway was used to transport peat out of the area.

3. The north of Thorne Moors was worked by a concern (probably William Smith and Company) whose works, known as 'Creykes Siding', were located adjacent to the Thorne-Goole railway. A branch of this railway led to the north-west margin of The Moors; peat was transported to this point by means of an internal tramway system. The Creykes Siding peat works probably closed sometime after 1920.

4. The Goole Moss Litter Company used an internal tramway system to transport peat cut from the north-east of Thorne Moors to a mill located 2 km north-east of the peatland.

A fifth peat company, the Hatfield Chase Peat Moss Litter Company, which may have cut peat from Hatfield Moors, was also taken over by the British Moss Litter Company.

In 1900 the British Moss Litter Company merged with three other large national companies to form the Peat Moss Litter Supply Company. At this time the greatest concentration of sales was in northern England and the north-east Midlands. In addition to its use as litter for cattle and horses, peat was also used for the production of paraffin, creosote, ammonia water, tar and as an ingredient in cattle food.

The British Moss Litter Company (in spite of the merger in 1900 the Company retained its old name) continued to cut much of the area of Thorne Moors until 1950 when it was taken over by Fisons (Horticultural Division) Ltd. This company extracts substantial quantities of peat from most of The Moors at the present time (Fig. 1.2). The peat is transported to the 'Swinefleet' processing plant (of the old Goole Moss Litter Company) 2 km north-east of Thorne Moors by means of an internal tramway system.

2.7 THE DUTCH CANAL SYSTEM

2.7.1 The canal and drainage systems

The Dutch worked an area of Thorne Moors bordered in the north by Mill Drain, in the east by Thousand Acre Drain and in the south by Southern Drain and the Southern Boundary Drain (Figs. 1.2 and 2.2).

They excavated two major canal series: the Northern and Southern Systems. In each of these, lateral or 'side' canals (12 in the Southern System and 11 in the Northern System) were cut perpendicular to a 'main' canal at intervals of 9 chains (c. 180 m). The side canals are numbered in a westerly sequence (Fig. 2.2). The pNNR (Fig. 1.3) consists of an area bordered by the Main Canal and canals 1 and 6 of the Southern System and the Southern Boundary Drain (Fig. 2.2).

The Main Canal of the Southern System was joined to Main Canal North by canal 1; from the north end of canal 1 the route of the Main Canal was west to the edge of The Moors; from here it ran in a north-west direction to the Paraffin Mill, crossing the Durham Warping Drain by means of a brick aqueduct (Goodchild 1973).

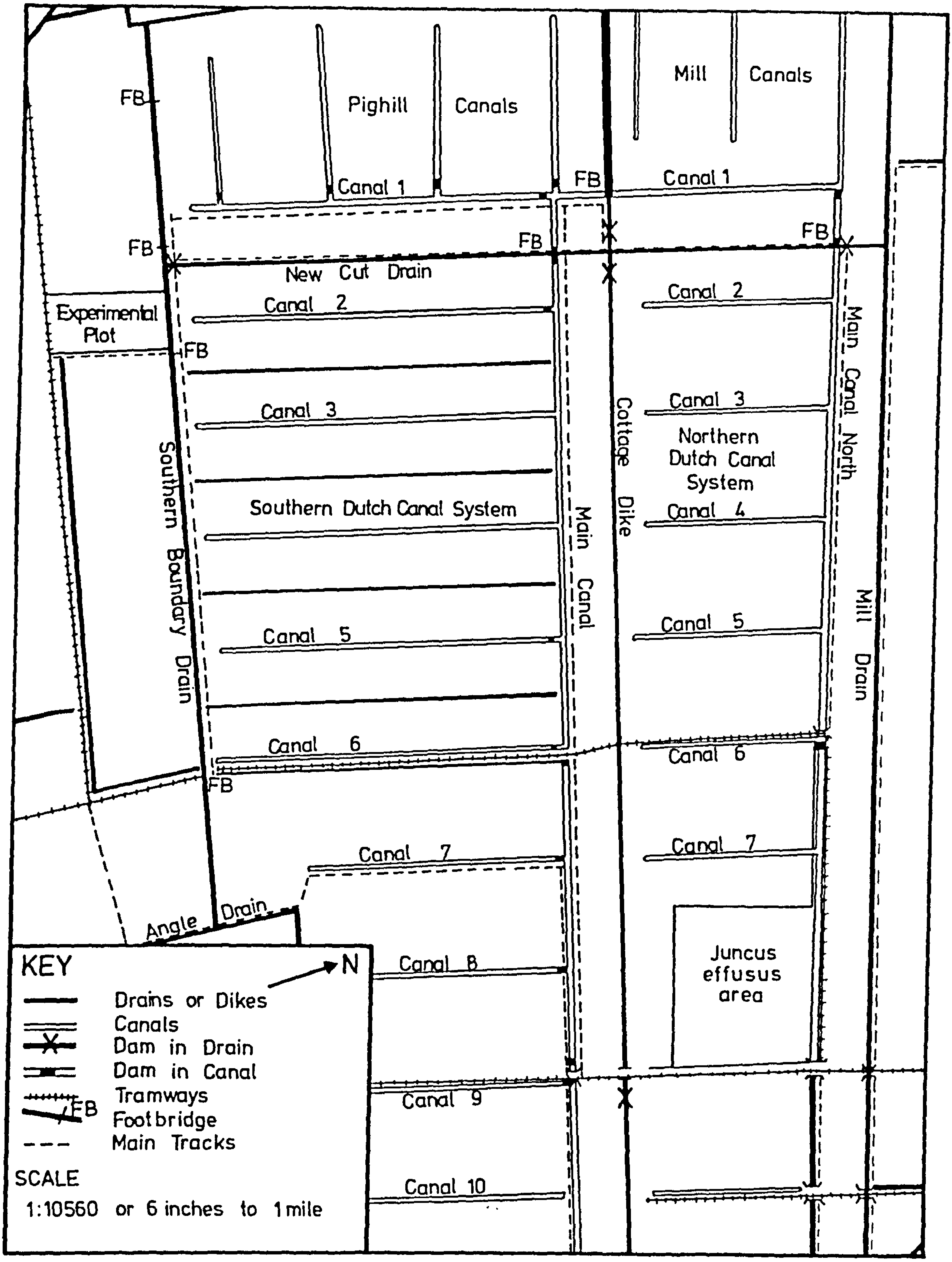


Fig. 2.2 The Dutch Canal System. See also Fig. 1.2.

Two smaller canal series, the Pighill and Mill Canals, were cut perpendicular to canal 1 (south) and the north-west portion of the Main Canal respectively (Fig. 1.2).

The canals were approximately 5 m wide and enclosed on both sides by banks or baulks of peat, also approximately 5 m wide.

A drainage system was excavated quite separate from the canal systems. Drains between the side canals of the Southern System ran into the Southern Boundary and Southern Drains whilst those between the side canals of the Northern System ran into Cottage Dike (Fig. 1.2). In some places drains are thought to have run under the canals by means of culverts; for example, where canal 1 crossed Cottage Dike. The aim of this system was to drain the bog sufficiently to cut the surface layers of peat, whilst maintaining a relatively high water level in the canals. However, it seems that there was a chronic water shortage in the canals which was partially rectified by pumping water into the Main Canal from the Durham Warping Drain (Goode 1973). Warp clay (2.5) was also dumped into some of the canals in an attempt to ease this problem.

Double-ended barges similar to those used on the early Boating Dyke System (2.4.2) were used to transport peat from the cuttings to the Paraffin Mill. They were drawn by horses and steered by a pole from behind along a towpath constructed on the north side of the Main Canal. This was made from limestone rubble and other hard core material (Goode 1973). The canals were widened at intervals to form passing places.

2.7.2 The peat cuttings

The first stage in the cutting of areas between the side canals appears to have been the excavation of deep ditches at intervals of ½ chain (c. 10 m), perpendicular to the side canals and larger drains (Fig. 2.3). Peat was then removed from a series of cutting bays; these were generally 1 chain (c. 20 m) in width and encompassed two of the original ditches. The cuttings were separated by uncut areas (peat baulks) generally 1½ chains (c. 30 m) in width (Fig. 2.4). In addition to 3 of the original west-east ditches the peat baulks were also usually drained by 3 lateral (north-south) ditches. Peat was also removed from the area between the end of the peat baulks and the drains (Figs. 2.3 and 2.4). In the pNNR 12 cutting bays were excavated between each side canal and drain (Fig. 1.3); this diagram also shows that the dimensions of the cuttings and baulks varied somewhat.

Peat removed from the cuttings was stacked and dried on the peat baulks. From here, peat wheelbarrows were used to cart the peat to the canals.

The peat baulks now stand approximately 35 cm above the 'central' section of each cutting (that part enclosed by the two original ditches) so that it is known that at least 35 cm of peat was removed from these areas (Chapter 4). A further 15 cm of peat, at least, was removed from the parts of the cuttings between the original ditches and the long edges of the peat baulks (subsequently referred to as 'outer' or 'peripheral' cutting sections).

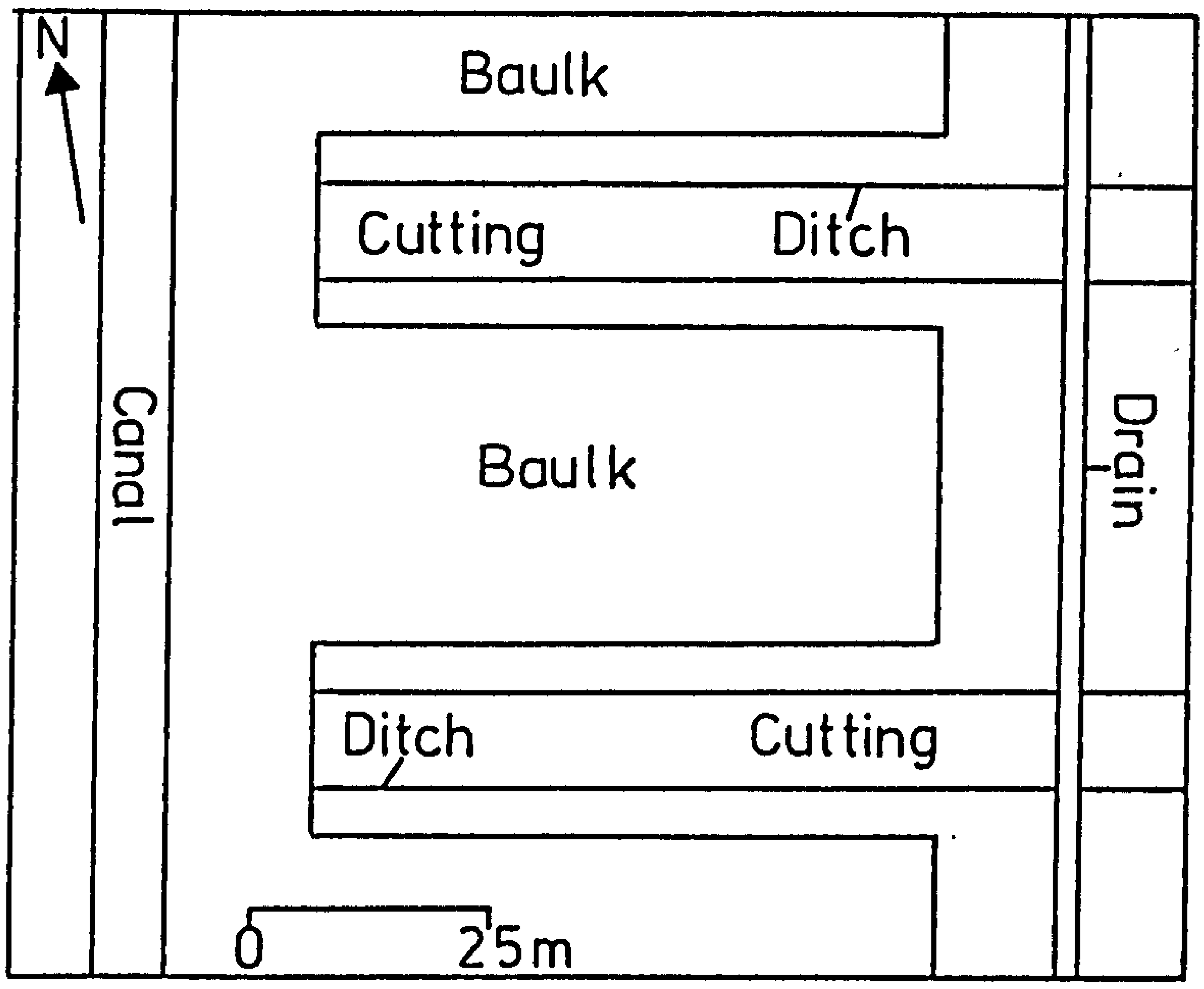


Fig. 2.3 The relationship between cuttings, baulks, drains, ditches and canals in the Dutch Canal System (ditches on baulks are not shown for clarity).

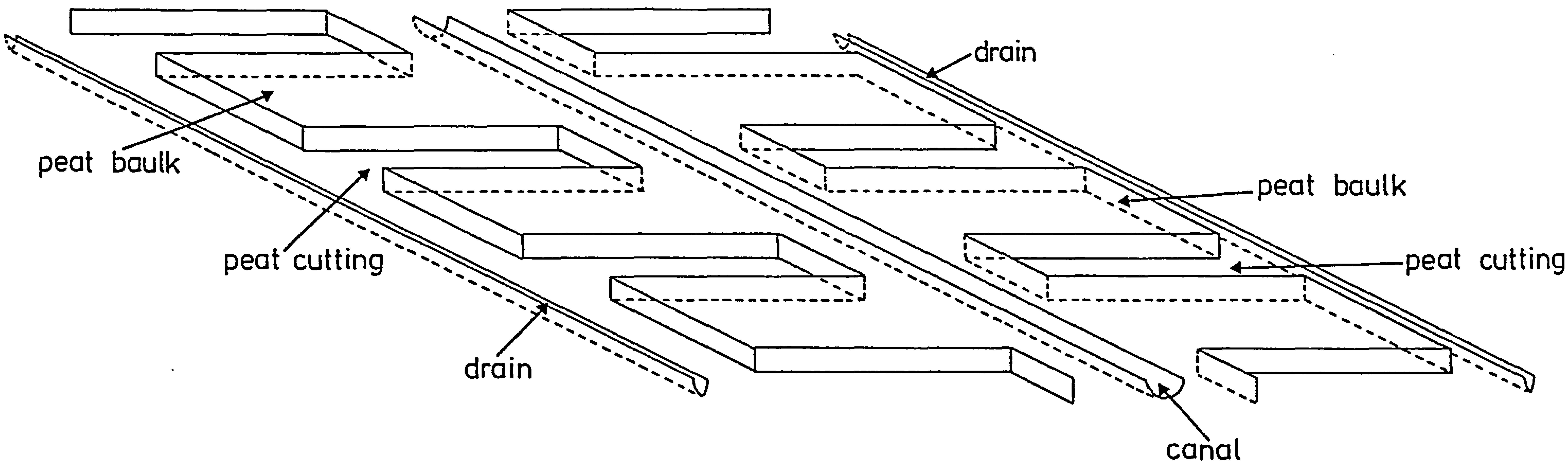


Fig. 2.4 Three-dimensional view of the peat cuttings, baulks, drains and canals of the Dutch Canal System (not to scale).

Vegetation cleared from the surface of the cuttings was apparently piled up in the middle of the central sections of the cuttings; this is subsequently referred to as peat 'rubble'.

The Southern Dutch Canal System may have been worked from west to east so that western areas may have been abandoned before eastern areas (Mr J Kempton, Dutch peat cutter, personal communication).

2.7.3 The Dutch Canal System since 1920

Since it was abandoned in 1920 the Dutch Canal System has been modified in a number of ways:

1. At present shallow ditches perpendicular to the canals occur at regular intervals across the peat baulks (parallel to the canals); these may have been cut sometime after 1920 to drain the canals.

2. The culverts by which the drains ran under the canals have collapsed.

3. Peat baulks have been cut away from: areas between the Mill and Pighill Canals; from some parts of the Northern Dutch Canal System; and from between canals 1 and 2 and the western series between canals 2 and 3 of the Southern Dutch Canal System (Fig. 1.3). It is not known when this cutting took place but since it probably involved breaching of the canals it presumably was after 1920.

4. Tramways have been constructed adjacent to canals 6 and 9. This involved the filling in of canal 9.

5. In 1956, an area to the east of canal 6 (north and south) and part of the Northern Dutch Canal System (the '*Juncus effusus*' area, Fig. 2.2; 3.3.2.1) was cut away by Fisons Ltd. Main Canal North east of canal 6 was apparently deepened and effectively became a drain. This operation was abandoned, however, about 1960 owing to flooding. (Mill Drain did not drain the area as effectively as it does now - see no. 8 below).

6. In the Northern Dutch Canal System, canal 11 and the cuttings adjacent to it have been completely cut away; in the Southern Dutch Canal System parts of canals 10, 11 and 12, and cuttings adjacent to them have been cut (Fig. 1.2).

7. To the north-west of the Mill Canals the Main Canal has almost completely dried out (Fig. 1.2).

8. In March 1972 Fisons Ltd. began to drain the Dutch Canal System. Mill Drain and the Southern/Southern Boundary Drains (including the nothern part of Angle Drain) were enlarged and the New Cut was constructed (Figs. 1.2 and 2.2). These drains were cut down to between 45 and 70 cm into the underlying clay (Dr D Shimwell, personal communication). Canal 10 (south) was connected to Mill Drain by way of canal 10 (north), and canals 6 and 9 (south) were connected to the Southern Boundary/Southern Drain. In addition, the southern ends of the drains which run parallel to the side canals in the Southern System were joined to the Southern Boundary Drain.

The complete drainage of the Dutch Canal System was prevented by Wm. Bunting of Thorne and a team of concerned naturalists (known as 'Bunting's Beavers') who dammed the drains at strategic points. A period of over one year elapsed, however, before the Canal Systems were 'sealed off'. These dams are indicated on Fig. 2.2 by means of symbols as well as by discontinuities in the drains and canals.

9. Many dams have been reinforced and new ones constructed by the NCC warden, especially in the pNNR.

2.8 PEAT CUTTING METHODS USED BY THE BRITISH MOSS LITTER COMPANY (EXCLUDING THE GRIENDSTVEEN COMPANY) AND FISONS LTD .

2.8.1 Peat cutting methods used by the British Moss Litter Company

In contrast to the methods used by the Dutch, the other constituent companies of the British Moss Litter Company excavated large, rectangular peat cuttings adjacent to continuous, narrow baulks of peat on which the tramways were located. Smaller peat baulks were used for stacking and drying the peat (Bunker 1898).

Most of the early peat cuttings have been re-cut by Fisons Ltd.; however, a small area of cuttings which date from 1900 occurs in the south of the site (3.3.2.1, no. 1).

Many of the tramways had a foundation of 'cinders from the engine room fire' (Peacock, YNU 1907; 3.3.5). Small waggons of turves were drawn by horses in the early 1900's; these were later replaced by locomotives. Many of the tramways are abandoned but are retained under the Section 15 Agreement (Chapter 1).

2.8.2 Peat cutting methods used by Fisons Ltd.

Fisons Ltd. extract peat from areas which have been previously drained and cleared of vegetation by means of a machine which cuts a series of 'channels' c. 1.5 m wide and c. 0.8 m deep. Baulks are left between the 'channels' on which the cut peat 'blocks' are stacked to dry for several months. The peat is then transported to the peat processing plant. 'Modern' cuttings therefore consist of series of large, shallow cuttings and baulks. Areas are re-cut at intervals of approximately 5 years. By contrast, on Hatfield Moors, a more up-to-date process, peat milling, is carried out.

The Experimental Plot, (Chapter 1; Figs. 1.2 and 2.2; 3.3.2) was last cut in 1972.

Fisons Ltd. control the water level at Thorne Moors by constructing temporary dams in the main drains, breaching existing dams, constructing new drains and by means of sluices in the main drains, for example at the west end of the Southern Boundary Drain.

Fire is a hazard on The Moors where so much dry peat is exposed. Some of Fisons' employees therefore carry out 'fire watching' activities.

2.9 DEVELOPMENT PRESSURES

2.9.1 Thorne Colliery

The 'High Hazel' coal seam was extensively worked at Thorne Colliery from 1930 until the colliery closure in 1956. Approximately 500 hectares of Thorne Moors were undermined; this has resulted in a shallow subsidence basin extending to c. 5 km east of the colliery, ranging from zero to a calculated maximum of 110 cm in depth (National Coal Board, personal communication).

The NCB is currently carrying out work to reopen Thorne Colliery. The Board originally expected to begin production in 1984-5; recent financial cutbacks, however, seem likely to affect the target date . The renewal of mining operations is likely to cause further subsidence of the Thorne Moors area.

Colliery waste production is likely to be high once the mine runs into full production. The existing tip (Fig. 1.2) has spare capacity until 1991; pressure for extension of the tip may become necessary after this date (South Yorkshire County Council 1981). Such a proposal is likely to cover land on the fringe of Thorne Moors.

Drainage water from the mine flows into the Durham Warping Drain and south towards Thorne Moor Drain (Fig. 1.2; Chapter 6).

2.9.2 Pulverized fuel ash disposal

In 1969, proposals were made by the Central Electricity Generating Board to use the western portion of Thorne Moors for the tipping of pulverized fuel ash from Drax Power Station (3.2.3). Although this threat was averted, further proposals were made to dump this material on Thorne Moors, once the peat has been extracted. However, in May 1974 South Yorkshire County Council decided to take an unfavourable view of this proposal 'for agricultural, nature conservation and peat operational reasons'.

2.9.3 Regional airport

There has been a long-standing proposal to construct a new regional airport for Yorkshire and Humberside on the northern part of Thorne Moors. South Yorkshire County Council consider, however, that such a proposal would have serious repercussions on conservation and agricultural after-use and therefore decided to withdraw its 'protection' of the potential airport site in April 1979 (South Yorkshire County Council 1981).

CHAPTER 3

THE VEGETATION OF THORNE MOORS

3.1 INTRODUCTION

The flora of the raised bog at Thorne has undergone many changes since the peat was first cut, drained and warped. Past records of the vegetation are presented here in order to assess the nature of the undisturbed raised bog and the effect of reclamation and 'improvement' (3.2).

Also included in this chapter are accounts of:

1. The present vegetation of the Thorne Moors peatland, excluding areas described in 3.4 and 3.5 (3.3).

2. A detailed investigation into the vegetation of the re-colonized peat cuttings and baulks of the Dutch Canal System (3.4).

3. An investigation into the flora of the Dutch Canals (3.5).

Owing to the present rapid exploitation of the area by peat cutting, the accounts of the vegetation of some areas may already be out of date. No attempt was made to make full species lists from areas other than the peat cuttings of the pNNR.

3.2 PAST RECORDS OF THE VEGETATION

3.2.1 The 18th and 19th Centuries

3.2.1.1 The raised bog flora

One of the earliest references to plants growing on the raised bog at Thorne was made by Stovin (see Jackson 1881) in a manuscript written around 1730: '.... this waste .... affords plenty of cranberries, and an odoreferous (sic) shrub called Gale; some call it Sweet willow or Dutch myrtle'.

Although few specific references were made to species of *Sphagnum* by the early botanists it seems likely that the bog was covered with several species of this genus. Casson (1869), for example, states that 'the margins of the ponds at some seasons are beautifully fringed with variously coloured moss, in greens, in pinks, and up to dark maroon or brown' and Tomlinson (1882) writes that '.. we used to gather bundles of bright-coloured moss, the hues of which were almost endless, or bunches of the cotton-grass' (from the turf-moor).

The mire surface may have exhibited some patterning; Casson (1869) describes 'large ponds ... of dark coloured water, clear and perfectly free from weeds and aquatic plants; many of them are extremely curious in shape - one perhaps will be like two miniature seas divided by a narrow strait, others will have the edges indented with large bays and inlets'. Peacock (1920, 1921), writing of the closing decades of the 19th Century, mentions 'pools of the central waste' ..... 'constantly growing up on the *Sphagnum* peat (which) when used (for duck rests) had to be frequently opened out'.

Plants associated with the pools included *Carex limosa, Eleocharis palustris, Menyanthes trifoliata, Rhynchospora alba, Osmunda regalis* and *Scheuchzeria palustris* (Peacock 1920).

Scheuchzeria palustris was found at Thorne Moors 'in great plenty' by Appleby in 1831 (Appleby 1832). In 1870, however, the last authenticated Thorne Moors specimen of *Scheuchzeria* was collected by Lees (1888). Just forty years after its discovery the Rannoch Rush was extinct in the area.

Elsewhere on Thorne Moors *Calluna vulgaris* and *Erica tetralix* were frequent as were *Andromeda polifolia* and *Vaccinium oxycoccus* (Bunker 1898). Bunker (1898) also observed that 'the crow berry (*Empetrum nigrum*) .... grows sparingly' and that 'you may meet with a bed of bog asphodels' (*Narthecium ossifragum*). *Drosera anglica, D. intermedia* and *D. rotundifolia* were 'so common that wheelbarrow loads might be collected' (Bunker 1898); indeed Peacock (1920) 'sent out hundreds of specimens of the *Droserae* to workers in many parts of England'.

3.2.1.2 The flora of the bog margins and ancient turbaries

It was perhaps owing to the difficult terrain that much botanising was carried out at the margins of the bog as well as because the flora of the edges was particularly diverse. Lees (1884), for example, gathered *Lastraea cristata* (*Dryopteris cristata*) and *Peucedanum palustre* on the 'less open border' of The Moors nearer Thorne. Bunker (1898), too, noted that 'sweet gale or bog myrtle (*Myrica gale*) is very common near the borders'.

Peacock (1920, 1921) recognized that the flora of the bog in the mid 19th Century was, through the cutting of drains, dykes, turbaries and decoys, more diverse than that of an undisturbed bog. He notes that ancient turbaries on the eastern edge of The Moors which 'had long ceased to be used' were the most 'botanically interesting districts' in the area. Bewailing the warping of these turbaries in approximately 1842, Peacock (1920, 1921) considered that the area subsequently became a botanical wilderness. These turbaries contained plants such as *Cladium mariscus*, *Lathyrus palustris*, *Dryopteris cristata* and *Scheuchzeria palustris*. Peacock (1921) thought that the latter plant survived throughout the mid 19th century in the turbaries on account of their 'wetness'.

The influence of the 'limy' Keuper Marl in the turbaries on the eastern side of the bog (Chapter 1) was also recognized by Peacock (1920, 1921). *Anagallis tenella*, *Pyrola minor*, *Hypericum elodes* and *Potentilla palustris* were some of the plants associated with the Keuper Marl recorded from the Lincolnshire turbaries.

3.2.1.3 The effects of drainage and reclamation

In 1829 Casson (1869) remarked that owing to the drainage of The Moors 'such plants as the *Utricularia minor* and the *Scheuchzeria palustris* will soon be found there no more'. Indeed, as has been mentioned, *Scheuchzeria palustris* was to become extinct before the end of the 19th Century. Casson (1869) also observed that 'on the margin of the moras, the *Osmunda regalis*, the *Peucedanum palustre* and the *Lastraea (Dryopteris) cristata* are fast giving way to oats, and turnips, and marigolds'. The drying of the bog was also noted by Peacock (1920, 1921) who observed that the 'south edge flora consisted practically wholly of pure *Pteris' (Pteridium aquilinum)*.

3.2.2 Records of the vegetation between 1900-1966

3.2.2.1 Recording of the vegetation

The Yorkshire Naturalists' Union (YNU) was responsible for the majority of the botanical records from Thorne Moors between 1900-1966. The area may have received more attention from the YNU and others were it not for the difficulty of access, not helped by the restrictions imposed by the peat-cutting authorities. In addition, the paper published by Peacock (1920, 1921) which included the gloomy prediction that it was only a matter of time before 'the whole area of turf is removed or covered with alluvium' may have convinced naturalists that the site was doomed (Skidmore 1970).

3.2.2.2 The plant records

The 204th YNU excursion, in July 1907 (see YNU 1907) was the first to Thorne Moors. On the southern borders of The Moors *Myrica gale* and *Potentilla palustris* were plentiful; *Peucedanum palustre* was also observed. Peacock, however, present on this excursion, felt that the bog flora was 'characteristic of a desiccating quagmire'. *Pteridium aquilinum* was the dominant species with *Calluna vulgaris* and *Eriophorum vaginatum*. It was also considered that the place was 'far too well drained to harbour many mosses'.

In 1934 the YNU visited Goole Moors (YNU 1934) in the north of the site (see Fig. 1.2) and recorded large quantities of *Erica tetralix*, *Myrica gale* and *Andromeda polifolia*.

W A Sledge visited Thorne Moors in 1941 to search for some of the rarities recorded by Lees (1888). On the south-west margin he found some plants of *Peucedanum palustre* but did not find *Dryopteris cristata* (Sledge 1941). A search for *Drosera anglica*, *Rhynchospora alba* and *Carex limosa* on the north-east margins was also without success, although he considered that all these plants might be found on the less accessible parts of the area. Sledge (1943) also confirmed the identification of *Viola stagnina*, a plant which had long been puzzling naturalists from Thorne Moors. Lees (1888) had 'considered it very unlikely indeed that the true *stagnina*' occurred.

The YNU next visited Thorne Moors in 1946 (YNU 1946). In the 'boggy thickets of the south-west margin' species found included one surviving plant of *Lathyrus palustris*, a few plants of *Peucedanum palustre, Viola stagnina* and *Myrica gale*. *Sphagnum fimbriatum* and *S. squarrosum* were also recorded.

In 1949 W Bunting, who began working on The Moors in the 1940's, introduced a few hundred plants of *Drosera intermedia* onto the area (Bunting 1949). At the time this plant had not been recorded on Thorne Moors for several years.

The 1966 YNU excursion to Thorne Moors visited Snaith and Cowick Moors (YNU 1966), to the north-west of the site (Fig. 1.2). Sledge (YNU 1966), writing on the vascular plants, observed that the flora was only an 'impoverished remnant of early days'. On this excursion no *Myrica gale* was encountered and only two small colonies of *Andromeda polifolia* were seen.

3.2.3 Recent investigations into the vegetation

Modern vegetation recording can be said to have begun in 1969 after proposals had been made by the Central Electricity Generating Board to use the western portion of Thorne Moors for the tipping of pulverized fuel ash from the new Drax Power Station (2.9). William Bunting, who had been working on the natural history of The Moors for several years, joined forces with the Natural History Department of Doncaster Museum to survey the entire site. The result was a dossier entitled 'An Outline Study of Hatfield Chase' (Bunting *et al.* 1969) which included a summary of all records relating to the flora and fauna of Thorne Moors. This, together with further survey work summarized by Skidmore (1970), showed that the site was botanically richer than at the time Peacock was writing (1920, 1921). Subsequent to this work the Nature Conservancy Council (e.g. Goode 1973) and other workers (e.g. Rogers 1971; Rogers & Bellamy 1972) carried out vegetation surveys of the site. In 1970 the Yorkshire Naturalists' Union also re-visited the site (YNU 1970).

3.3 THE PRESENT VEGETATION OF THORNE MOORS

3.3.1 Current or recent peat workings (Fig. 1.2)

The cuttings and drier baulks of peat produced by modern peat cutting methods (2.8) become colonized by some plants which are subsequently stripped off when the area is re-cut. Wetter areas contain *Eriophorum angustifolium* and *E. vaginatum* with some *Erica tetralix* whilst drier areas favour the growth of *Rumex acetosella* and *Pteridium aquilinum*; *Calluna vulgaris, Pohlia nutans* and *Betula pubescens* may also colonize the baulks. The extent of re-colonization of the bare peat surface depends on the time which elapses before re-cutting (usually less than five years).

3.3.2 Re-vegetated peat cuttings and baulks (Fig. 1.2)

Cuttings range in age from those abandoned in 1920 or before (the Dutch Canal Systems - see 3.4) to cuttings recently abandoned by Fisons Ltd. and colonized by the vegetation described in 3.3.1. The size, shape and depth of the cuttings and baulks are very varied; for convenience, however, the communities are described under three headings which represent broad categories with respect to water depth and occupy approximately equal areas of The Moors.

3.3.2.1 Flooded peat cuttings

In addition to *Eriophorum angustifolium*, *E. vaginatum* and *Erica tetralix*, most flooded peat cuttings have become colonized by mats of *Sphagnum recurvum* on which *Drosera rotundifolia* grows. Open water areas contain *Juncus bulbosus*, *Sphagnum cuspidatum*, *Drepanocladus revolvens* and *D. fluitans*. *Vaccinium oxycoccus* and *Andromeda polifolia* are also sometimes present in these cuttings.

Flooded cuttings of particular interest include:

1. A series of peat cuttings to the south of the Southern Dutch Canal System and the east of Angle Drain. These were abandoned in approximately 1900 and contain extensive *Sphagnum recurvum* flats with much *Andromeda polifolia* and *Vaccinium oxycoccus*; *Sphagnum balticum* has also been recorded from these cuttings (Mr B Eversham, personal communication).

2. *Juncus effusus* swamps

Two areas have become almost entirely dominated by *Juncus effusus* with some *Drepanocladus fluitans*, *Sphagnum recurvum* and stunted *Betula pubescens*. One large *Juncus effusus* swamp occurs in a cutting made into the Northern Dutch Canal System (2.7; JA on Fig. 1.2); the other is situated south of Blackwater Dike and west of Thousand Acre Drain. Both these cuttings are periodically used by Black-headed gulls as nesting sites (see 6.3).

3.3.2.2 Cuttings in which the water table is near the peat surface

These cuttings are generally dominated by *Calluna vulgaris* and *Betula pubescens* with *Erica tetralix; Andromeda polifolia* and *Vaccinium oxycoccus* also occur. Bare peat areas are colonized by bryophytes including *Pohlia nutans* and *Campylopus paradoxus* as well as *Drosera rotundifolia* whilst *Molinia caerulea*, present only occasionally, is associated with the sides of drains. Of the *Sphagna*, *S. recurvum* is the most common species but *S. fimbriatum*, *S. subnitens* and *S. papillosum* are also present. *Rhododendron ponticum* occurs sporadically.

This category of peat cuttings includes:

1. The Experimental Plot (Fig. 1.2).

The Experimental Plot consists of several cutting strips which run north-south. Cutting strips just above the level of the water table are dominated by *Calluna vulgaris* whilst those situated at, or just below, the water table are dominated by *Eriophorum vaginatum* or *E. angustifolium*. *Betula pubescens* is present in the whole area.

2. Casson Gardens (Fig. 1.2)

In the middle of the last century William Casson of Thorne planted a garden of flowering shrubs, including rhododendrons, fuchsias and dahlias, in the south of The Moors (Tomlinson 1882). All that remains of the garden today is a dense *Rhododendron* thicket with a small patch of *Empetrum nigrum* and some plants of the exotic *Kalmia angustifolia*.

3.3.2.3 Dry peat baulks

In addition to *Pteridium aquilinum* and *Rumex acetosella* (3.3.1), dry peat baulks are colonized by *Calluna vulgaris*, *Betula pubescens* and a range of bryophytes including *Pohlia nutans*, *Campylopus introflexus*, *Polytrichum juniperinum*, *P. piliferum* and *Cephalozia bicuspidata*. Seedlings of *Pinus sylvestris* are infrequent. Lichens present include *Lecidea granulosa*, *L. uliginosa*, *Cladonia floerkeana*, *C. fimbriata*, *C. coccifera* and *C. chlorophaea*.

3.3.3 Vegetation of the drains

The deep peatland drains generally contain little vegetation; however, *Typha latifolia* and *Juncus effusus* are occasionally present. *Molinia caerulea* and *J. effusus* also occur along the drain edges.

3.3.4 Wood and warpland

3.3.4.1 Woodland

The semi-mature woodland in the southern section of The Moors (Fig. 1.2), which has never been warped (Mr W Bunting, personal communication; cf. Rogers & Bellamy 1972), but which has probably been cut, consists principally of *Betula pubescens*. *Quercus robur*, *Populus tremula* and *Crataegus monogyna* also occur with *Vaccinium oxycoccus* in the understory.

3.3.4.2 Warpland

The poor class warpland to the west of the Swinefleet Warping Drain has reverted to fen and marshland; many of the plants which Peacock (1920, 1921) never found and feared completely lost when parts of the area were warped over in the 1840's have re-appeared (Skidmore 1970).

This area consists of *Salix caprea-Betula pubescens* carr (with *Frangula alnus, Carex paniculata* and *Sparganium erectum*) together with beds of *Phragmites australis* (with *Potentilla palustris*) and stands of *Glyceria maxima* and *Typha latifolia*. Other plants recorded include *Eupatorium cannabinum, Scirpus maritimus* and *Ophioglossum vulgatum*.

Warp-influenced drains in the area (for example the eastern reaches of Cottage Dike (Fig. 1.2)), contain plants such as *Callitriche platycarpa, C. hamulata* and *Polygonum persicaria; Epipactis palustris* occurs at the drain edges. The Swinefleet Warping Drain (Fig. 1.2) contains *Hottonia palustris, Lycopus europaeus, Alisma plantago-aquatica* and *Ranunculus sceleratus* (Rogers 1971).

Portions of Inkle Moor, a cut and warped area in the west of The Moors, are variously dominated by *Phragmites australis, Phalaris arundinacea* and *Glyceria maxima*. Other plants characteristic of the eastern warpland are also present together with *Lathyrus palustris*.

3.3.5 Tramways

Some of the numerous tramways or trackways on The Moors (Fig. 1.2) are still in operation but more are abandoned (2.8) and used as footpaths. Those with a limestone foundation support a particularly interesting flora which Peacock (YNU 1907) listed in full; Skidmore considered this list equally applicable in 1970 except for a few species which had arrived since Peacock's time, e.g. *Senecio viscosus* (Skidmore 1970). The species list included *Linum catharticum, Euphrasia officinalis, Angelica sylvestris, Prunella vulgaris, Lotus corniculatus, Equisetum arvense* and *Rhytidiadelphus squarrosus.*

The limestone-based towpath along the northern side of the Main Canal is particularly rich; *Ophioglossum vulgatum, Listera ovata, Calamagrostis epigejos, Eurhynchium praelongum* and *Lophocolea bidentata* have all been observed there.

3.4 CLASSIFICATION OF THE VEGETATION OF PEAT CUTTINGS AND BAULKS IN THE DUTCH CANAL SYSTEM

3.4.1 Introduction

This section describes a detailed investigation into the vegetation of the pNNR area (part of the Southern Dutch Canal System). The vegetation of cuttings in the eastern section of the Southern Dutch Canal System, the Northern Dutch Canal System and the Mill and Pighill Canals (Fig. 2.2) is also described briefly and compared with that of the pNNR.

3.4.2 Identification of individual peat cuttings

The peat cuttings of the pNNR are identified according to their position within this area. Fig. 3.1 shows the reference codes of all cuttings studied in this and subsequent investigations. The first two numbers (separated by an oblique stroke) refer to the two canals between which the cutting is situated (the canals are numbered 1-6 in a west-east sequence); the suffix locates the cutting in either the western or eastern cutting series between any two canals. In each series individual cuttings are numbered 1-12 in a north to south sequence and the final digit refers to this location. Thus, for example, cutting 4/5W5 is located in the fifth cutting of the western series between canals 4 and 5 and 3/4E9 is located in the ninth cutting of the eastern series between canals 3 and 4.

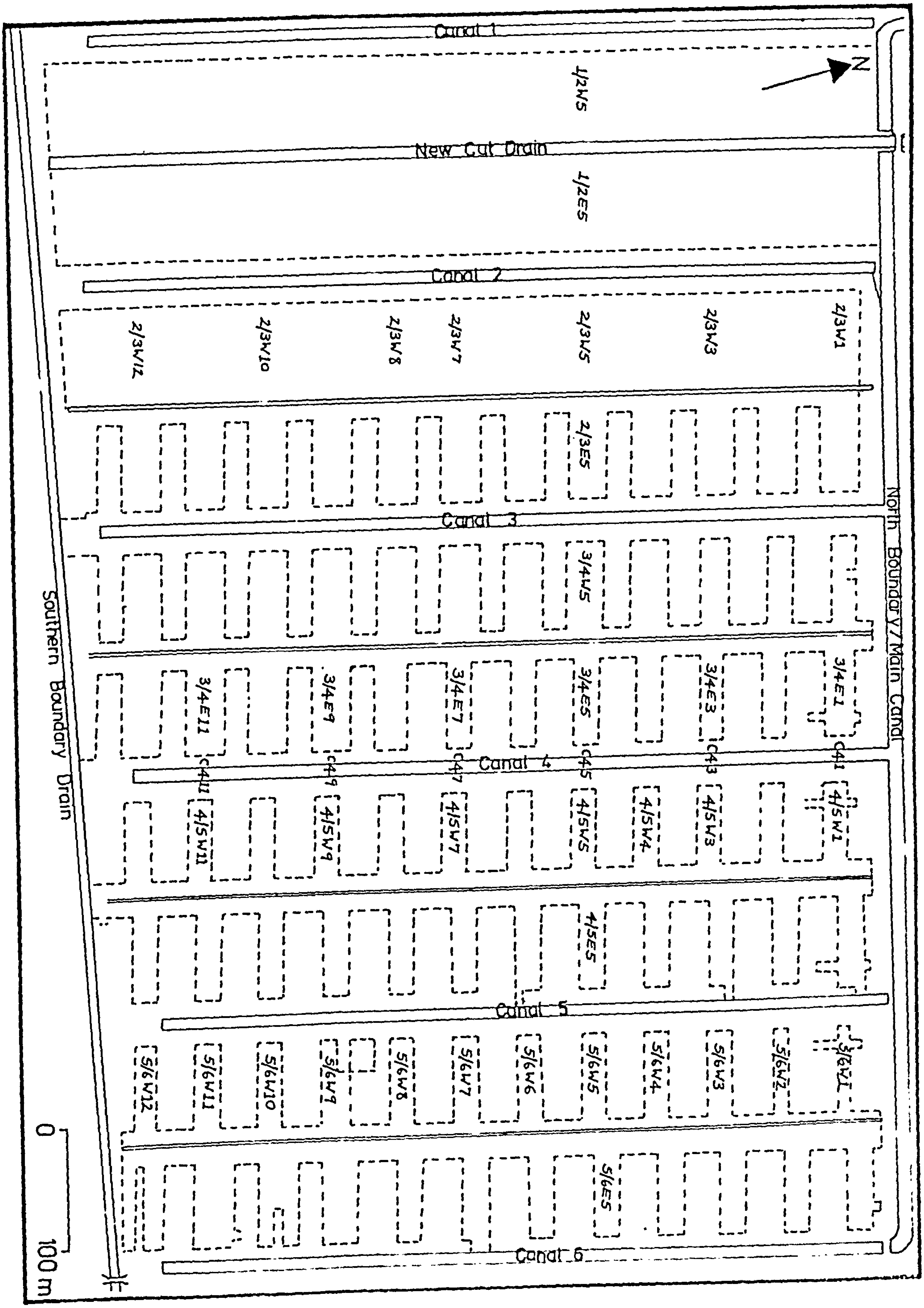


Fig. 3.1 Names and locations of main peat cutting study sites in the pNNR referred to in subsequent investigations.

In the area between canals 1 and 2 and in the western section of the area between canals 2 and 3, peat baulks are absent; for convenience, however, the reference system is used here and applied as if peat baulks were present. Cutting 2/3W10, for example, is positioned by its location opposite 2/3E10.

In studies relating to canal 4 (C4; Fig. 3.1) sample positions are located by their adjacent cutting numbers so that C49 refers to a point in canal 4 adjacent to cutting 9.

To locate a peat baulk the suffix 'NB' or 'SB' (abbreviations for 'north baulk' and 'south baulk' respectively) can be added to the cutting reference code.

3.4.3 Methods of vegetation analysis

3.4.3.1 Location of sample sites

In order to a) investigate the vegetation in cuttings across the length and breadth of the pNNR and b) compare the vegetation in the cutting area where peat baulks separate the cutting bays with that of the cutting area where baulks are absent,the vegetation was surveyed along 3 transects (Figs. 3.1, 3.3 and 3.4):

1. West-east across the pNNR through cutting no. 5.

2. North-south along section 2/3W (along this transect the only sample sites investigated were those where hydrological and chemical studies were carried out (Chapters 5 and 6).

3. North-south along section 5/6W.

A west-east transect along the peat baulks north of cutting 5 was also sampled.

3.4.3.2 Data collection

In the part of the pNNR where baulks separate the cutting bays the vegetation at each cutting or baulk was sampled by means of quadrats arranged as shown in Fig. 3.2. In sections 1/2W, 1/2E and 2/3W, where baulks are absent, areas equivalent to 'main' cuttings only were sampled (Fig. 3.2). Two data sets were collected at each cutting or baulk:

1. Lists were made of all species present in 'main' cuttings, 'side' cuttings and on baulks. The location and number of the 52 quadrats used in the collection of this data set, subsequently referred to as 'MS' (an abbreviation for 'main/side'), are shown in Fig. 3.3.

2. The vegetation was further sampled in the main cuttings by means of three 5x5 m quadrats, one located in the central section and one located in each of the two outer or peripheral sections of each cutting (Fig. 3.2). In 5/6W1 and 5/6W2, where the total cutting area was equivalent to the central section of most other cuttings, only one quadrat was sampled (Fig. 3.4). The peat baulks were further sampled by means of two 5x5 m quadrats (Fig. 3.2).

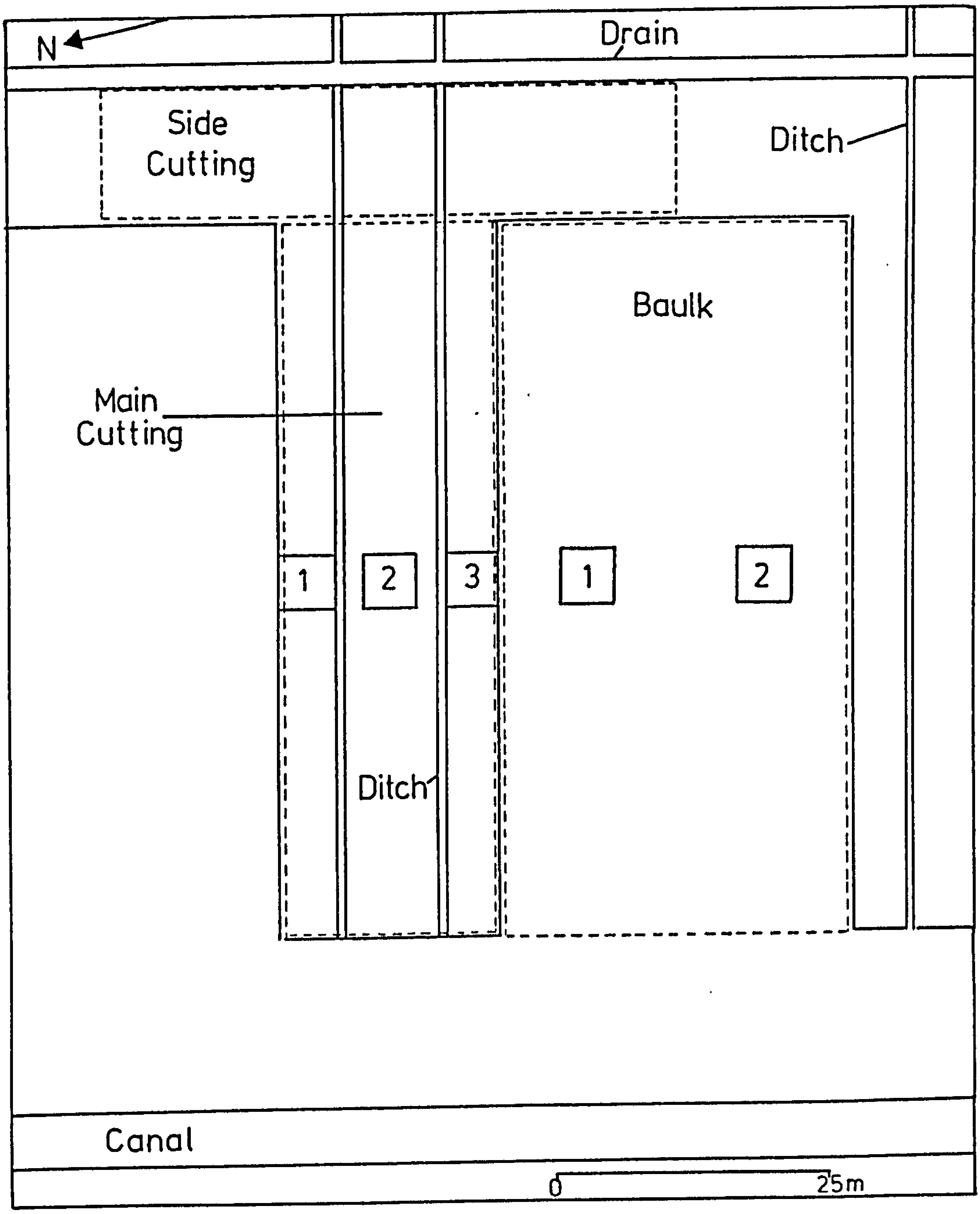


Fig. 3.2 Arrangement of quadrats used for vegetation sampling in the area of the pNNR where baulks separate the cutting bays.

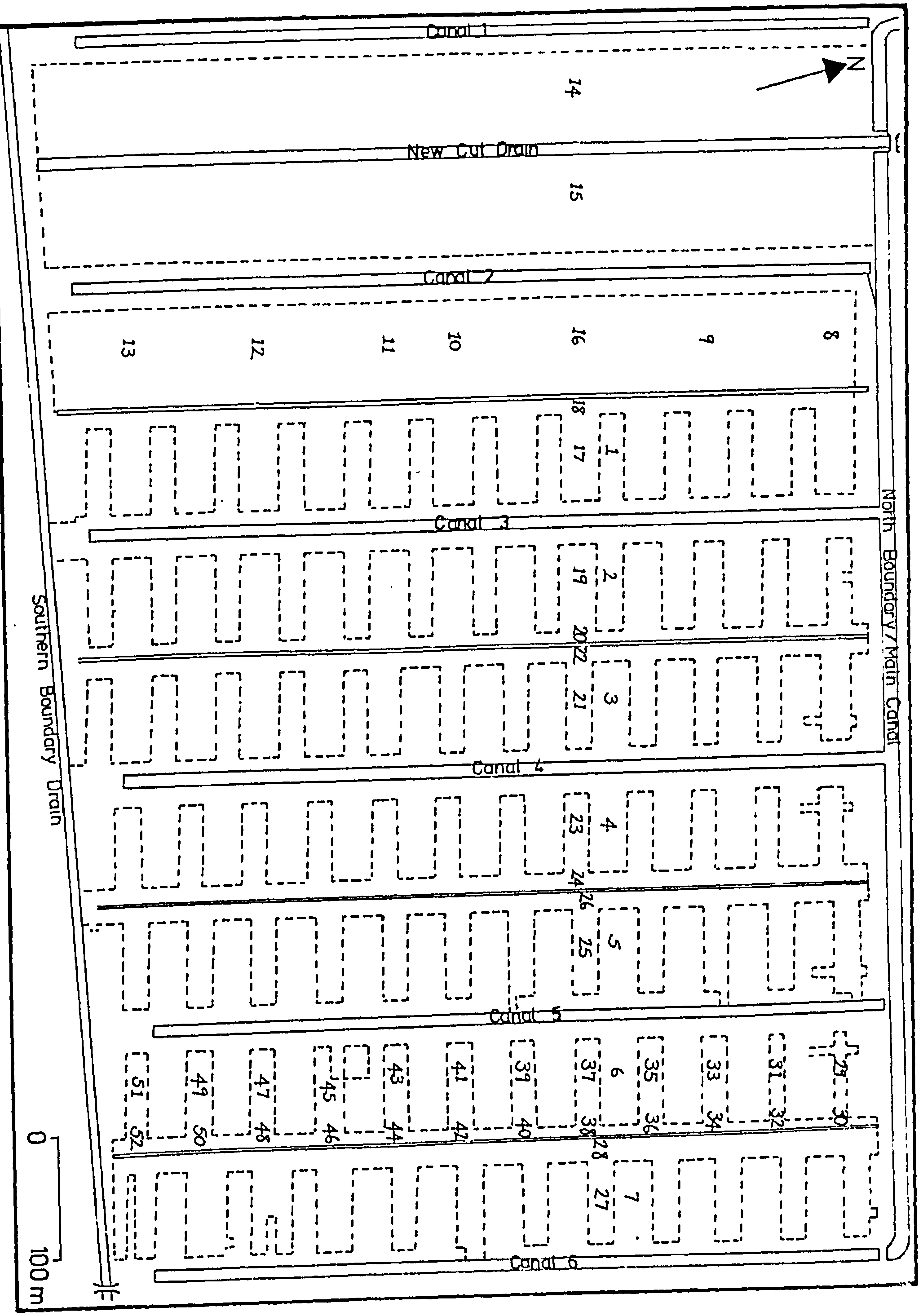


Fig. 3.3 Vegetation survey MS: location and number of quadrats.

In each quadrat, species lists were recorded using the cover-abundance scale (Table 3.1) of Braun-Blanquet (1964). This data set is subsequently referred to as 'AC' (an abbreviation for 'all cutting sections'). The location and number of the 91 quadrats used in the collection of these data are shown in Fig. 3.4.

+ sparsely or very sparsely present; cover very small
1 plentiful but of small cover value
2 very numerous, or covering at least 1/20 of the area
3 any number of individuals covering ¼ to ½ of the area
4 any number of individuals covering ½ to ¾ of the area
5 any number of individuals covering more than ¾ of the area

Table 3.1. The cover-abundance scale of Braun-Blanquet (1964).

3.4.3.3 Analysis of data

The data from surveys MS and AC were classified by cluster analysis (CLUSTAN IC package) using Ward's method of hierarchical fusion (Ward 1963). The cover-abundance data (AC data set only) were transformed by an 'ordinal transformation' (van der Maarel 1979) prior to analysis, according to the following scale:

Braun-Blanquet value	+	1	2	3	4	5
transformed value	2	3	5	7	8	9

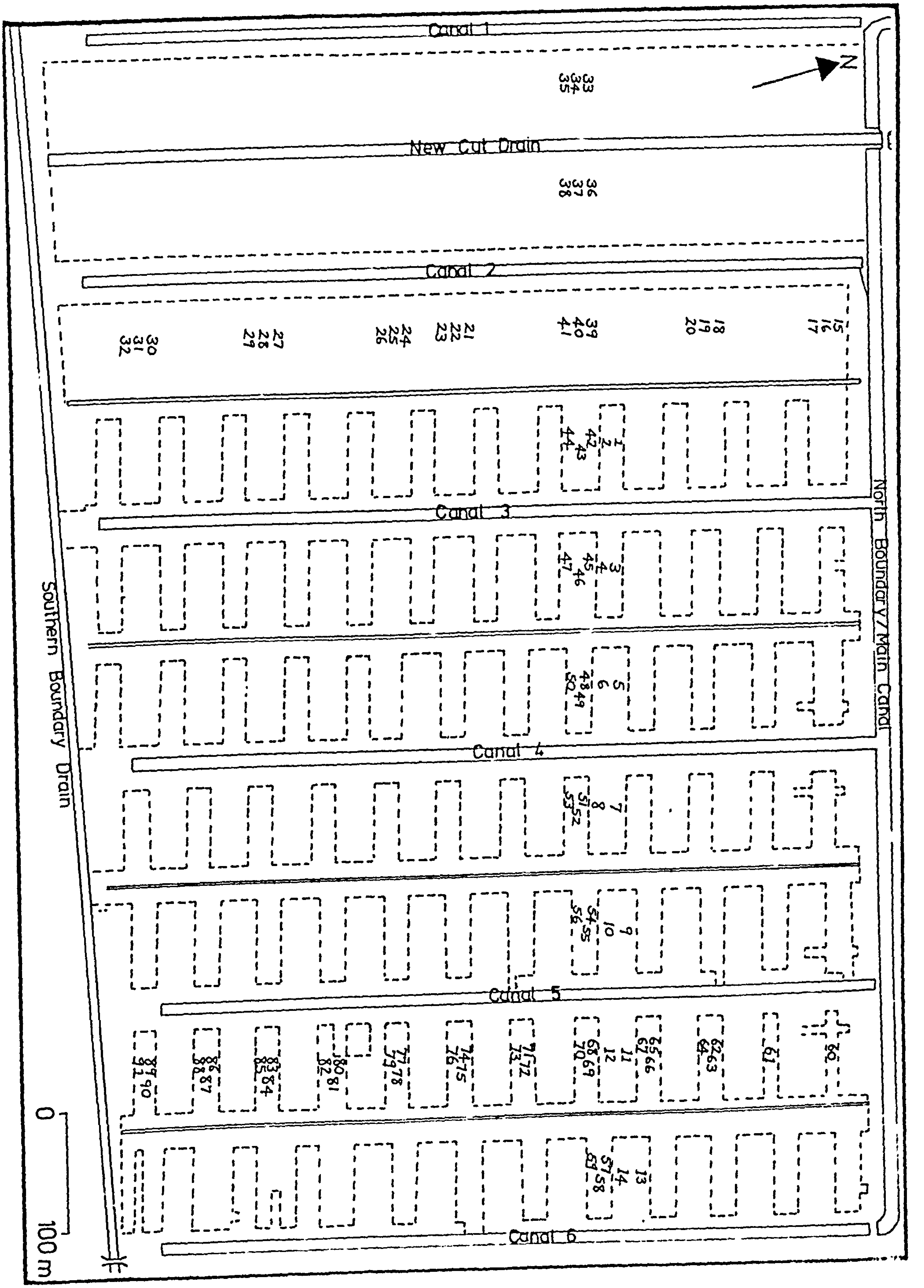


Fig. 3.4 Vegetation survey AC: location and number of quadrats.

3.4.4 Results

Dendograms displaying the classification of data sets MS and AC are shown in Figs. 3.5 and 3.6 respectively. The degree of similarity of the quadrats is indicated by the value of the error sum of squares at which they were fused together in the analysis.

Ten clusters, vegetation categories or noda (the term nodum is used to refer to an abstract vegetation unit of undetermined rank and status (Poore 1955)) were recognized from each of classifications MS and AC. The floristic features of these are displayed graphically in Appendices 1 and 2.

The data are also presented as structured species - site tables (Tables 3.2 and 3.3). In order to display clearly the main floristic features of each nodum some species occurring in one or two quadrats only were deleted. The sequence of noda and quadrats within them was also re-ordered. Species removed from both the MS and AC lists were *Calamagrostis canescens*, *Phragmites australis*, *Potentilla palustris* and *Sphagnum subnitens*. *Aulacomnium palustre* and *Sphagnum squarrosum* were also deleted from the AC list.

The distribution of noda generated by both classifications is shown in Figs. 3.7 and 3.8.

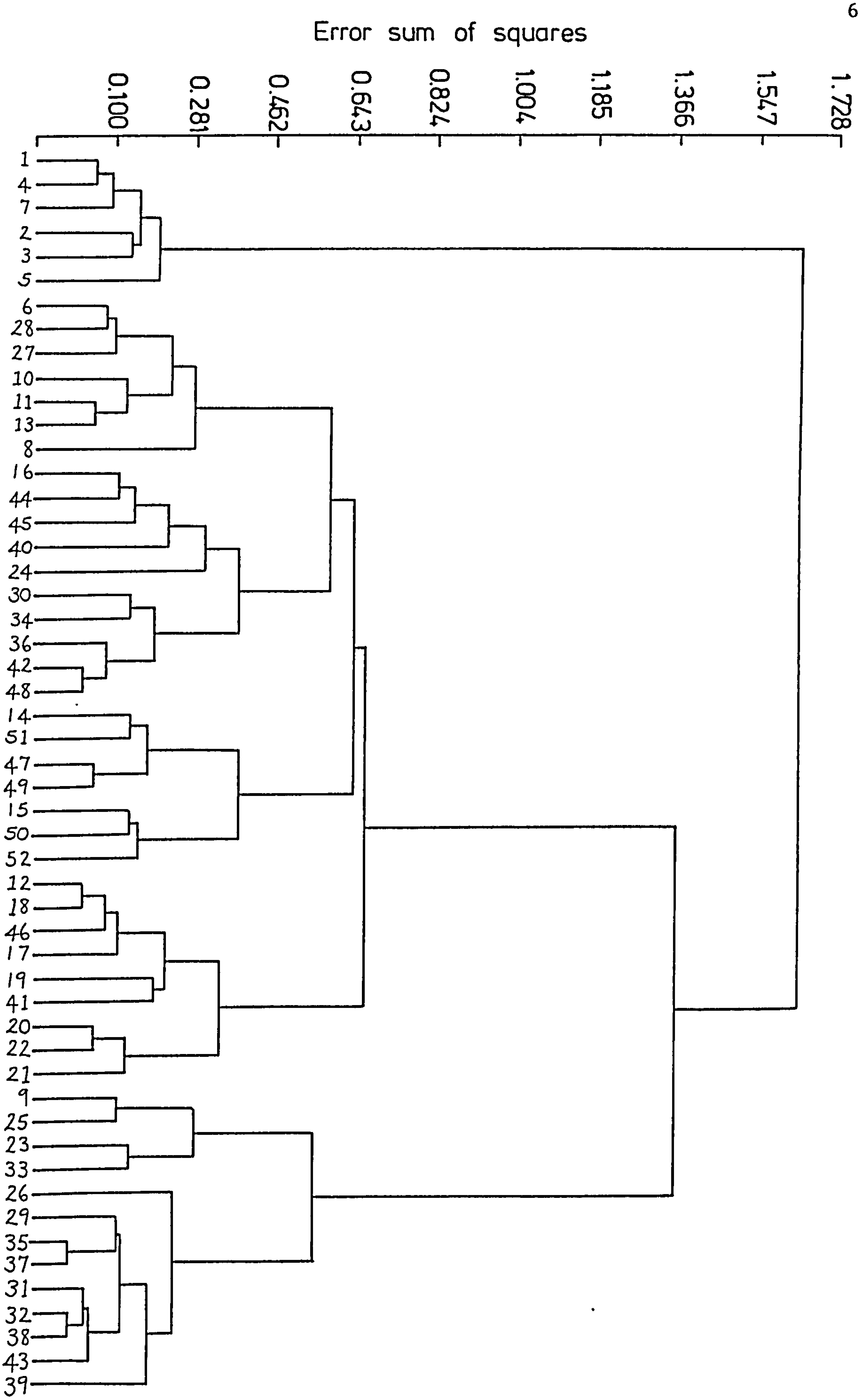


Fig. 3.5 Classification of MS quadrat data using Ward's method, based on qualitative (presence/absence) values. Quadrat locations are shown in Fig. 3.3.

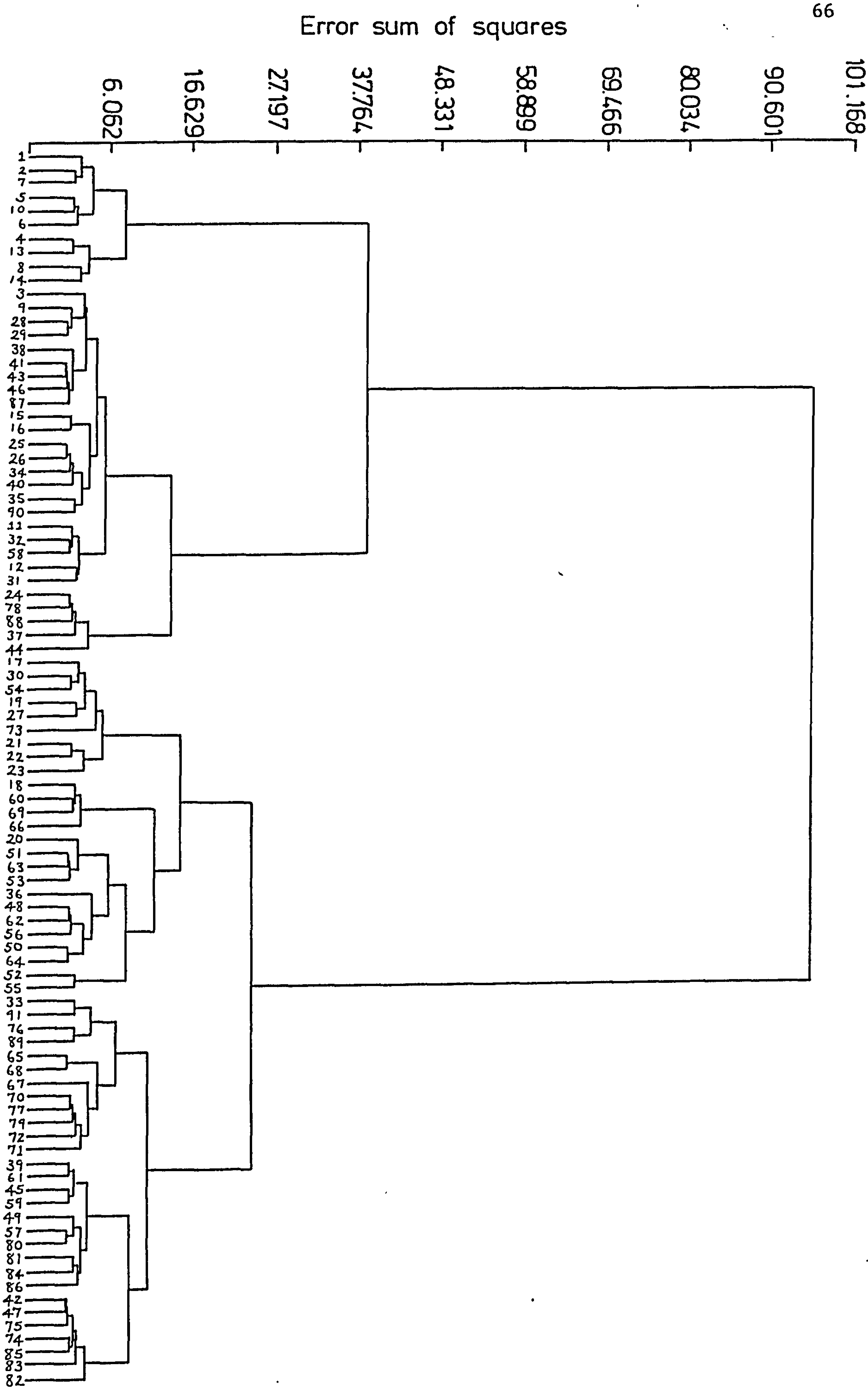


Fig. 3.6 Classification of AC quadrat data using Ward's method, based on transformed cover-abundance values. Quadrat locations are shown in Fig. 3.4.

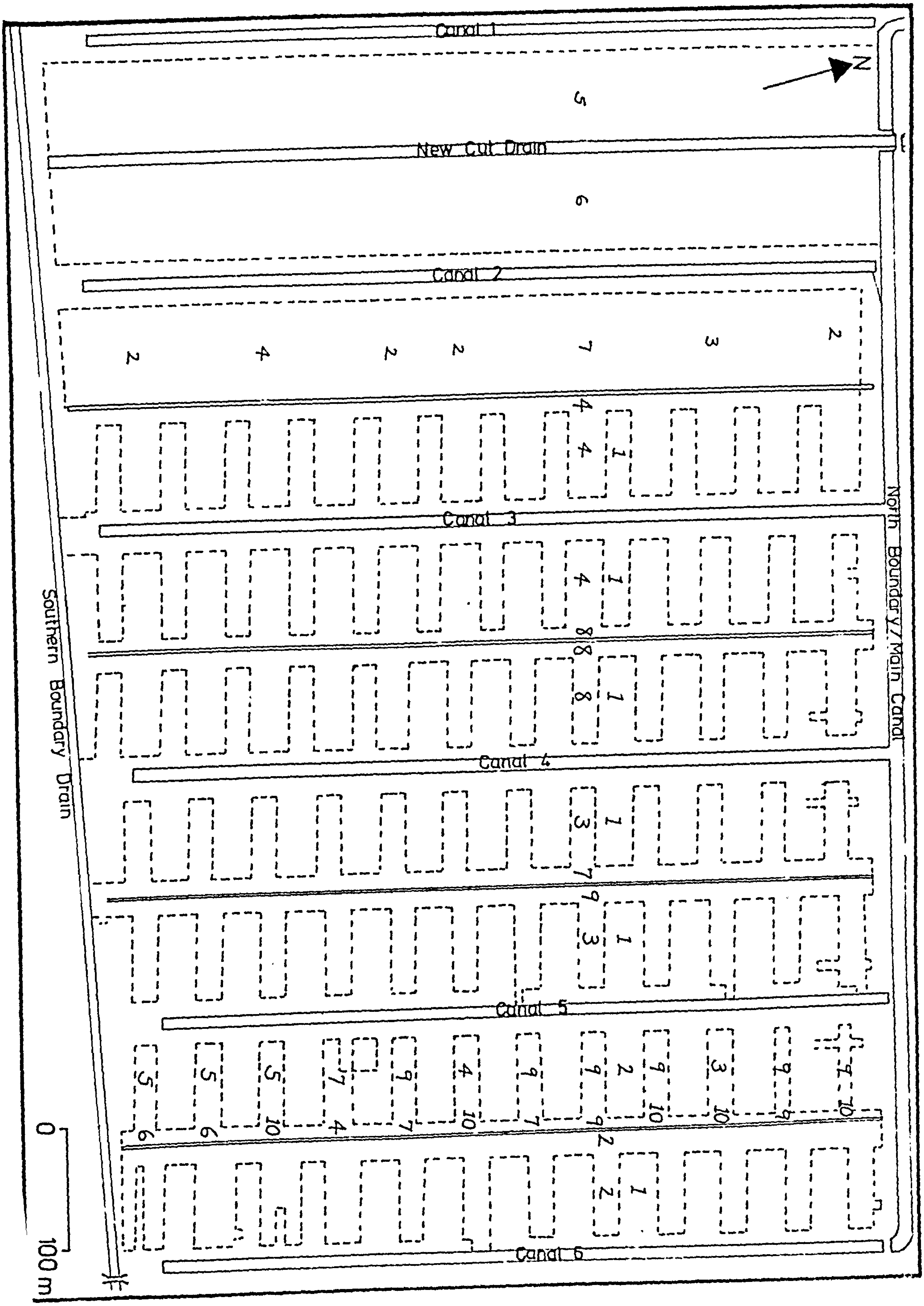


Fig. 3.7 Distribution of the ten vegetation noda generated by classification MS. Nodum names are given in Table 3.4.

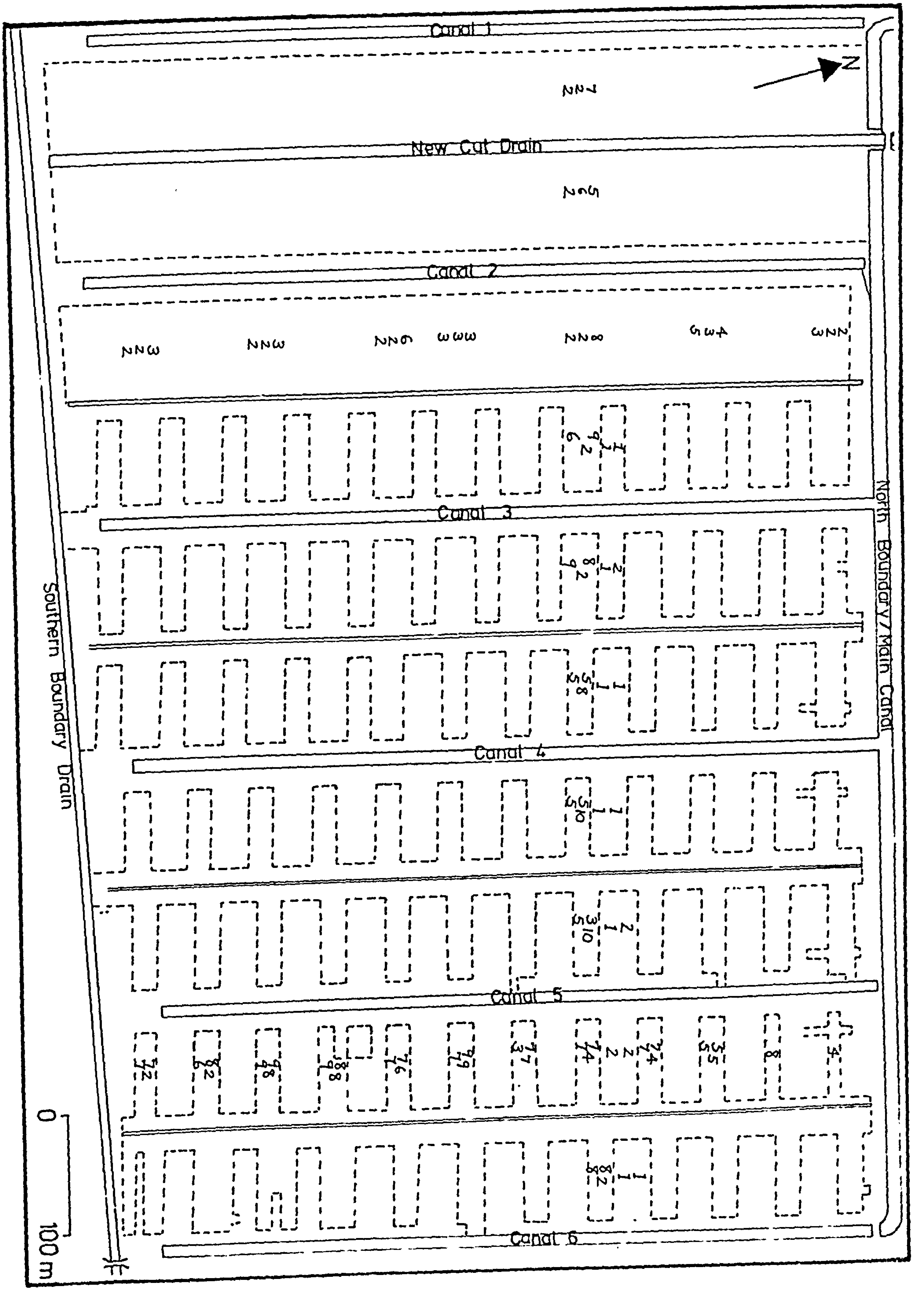


Fig. 3.8 Distribution of the ten vegetation noda generated by classification AC. Nodum names are given in Table 3.5.

3.4.5 Features of noda generated by classifications MS and AC

The floristic identity of the vegetation noda was determined by inspection of the structured species-site tables and from the graphs displaying the characteristics of each nodum (Appendices 1 and 2). The vegetation noda were named subjectively by dominant and/or characteristic species. This section describes floristic and distributional features of each nodum.

3.4.5.1 Classification MS

Table 3.4 Noda generated by classification MS

nodum number	name
1	*Pteridium-Campylopus*
2	*Sphagnum recurvum - Cephalozia*
3	*Vaccinium - Andromeda*
4	*Pteridium - Rhododendron - Sphagnum recurvum*
5	*Sphagnum fimbriatum - Quercus*
6	*Polytrichum commune - Juncus*
7	*Sphagnum - Drosera*
8	*Sphagnum - Juncus - Molinia*
9	*Sphagnum - Drepanocladus*
10	*Sphagnum fimbriatum*

Pteridium-Campylopus (nodum 1)

This nodum is characterized by high constancies of *Pteridium aquilinum, Campylopus paradoxus* and *Pohlia nutans; Polytrichum juniperinum* and *Calypogeia trichomanis* are also consistently present. This vegetation type is entirely restricted to the peat baulks.

Sphagnum recurvum-Cephalozia (nodum 2)

Sphagnum recurvum and *Cephalozia bicuspidata* occur consistently in nodum 2; *Pohlia nutans* and *Campylopus paradoxus* are also present. This vegetation type occurs in several sample sites along the 2/3W transect, at the eastern end of the transect in cutting 5 and on one peat baulk.

Vaccinium-Andromeda (nodum 3)

Vaccinium oxycoccus and *Andromeda polifolia* are consistently present in nodum 3; three species of *Sphagnum* also occur: *S. recurvum, S. fimbriatum* and *S. cuspidatum.* Cutting 2/3W3 and three 'main' cuttings at the eastern end of the pNNR contain this vegetation type.

Pteridium-Rhododendron-Sphagnum recurvum (nodum 4)

Nodum 4 is characterized by high constancies of *Pteridium aquilinum, Rhododendron ponticum, Sphagnum recurvum* and *Cephalozia bicuspidata; S. fimbriatum* is also present. Vegetation of this type occurs in all three of the major transects; it is possibly associated with areas of peat 'rubble' (2.7) in the cuttings.

Sphagnum fimbriatum-Quercus (nodum 5)

The four quadrats which contain vegetation of nodum 5 occur in the extreme west and south-east of the pNNR. *Sphagnum fimbriatum* and *Quercus robur* which are consistently present are associated with *Pohlia nutans, Polytrichum commune* and *Cephalozia bicuspidata* in this vegetation type.

Polytrichum commune-Juncus (nodum 6)

This nodum is characterized by the consistent occurrence of *Polytrichum commune* and *Juncus effusus* and, like nodum 5, occurs in the west and south-east of the pNNR.

Sphagnum-Drosera (nodum 7)

Sphagnum fimbriatum, S. recurvum and *Drosera rotundifolia* are consistently present in this nodum. The sundew may have been missed in some other quadrats through winter sampling. This may have resulted in a degree of mis-classification. This vegetation type is present in cuttings along all three of the major transects.

Sphagnum-Juncus-Molinia (nodum 8)

Sphagnum recurvum, S. fimbriatum, Juncus effusus, Molinia caerulea, Cephalozia bicuspidata and *Pteridium aquilinum* are all consistently present in this nodum. The three quadrats which contain this vegetation type are restricted to an area between canals 3 and 4 in and adjacent to cutting 5.

Sphagnum-Drepanocladus (nodum 9)

Nodum 9 is characterized by high frequencies of three species of *Sphagnum: S. recurvum, S. fimbriatum* and *S. cuspidatum,* as well as *Drepanocladus revolvens.* The quadrats which contain this vegetation type occur mainly in the 5/6W transect.

Sphagnum fimbriatum (nodum 10)

Sphagnum fimbriatum is consistently present in this nodum; *S. recurvum* and *Cephalozia bicuspidata* also occur. Nodum 10 vegetation is entirely restricted to side cuttings in the 5/6W transect.

3.4.5.2 Classification AC

Table 3.5 Noda generated by classification AC.

nodum number	name
1	*Pteridium-Campylopus*
2	*Calluna-Sphagnum recurvum*
3	*Eriophorum vaginatum-S. recurvum-Vaccinium*
4	*Eriophorum angustifolium-Sphagnum*
5	*Andromeda-Sphagnum recurvum*
6	*Calluna-Erica*
7	*Sphagnum fimbriatum-Sphagnum cuspidatum*
8	*Erica-Eriophorum vaginatum-Sphagnum fimbriatum*
9	*Sphagnum fimbriatum-Sphagnum recurvum*
10	*Vaccinium-Andromeda*

Pteridium-Campylopus (nodum 1)

This nodum is characterized by dominant *Pteridium aquilinum*, *Campylopus paradoxus*, *C. introflexus* and *Polytrichum juniperinum*; *Pohlia nutans*, *Polytrichum piliferum* and *Calypogeia trichomanis* also occur frequently. Vegetation of nodum 1 type is entirely restricted to the peat baulks.

Calluna-Sphagnum recurvum (nodum 2)

Nodum 2 is characterized by dominant *Calluna vulgaris* and the consistent presence of *S. recurvum*. *Betula pubescens*, *Pohlia nutans* and *Campylopus paradoxus* are also present and *Rhododendron ponticum* and *Pteridium aquilinum* occur sporadically. This vegetation type is widespread; it occurs on some peat baulks, in the central sections of cuttings towards the east of the pNNR and in both central and peripheral cutting sections in the south and west of the pNNR.

Eriophorum vaginatum-Sphagnum recurvum-Vaccinium (nodum 3)

Eriophorum vaginatum and *S. recurvum* are dominant in this nodum; *Vaccinium oxycoccus* is frequent. Some *Andromeda polifolia* and *S. papillosum* also occur. Nodum 3 type vegetation occurs in peripheral sections of cuttings 4/5E5 and 5/6W6 but is mostly restricted to the cuttings of the 2/3W transect.

Eriophorum angustifolium-Sphagnum (nodum 4)

This nodum is dominated by *E. angustifolium* and three species of *Sphagnum: S. recurvum, S. fimbriatum* and *S. cuspidatum; Drepanocladus revolvens* is also characteristic. Nodum 4 vegetation occurs in the northern portion of the pNNR, mainly in the central sections of cuttings in the 5/6W transect.

Andromeda-Sphagnum recurvum (nodum 5)

Andromeda polifolia and *S. recurvum* characterize this vegetation type; *Eriophorum angustifolium* and *E. vaginatum* are also frequent. Peripheral sections of peat cuttings contain this vegetation type; it also occurs in the central section of 5/6W3.

Calluna-Erica (nodum 6)

This vegetation type is dominated by *Calluna vulgaris* and *Erica tetralix*. *Eriophorum vaginatum* is also abundant. Nodum 6 occurs in the south and west of the pNNR.

Sphagnum fimbriatum-Sphagnum cuspidatum (nodum 7)

Sphagnum fimbriatum, S. cuspidatum and *Eriophorum vaginatum* are abundant in nodum 7; *Drepanocladus* spp. also occur. Vegetation of this type is mostly restricted to the peripheral sections of peat cuttings in the 5/6W transect.

Erica-Eriophorum vaginatum-Sphagnum fimbriatum (nodum 8)

Nodum 8 vegetation is dominated by *Erica tetralix*, *Eriophorum vaginatum* and *Sphagnum fimbriatum; Betula pubescens* and *E. angustifolium* are also consistently present and some *S. recurvum* occurs. This vegetation occurs in all three transects but mostly in the peripheral sections of cuttings and towards the eastern end of the pNNR.

Sphagnum fimbriatum-Sphagnum recurvum (nodum 9)

Sphagnum fimbriatum, *S. recurvum* and *Eriophorum vaginatum* are abundant and dominant in this nodum. Vegetation of this type occurs mostly in the peripheral sections of peat cuttings; it is found in the transect along cutting 5 and in the south of the 5/6W transect.

Vaccinium-Andromeda (nodum 10)

Vaccinium oxycoccus and *Andromeda polifolia* are both abundant in this nodum which also contains *Eriophorum vaginatum*, *E. angustifolium* and four species of *Sphagnum: S. recurvum*, *S. cuspidatum*, *S. fimbriatum* and *S. papillosum*. Only the central sections of cuttings 4/5W5 and 4/5E5 contain this vegetation type.

3.4.6 Comparison of classifications MS and AC

3.4.6.1 The effect of common species

Table 3.2 and Appendix 1 show that *Eriophorum angustifolium*, *E. vaginatum*, *Calluna vulgaris*, *Betula pubescens* and *Erica tetralix* were present in nearly all the quadrats examined in survey MS. They therefore played little part in the discrimination of vegetation classes in the presence-absence classification (3.4.5.1). The varying abundance of these species, however, as recorded in survey AC, does help differentiate the quadrat data into classes based on the quantitative records (Table 3.3, Appendix 2 and 3.4.5.2). For example, the dominance of *Calluna vulgaris* in AC nodum 2 and *Eriophorum vaginatum* in AC nodum 3 distinguishes these noda. Classification MS is largely dependent on species of intermediate constancy to differentiate noda; as these may, for example, be missed (e.g. *Drosera rotundifolia*), the usefulness of some of the noda generated by this classification may be questioned.

3.4.6.2 Noda of similar composition

Table 3.6 Noda of similar composition generated by classifications MS and AC.

Classification MS		Classification AC	
nodum number	nodum name	nodum number	nodum name
1	*Pteridium-Campylopus*	1	*Pteridium-Campylopus*
2	*Sphagnum recurvum-Cephalozia*	2	*Calluna-Sphagnum recurvum*
3	*Vaccinium-Andromeda*	10	*Vaccinium-Andromeda*

The noda shown in Table 3.6 are comparable vegetation types recognized in both classifications. MS nodum 1, for example, is characterized by *Pteridium aquilinum*, *Campylopus paradoxus* and *Pohlia nutans* as is AC nodum 1. The species composition of the other nodum pairs listed is also similar.

Figs. 3.7 and 3.8 show that these pairs of noda also have a similar distribution in the pNNR: the nodum 1 vegetation of both classifications is restricted to peat baulks; MS nodum 3 and AC nodum 10 occur only in cuttings 4/5W5 and 4/5E5 and the nodum 2 vegetation of MS and AC occurs in the west, south-west and eastern portions of the pNNR.

The greater use of the relative abundance of species to differentiate units in classification AC probably explains why only three noda of similar composition were generated by these two classifications.

3.4.7 Other peat cuttings of the Dutch Canal System

The noda generated by classification AC may be used to describe the vegetation of peat cuttings of the canal systems outside the pNNR.

3.4.7.1 The eastern Southern and Northern Dutch Canal Systems

Most of the Northern Dutch Canal System and the area to the east of canal 6 in the Southern Dutch Canal System consist of series of alternating baulks and cuttings similar to those of the pNNR (2.7).

In the cuttings most of the vegetation may be classified in noda dominated by *Eriophorum* spp.: noda 3 (*Eriophorum vaginatum-Sphagnum recurvum-Vaccinium*), 4 (*Eriophorum angustifolium-Sphagnum*) and 8 (*Erica-E. vaginatum-Sphagnum fimbriatum*). Nodum 2 (*Calluna-S. recurvum*) and nodum 6 (*Calluna-Erica*) also frequently occur in parts of the cuttings. In the eastern Southern Dutch Canal System noda dominated by *Sphagnum fimbriatum* (7: *S. fimbriatum-S. cuspidatum* and 9: *S. fimbriatum-S. recurvum*) cover a greater cutting area than in the Northern Dutch Canal System. *Andromeda polifolia* is less common in the eastern Southern and Northern Dutch Canal Systems than in the pNNR and noda 5 (*Andromeda-S. recurvum*) and 10 (*Vaccinium-Andromeda*) occur only rarely. The dry peat baulks are mostly occupied by vegetation of nodum 1 (*Pteridium-Campylopus*); nodum 2 vegetation (*Calluna-S. recurvum*) also occurs in these areas.

3.4.7.2 The Mill and Pighill Canals area

The region between the Mill and Pighill Canals consists mostly of peat cutting areas with a few, relatively small, intervening peat baulks (2.7).

Flooded peat cuttings principally contain *Eriophorum* dominated noda (3, 4 and 8). Towards the western edge of The Moors vegetation of nodum 2 (*Calluna-Sphagnum recurvum*), nodum 6 (*Calluna-Erica*) and the *Pteridium-Campylopus* nodum (also present on the peat baulks) becomes more frequent in the cutting areas.

3.4.8 Other species recorded from peat cuttings and baulks

Species present in the peat cuttings of the pNNR but rare and not recorded during surveys MS and AC, include *Juncus bulbosus, Dryopteris dilatata, D. carthusiana, Sphagnum palustre, S. capillifolium, Calypogeia muellerana, C. fissa* and *Dicranella heteromalla*. *Betula pendula* and *Populus tremula* occur infrequently on the peat baulks.

Some species formerly recorded from Thorne Moors have not been observed at all during the present investigation e.g. *Drosera intermedia*. This species was seen in 1973 (Dr J G Hodgson, personal communication); however, it is likely that the specimens observed at this time were present as a result of the introduction of this plant to the area by Bunting (Bunting 1949; 3.2.2.2).

Myrica gale, recorded as 'scarce' by Skidmore (1970) and *Sphagnum russowii* recorded by Dalby (YNU 1970) were also not observed.

3.5 VEGETATION OF THE DUTCH CANALS

3.5.1 Introduction

The Dutch Canals would probably have been of little botanical interest when Peacock wrote his monograph (Peacock 1920, 1921). Since their abandonment in 1920, however, they have become colonized by a flora which contains some species Peacock thought had disappeared completely from the site (Skidmore 1970; 3.2.3).

In June 1974 Dr T Dargie carried out an investigation into the vegetation of the Dutch Canals in the pNNR area: canals 1-6 of the Southern Dutch Canal System and the Main Canal between canals 1-6 (Fig. 2.2). A summary of the results of this investigation is presented here. The vegetation of the other canals is also described briefly.

3.5.2 Data analysis and results

The data were classified by a cluster analysis with Ward's method of hierarchical fusion (Ward 1963).

Six noda (subsequently referred to as noda C1-C6) were recognized from the cluster analysis. The number of occurrences of each species in the sample units of each nodum are represented as percentage values in Table 3.7. The distribution of the six vegetation noda in the canals is shown in Fig. 3.9.

3.5.3 Floristic and distributional features of each nodum

Nodum C1

This nodum is dominated by *Phragmites australis*, *Juncus articulatus*, *Sphagnum fimbriatum*, *Molinia caerulea* and *Rhododendron ponticum*. *Carex acutiformis*, *S. papillosum* and *Equisetum fluviatile* are also frequent in this vegetation type, *E. fluviatile* being entirely restricted to this nodum. This vegetation occurs in the northern reaches of canals 1, 2 and 4; one nodum C1 sample unit also occurs in the north of canal 5.

Table 3.7 Percentage occurrence of species in sample units within each nodum

NODUM NUMBER	C1	C2	C3	C4	C5	C6
NUMBER OF SAMPLE UNITS	14	17	19	15	25	17
Agrostis stolonifera	0	6	32	40	8	0
Andromeda polifolia	21	0	11	67	32	6
Betula pubescens	100	100	100	100	100	47
Calamagrostis canescens	79	94	89	47	92	53
Calamagrostis epigejos	0	0	11	13	4	0
Calluna vulgaris	57	29	32	67	68	6
Cardamine pratensis	7	41	0	27	0	12
Carex acutiformis	14	0	0	7	8	0
Carex curta	57	100	32	73	76	29
Carex elata	0	0	21	13	4	0
Carex nigra	14	6	0	33	4	0
Cirsium palustre	0	0	5	0	0	0
Cladium mariscus	0	6	0	0	0	18
Drosera rotundifolia	21	6	47	27	92	0
Dryopteris dilatata	7	12	0	0	32	0
Equisetum fluviatile	21	0	0	0	0	0
Erica tetralix	93	82	100	100	100	18
Eriophorum angustifolium	71	41	100	80	100	0
Eriophorum vaginatum	64	24	63	73	80	0
Galium palustre	57	71	32	33	32	76
Glyceria maxima	7	18	0	0	4	47
Hydrocotyle vulgaris	29	71	58	73	48	12
Juncus articulatus	79	41	42	33	12	0
Juncus bulbosus	14	12	95	80	24	12
Juncus effusus	100	100	100	100	100	82
Lemna spp.	14	29	0	20	4	41
Lycopus europaeus	0	6	0	100	0	18
Lythrum salicaria	43	59	53	67	52	76
Molinia caerulea	79	24	100	0	8	6
Osmunda regalis	0	0	21	13	4	0
Phalaris arundinacea	0	59	0	0	0	65
Phragmites australis	79	47	32	60	8	35
Potamogeton polygonifolius	21	12	42	40	0	0
Potentilla palustris	79	88	16	33	100	29
Ranunculus flammula	0	35	0	7	0	24
Rhododendron ponticum	79	0	0	13	4	6
Salix cinerea	100	100	100	100	100	100
Salix repens	7	0	32	13	4	0
Schoenoplectus tabernaemontani	0	6	5	47	48	0
Scrophularia nodosa	7	18	0	0	0	6
Sparganium erectum	0	12	0	0	0	0
Typha latifolia	50	76	32	47	76	65
Utricularia vulgaris	14	24	0	7	32	41
Vaccinium oxycoccus	0	0	11	27	0	0
Aulacomnium palustre	79	47	21	100	8	6
Calliergon stramineum	29	47	21	60	4	24
Drepanocladus revolvens	14	29	47	80	92	6
Polytrichum commune	100	71	37	93	92	12
Sphagnum cuspidatum	36	6	37	0	4	6
Sphagnum fimbriatum	100	47	68	100	12	0
Sphagnum papillosum	50	6	16	7	0	0
Sphagnum recurvum	86	94	89	80	80	76
Sphagnum squarrosum	29	94	11	73	36	6
Sphagnum subnitens	57	12	89	100	32	6

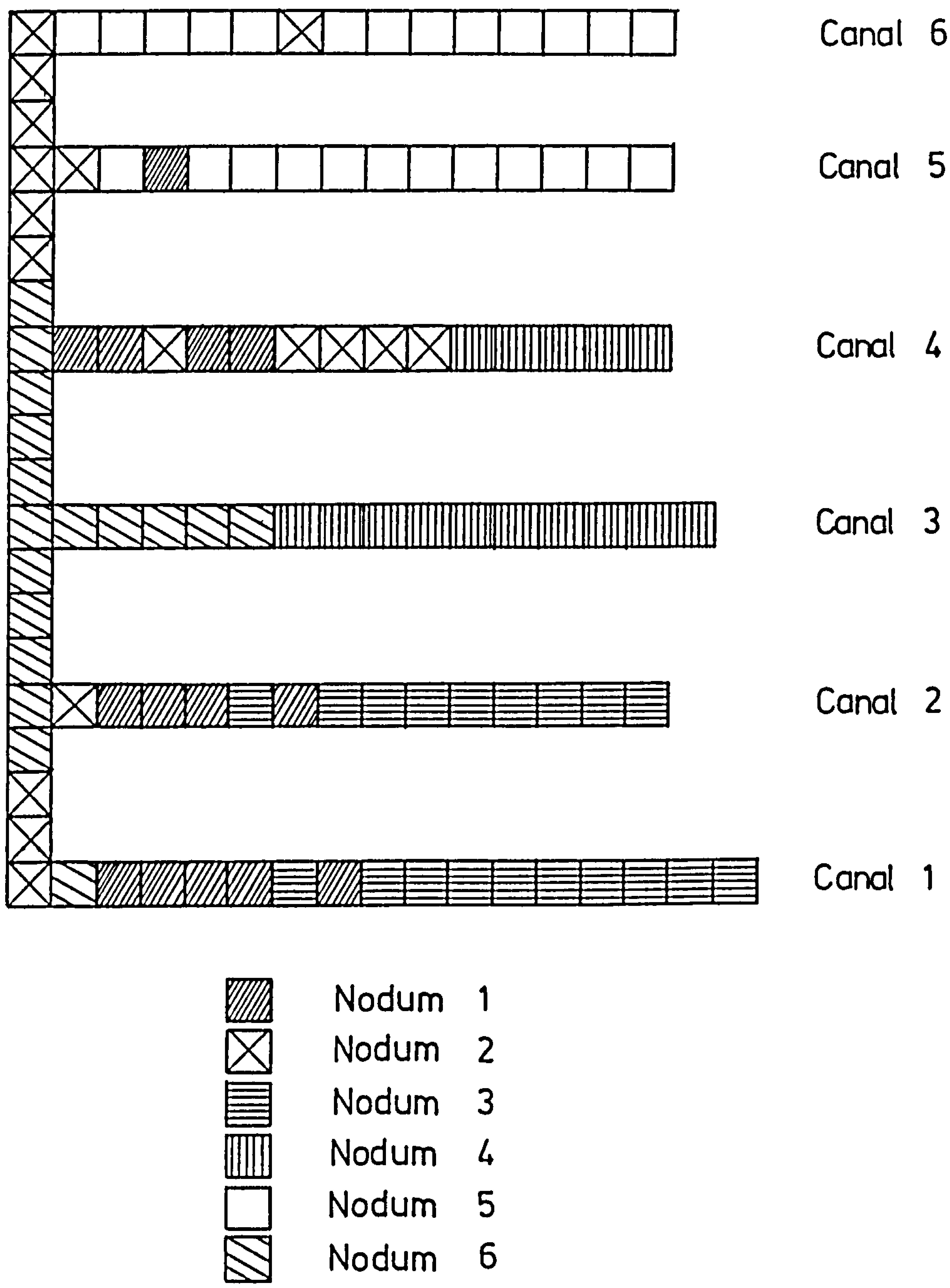


Fig. 3.9 Distribution of six vegetation noda in the canals of the Southern Dutch Canal System.

Nodum C2

Phalaris arundinacea, Typha latifolia, Carex curta and *Potentilla palustris* are dominant in nodum C2; *Sparganium erectum, Glyceria maxima, Cladium mariscus* and *Ranunculus flammula* also occur frequently. In addition, this vegetation type is characterized by a high proportion of *Sphagnum recurvum* and *S. squarrosum*. Nodum C2 vegetation occurs mainly at the west and eastern ends of the Main Canal and approximately half way down canal 4.

Nodum C3

Nodum C3 contains a high proportion of *Juncus bulbosus, Sphagnum subnitens, Carex elata, Salix repens* and *Potamogeton polygonifolius* and is also characterized by the presence of *Cirsium palustre, Vaccinium oxycoccus, Calamagrostis epigejos* and *Osmunda regalis*. This vegetation type occurs only in the middle and southern reaches of canals 1 and 2.

Nodum C4

Andromeda polifolia, Lycopus europaeus and *Aulacomnium palustre* are dominant in this nodum which is also characterized by a relatively high proportion of *Carex elata, C. acutiformis, C. nigra, Osmunda regalis, Schoenoplectus tabernaemontani* and *Vaccinium oxycoccus*. Of the Sphagna, *S. fimbriatum, S. subnitens* and *S. squarrosum* occur frequently. Nodum C4 vegetation is restricted to the middle and southern reaches of canal 3 and the south of canal 4.

Nodum C5

This nodum is dominated by *Calamagrostis canescens*, *Potentilla palustris*, *Drosera rotundifolia* and *Typha latifolia*. *Dryopteris dilatata* and *Schoenoplectus tabernaemontani* are also present in this vegetation type. This vegetation occupies most of canals 5 and 6.

Nodum C6

Phalaris arundinacea, *Glyceria maxima*, *Typha latifolia* and *Lythrum salicaria* are dominant in nodum C6; this reedswamp vegetation also contains *Phragmites australis*, *Cladium mariscus*, *Utricularia vulgaris*, *Galium palustre*, *Lemna* spp. and a relatively low proportion of *Sphagnum* spp. Nodum 6 vegetation is mostly restricted to the middle reaches of the Main Canal and the north of canal 3.

3.5.4 The vegetation of the Dutch Canals outside the pNNR

3.5.4.1 The Southern Dutch Canal System east of canal 6.

The vegetation of the Main Canal between side canals 6 and 12 grades from the nodum C6 reedswamp vegetation into a community dominated by *Carex demissa*, *Sphagnum squarrosum*, *S. cuspidatum* and *Potentilla palustris*; *Phragmites australis*, *Typha latifolia*, *Molinia caerulea* and *Schoenoplectus tabernaemontani* also occur.

Canal 7 is dominated by *Eriophorum angustifolium* and *Sphagnum* spp. - particularly *S. cuspidatum*, *S. auriculatum* var. *auriculatum* and *S. fimbriatum*; *Andromeda polifolia*, *Potentilla palustris*, *Juncus bulbosus*, *Sphagnum recurvum* and *Drepanocladus* spp. also occur.

Canal 8 contains much *Sphagnum fimbriatum*, *Eriophorum angustifolium*, *Juncus effusus*, *Typha latifolia* and *Phragmites australis*. Other species present in this canal include *Potentilla palustris*, *Erica tetralix*, *Drosera rotundifolia* and *Drepanocladus fluitans*.

Of the remaining canals, no. 9, adjacent to a tramway (Fig. 2.2), is filled in and no. 10 is much overgrown, containing mostly *Juncus effusus* and *Molinia caerulea*. Parts of canals 11 and 12 are either cut-away or contain *J. effusus*, *Phragmites australis* and *Molinia caerulea* (2.7).

3.5.4.2 The Northern Dutch Canal System and the Mill and Pighill Canals

The canals to the north of Cottage Dike and west of canal 1 are less species-rich than those of the Southern System. They contain stands of *Phragmites australis* with *Typha latifolia*, *Sphagnum fimbriatum* and some *Potentilla palustris* but otherwise communities similar to those of the peat cuttings of the pNNR (3.4) fill these canals.

3.5.5 Other species recorded from the Dutch Canals

Species observed during the present investigation or recorded relatively recently in the canals by other workers which are not shown in Table 3.7 are listed in Table 3.8.

At present the canals contain some species found originally on the bog margins and in the ancient turbaries such as, for example, *Cladium mariscus*, *Potentilla palustris*, *Lycopus europaeus* and *Ranunculus flammula* (Peacock 1920, 1921; 3.2.1.2). However, other species, also at one time characteristic of the mire edges including *Dryopteris cristata*, *Peucedanum palustre*, *Hypericum elodes*, *Anagallis tenella* and *Pyrola minor*, have not been recorded either in the canals or elsewhere on Thorne Moors for many years (3.2.2).

3.5.6. Species composition of the canal vegetation

Tables 3.7 and 3.8 show that the Dutch Canals, particularly those of the pNNR, are extremely species-rich. In addition, species characteristic of both ombrotrophic and mesotrophic mires and maritime habitats co-exist in the canals. Table 3.9 shows the habitats in which certain species recorded from the canals are usually restricted.

Table 3.8 Other species recorded from the Southern Dutch Canal System (not listed in Table 3.7). Species marked * have been observed during the present investigation.

Calamagrostis stricta	Dr J G Hodgson (1972), personal communication
*Carex demissa**	
*Carex otrubae**	
Carex panicea	Dr J G Hodgson (1972), personal communication
*Dryopteris carthusiana**	
*Eleocharis palustris**	
*Epilobium palustre**	
*Equisetum palustre**	
*Galium saxatile**	
*Holcus lanatus**	
*Hottonia palustris**	
*Juncus bufonius**	
*Lysimachia vulgaris**	
Menyanthes trifoliata	Skidmore (1970)
Myriophyllum alterniflorum	YNU (1970)
Oenanthe fistulosa	YNU (1970)
Pinguicula vulgaris	Skidmore (1970)
*Ranunculus sceleratus**	
Salix caprea	Dr J G Hodgson (1972), personal communication
Salix viminalis	Dr J G Hodgson (1972), personal communication
Schoenoplectus lacustris	YNU (1970)
Scirpus maritimus	YNU (1970)
*Sparganium emersum**	
Triglochin palustris	Skidmore (1970)
*Typha angustifolia**	
Utricularia minor	Miss F E Crackles (YNU 1969), personal communication
Viola stagnina	Skidmore (1970)
*Calliergon cordifolium**	
*Calliergon cuspidatum**	
*Calypogeia trichomanis**	
*Drepanocladus exannulatus**	
*Drepanocladus fluitans**	
*Gymnocolea inflata**	
*Pellia epiphylla**	
Sphagnum auriculatum var. *auriculatum**	
Sphagnum auriculatum var. *inundatum**	
*Sphagnum capillifolium**	
Sphagnum contortum	Goode (1973)
Sphagnum subsecundum	YNU (1970)
*Sphagnum palustre**	

Table 3.9 Typical habitats (in Britain) of species recorded from the canals

rich fen	poor fen
Carex acutiformis	*Carex curta*
Carex elata	*Carex demissa*
Cladium mariscus	*Juncus bulbosus*
Glyceria maxima	*Myriophyllum alterniflorum*
Lysimachia vulgaris	*Potamogeton polygonifolius*
Lythrum salicaria	*Calliergon stramineum*
Phalaris arundinacea	*Sphagnum squarrosum*

ombrotrophic mire	maritime habitats
Andromeda polifolia	*Schoenoplectus tabernaemontani*
Erica tetralix	*Scirpus maritimus*
Eriophorum vaginatum	*Triglochin palustris*
Vaccinium oxycoccus	
Sphagnum capillifolium	
Sphagnum cuspidatum	
Sphagnum papillosum	

CHAPTER 4

STRATIGRAPHICAL INVESTIGATIONS

4.1 INTRODUCTION

4.1.1 Previous research

The earliest palaeoecological studies on Thorne Moors were carried out by Erdtman (1928) who concluded that peat formation began late in the Atlantic period (zone VIIa). Subsequent work by Pigott (1956), however, suggested that the Thorne Moors peats corresponded to the upper part of zone VIIb and zone VIII. Investigations which involved radio-carbon dating of the peat deposits (Turner 1962, 1965; Buckland & Kenward 1973; Buckland 1979) confirmed Pigott's observations, showing that the main period of peat formation at Thorne Moors began c. 3000 years ago, during the Bronze Age. The palaeoecological studies carried out by Buckland & Kenward (1973) suggested that the construction of an ancient trackway, found at the base of the peat at Thorne, and the initiation of peat formation, were a response to increasingly wet conditions. They also considered that waterlogging of the area may have curtailed all agricultural activity in the region (cf. Turner 1962, 1965).

Of the investigations cited above, only Pigott (1956) carried out detailed stratigraphical studies into the plant macrofossils, but this work was not published in full. However, a detailed stratigraphical and palynological analysis has been carried out on Hatfield Moors, 3 km south of Thorne Moors, by Smith (1958).

4.1.2 Specific objectives

Peat cores were extracted down to the clay in several areas to investigate the general stratigraphical development of the mire. However, the main emphasis of the present work was on the most recent stratigraphical changes, as follows:

1. In the pNNR:

a) An attempt was made to determine the depth of the base of the abandoned peat cuttings (last cut around 1920). The stages in recolonization of cut-over areas were investigated in several cores.

b) Cores from peat baulks were examined to investigate recent vegetational changes and to establish if these areas were cut for peat.

c) The Dutch Canals were sampled in order to investigate their recolonization by vegetation since abandonment (around 1920).

2. Other peat cuttings

a) Recent vegetational changes were investigated in the *Juncus effusus* area (JA), a peat cutting abandoned in the early 1960's.

b) The Experimental Plot (EP) was sampled in order to investigate the extent of recolonization since 1972, when this cutting was abandoned.

c) A peat core was extracted from a peat cutting currently being worked by Fisons Ltd., subsequently referred to as a 'modern peat cutting'. Particular interest was in determining the type of peat being extracted at the present time.

The depth of the peat was established in all areas investigated.

4.2 MATERIALS AND METHODS

4.2.1 Location of sample sites

In the pNNR peat cores were extracted from a north-south transect across cutting 4/5W4 and from a west-east transect in the central sections of peat cuttings, on their adjacent southern peat baulks and in the canals at the position of cutting 5; the Main Canal was also sampled (Fig. 4.1). In addition, peat cores were collected from JA, EP (Fig. 5.3) and from a modern peat cutting located to the east of the tramway adjacent to canal 9 and north of the Main Canal (Fig. 2.2).

4.2.2 Collection of samples

Peat cores were obtained with a 'Russian' pattern borer (Jowsey 1966). In the peat cuttings the areas of peat 'rubble' (2.7) were avoided. With the exception of the central section of cutting 4/5W4 and its southern baulk (which were sampled down to the underlying clay), all cuttings and baulks in the pNNR were sampled to a depth of 1 m only. At all other sample sites

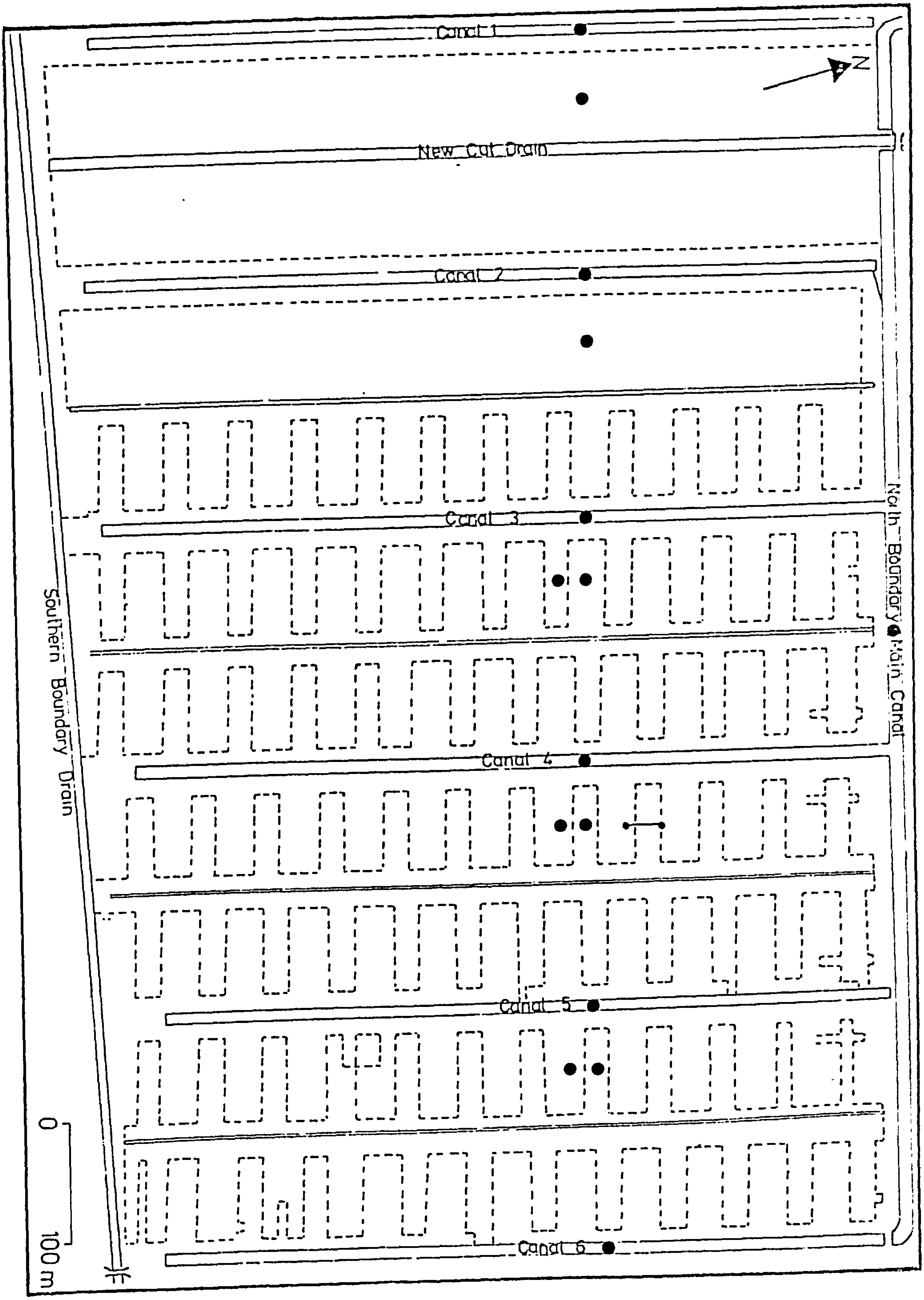


Fig. 4.1 Location of sample sites in the pNNR selected for stratigraphical investigation. Six peat cores were extracted from the transect across cutting 4/5W4 (Fig. 4.3); three peat cores were extracted from canal 3 (Fig. 4.8a).

(excluding additional samples collected from canal 3; see Fig. 4.8a) cores were extracted to the level of the underlying clay.

In an attempt to establish the depth of the original cutting surface the humification and density of some surface peat cores were examined in the field. Most cores, however, were transported to the laboratory in rigid plastic containers wrapped in plastic sheets. They were stored at 2^oC prior to examination (completed within 14 days).

4.2.3 Stratigraphical examination

The macrofossils, including leaves, cuticles, seeds, stems and wood in each 1 or 2 cm segment of each core were identified to a depth of 50 cm; below this depth each 10 cm segment was examined. In each sample the predominant macrofossil present was given a frequency rating on a three-class scale, according to whether it contributed up to 25%, 25-75% or 75-100% of the total sample. The degree of humification was also recorded on a three-class basis using the humification scale of Von Post & Granlund (1926): H1-H3 (weakly humified material); H4-H6 (moderately humified); H7-H10 (strongly humified).

4.3 THE PEAT STRATIGRAPHY DIAGRAMS

4.3.1 Representation of the stratigraphy

The peat stratigraphy is shown in Figs. 4.3-4.9; a key to stratigraphical symbols is given in Fig. 4.2.

To classify and subsequently describe the peat deposits a modification of the Troels-Smith (1955) system was used (Aaby 1979; Smart 1982). The number of symbols per unit area indicates the frequency of the predominant macrofossil on a three class scale (4.2.3); the highest density corresponds to the highest frequency class. The thickness of the symbol strokes indicates the degree of humification in one of three classes; the thickest strokes represent the most strongly humified deposits (H7-H10). The other classes are H4-H6 and H1-H3.

The vegetation of the sites from which peat cores were extracted is described in Chapter 3. The water level of the 4/5W4 transect (in April 1982) is shown in Fig. 4.3; this transect was levelled when the surface was completely flooded by determination of the depth of standing water above the peat surface. With the exception of the cores extracted from cuttings and their adjacent baulks (Figs. 4.5-4.7), the relative heights of the study sites are unknown; this is because of the difficulty in determining levels across the area (Chapter 1). The water level of the other peat cutting study sites is described in Chapter 5.

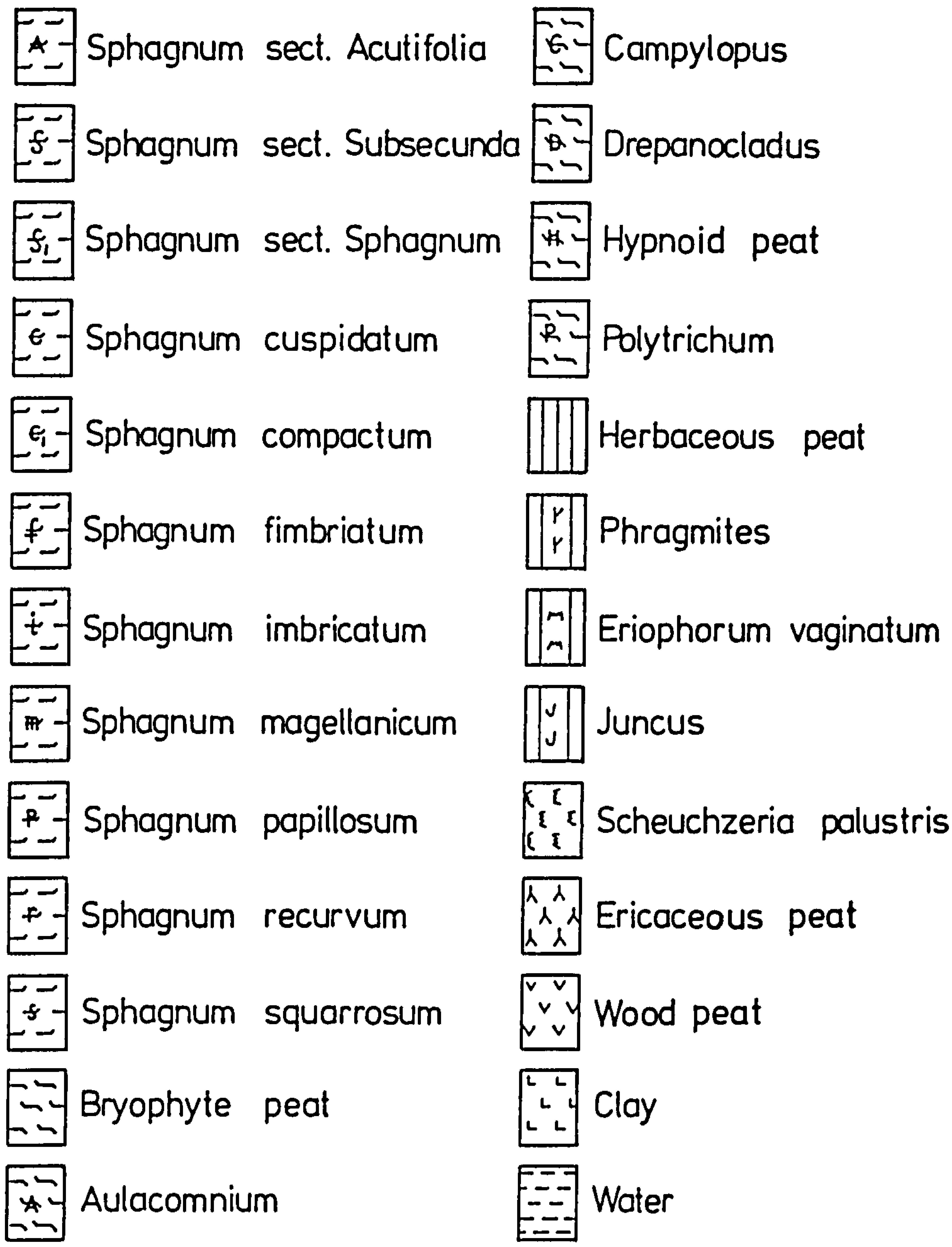


Fig. 4.2 Key to peat deposits.

In the following section the gross stratigraphy of the 4/5W4 transect is described; thereafter only contrasting and sub-surface features of the stratigraphy are mentioned in relation to the other study sites.

4.3.2 Stratigraphy of the 4/5W4 transect (Fig. 4.3)

4.3.2.1 Gross stratigraphical features

1. Wood peat, consisting mostly of the remains of *Betula* sp(p).,occupied the base of the complete cores (C and F) above the underlying clay.

2. Above the wood peat, to a depth of 95 cm, the cores contained a variety of peat types including the remains of *Sphagnum imbricatum* (often weakly humified), *S.* sect. *Acutifolia*, *S. cuspidatum*, *S.* sect. *Subsecunda*, *Aulacomnium*, ericaceous plants (consisting mostly of *Vaccinium oxycoccus* and *Calluna*) and *Scheuchzeria palustris*.

3. *Scheuchzeria palustris* peat did not form a consistent horizon across all cores. Nevertheless it was often present at a similar depth in several cores. Above 60 cm and between 165-175 cm and 205-235 cm remains of *Scheuchzeria palustris* were absent from all cores.

4. With the exception of the cores from the ditches (B and D), the weakly humified remains of *Sphagnum imbricatum* occurred in all cores above 95 cm; core F also contained *Scheuchzeria palustris* peat.

Fig. 4.3 Peat stratigraphy of cores from the 4/5W4 transect.

4.3.2.2 Sub-surface stratigraphical features

1. Core B (from a ditch)

Between 3-6 cm from the surface (at a depth of 83-86 cm) a band of ericaceous peat occurred above *Sphagnum imbricatum* peat; the surface deposit (at the base of the ditch) consisted of *Drepanocladus* remains.

2. Core D (from a ditch)

Between 14-15 cm from the surface (at a depth of 94-95 cm) a band of *Sphagnum recurvum* peat occurred over *S. cuspidatum* remains; ericaceous and *Drepanocladus* peats occurred between 4 and 14 cm from the surface (84-94 cm) whilst the top 4 cm of the core (at the base of the ditch) consisted of *Sphagnum recurvum* remains.

3. Cores A and E (from the peat cutting)

The surface deposits of peat in cores A and E (at depths of 50 and 40 cm respectively) consisted of moderately humified *Sphagnum imbricatum* remains.

4. Core C (from the peat cutting)

The top 10 cm peat deposit (between 35 and 45 cm) consisted of *Sphagnum fimbriatum*; this was present above remains of *S. imbricatum*.

5. Core F (from the peat baulk)

This core contained the remains of *Sphagnum compactum* to a depth of 30 cm; below this was *S. imbricatum* peat.

4.3.3 Stratigraphy of cores from peat cuttings 1/2W5 and 2/3W5 (Fig. 4.4)

4.3.3.1 Gross stratigraphical features

The gross stratigraphy of these peat cores was similar to that of the cores from the 4/5W4 transect.

4.3.3.2 Sub-surface stratigraphical features

1. Cutting 1/2W5

The surface peat deposit consisted of a 6 cm layer of ericaceous remains; these occurred above moderately humified *Sphagnum imbricatum* peat.

2. Cutting 2/3W5

A 4 cm deposit of ericaceous peat was present above moderately humified remains of *S. imbricatum* at the surface of this core.

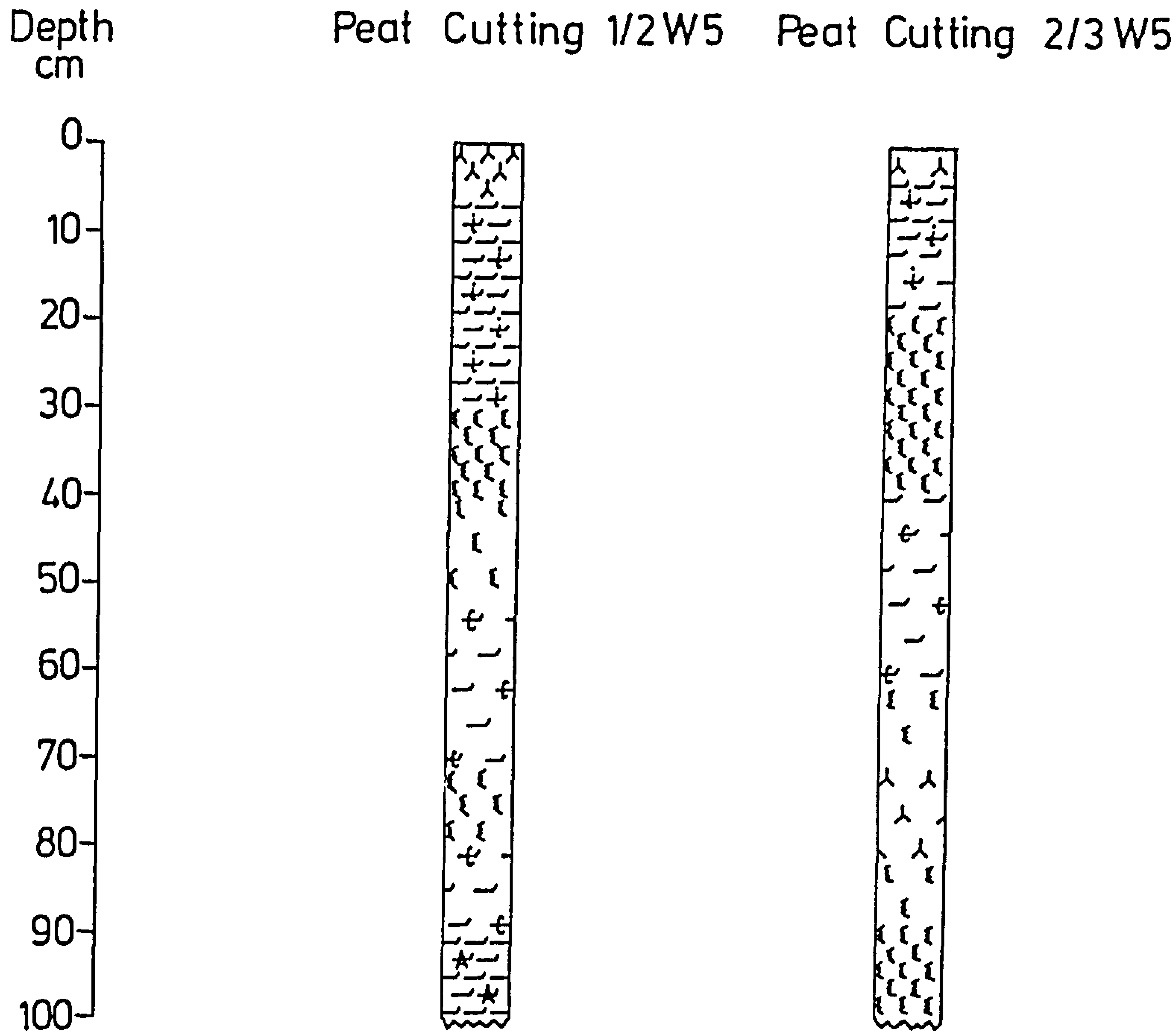


Fig. 4.4 Peat stratigraphy of surface cores from peat cuttings 1/2W5 and 2/3W5.

4.3.4 Stratigraphy of cores from peat cutting 3/4W5 and its adjacent southern baulk (Fig. 4.5)

4.3.4.1 Gross stratigraphical features

The gross stratigraphy of these peat cores was similar to that of the cores from the 4/5W4 transect.

4.3.4.2 Sub-surface stratigraphical features

1. Cutting 3/4W5

The surface peat consisted of a 4 cm deposit of *Sphagnum recurvum;* below this a 12 cm band of ericaceous peat occurred above the remains of *S. imbricatum.*

2. The peat baulk

Strongly humified remains of *Polytrichum* occurred to a depth of 2 cm above the remains of *Sphagnum imbricatum.*

4.3.5 Stratigraphy of cores from peat cutting 4/5W5 and its adjacent southern baulk (Fig. 4.6)

4.3.5.1 Gross stratigraphical features

Between 49-65 cm the core from the peat cutting contained a 16 cm deposit of *Sphagnum magellanicum* remains. Otherwise, the gross stratigraphy was similar to that of the cores from the 4/5W4 transect.

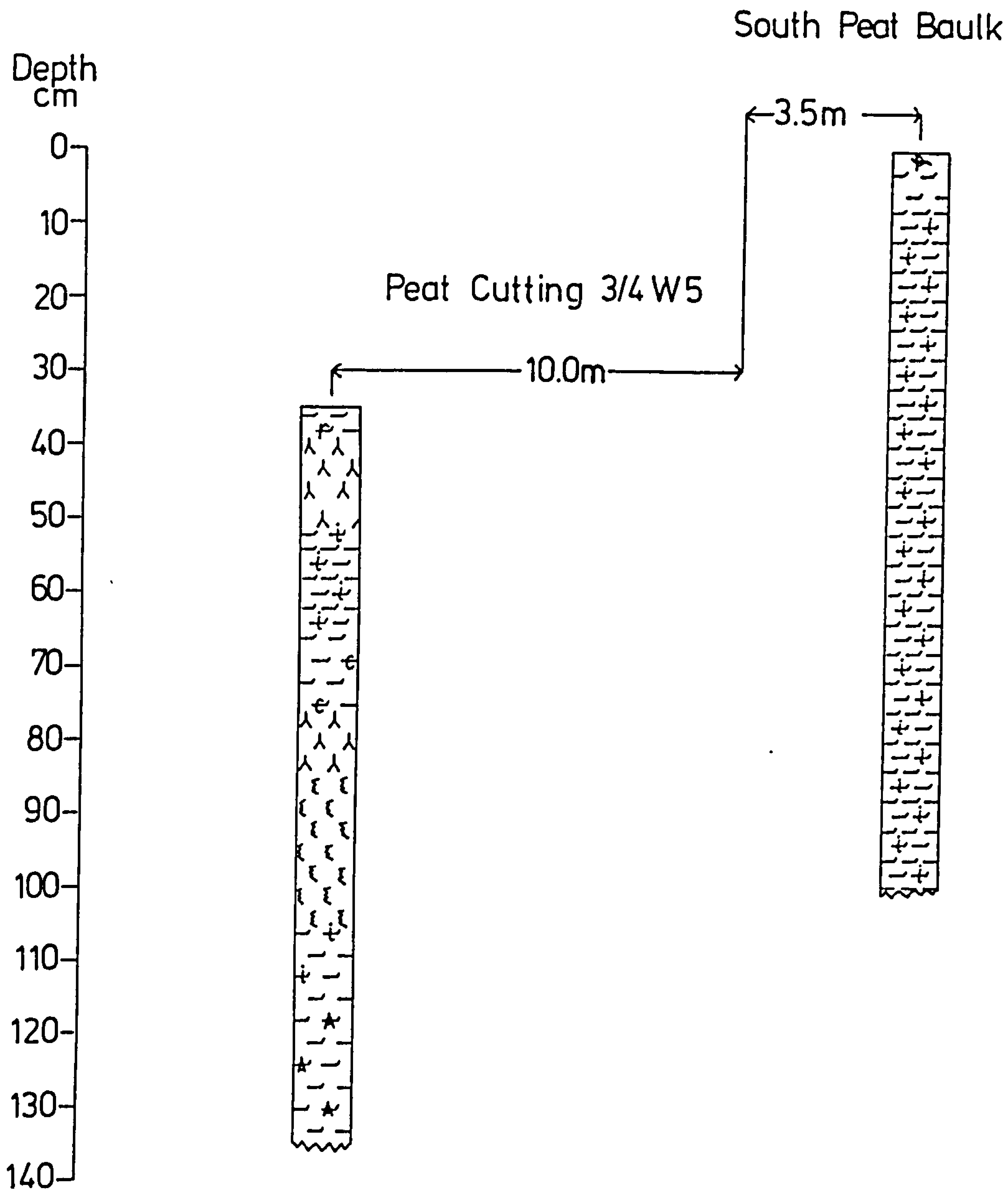


Fig. 4.5 Peat stratigraphy of surface cores from peat cutting 3/4W5 and its adjacent southern peat baulk.

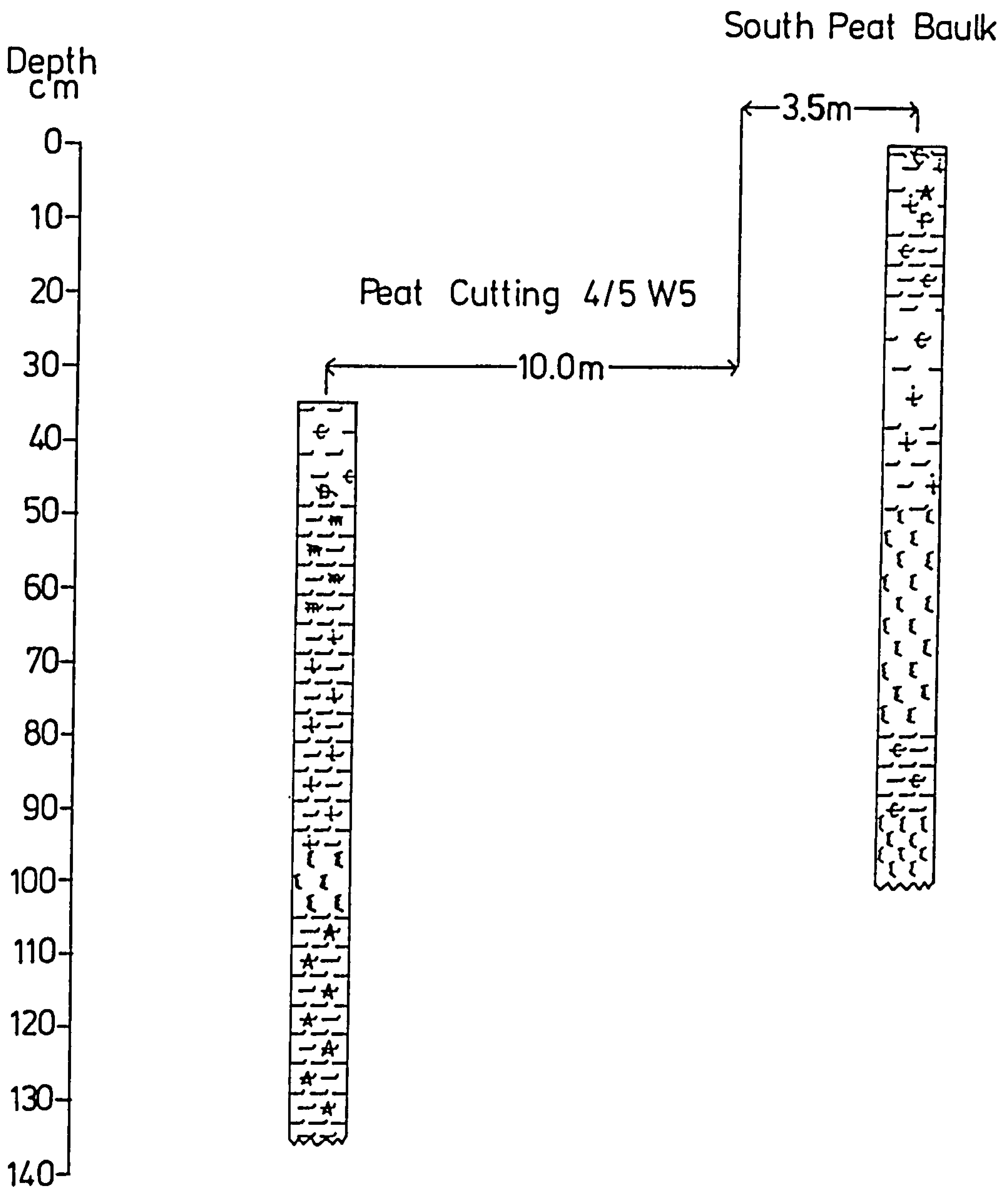


Fig. 4.6 Peat stratigraphy of surface cores from peat cutting 4/5W5 and its adjacent southern peat baulk.

4.3.5.2 Sub-surface stratigraphical features

1. Cutting 4/5W5

The surface deposit consisted of a 10 cm layer of *Sphagnum cuspidatum* peat; below this the remains of *Drepanocladus* occurred above the *Sphagnum magellanicum* peat.

2. The peat baulk

Between 10-30 cm below the surface, a layer of *Sphagnum cuspidatum* peat was present above moderately humified *S. imbricatum* remains; above the *S. cuspidatum* peat shallow deposits (2-3 cm) of *S. recurvum, S. imbricatum* and *S.* sect. *Acutifolia* occurred; the surface peat layer consisted of a 2 cm band of *Campylopus* remains.

4.3.6 Stratigraphy of cores from peat cutting 5/6W5 and its adjacent southern baulk (Fig. 4.7)

4.3.6.1 Gross stratigraphical features

In the core from the peat cutting, the remains of *Sphagnum papillosum* occurred between 65-75 cm. Otherwise, the gross stratigraphy was similar to that of the cores from the 4/5W4 transect.

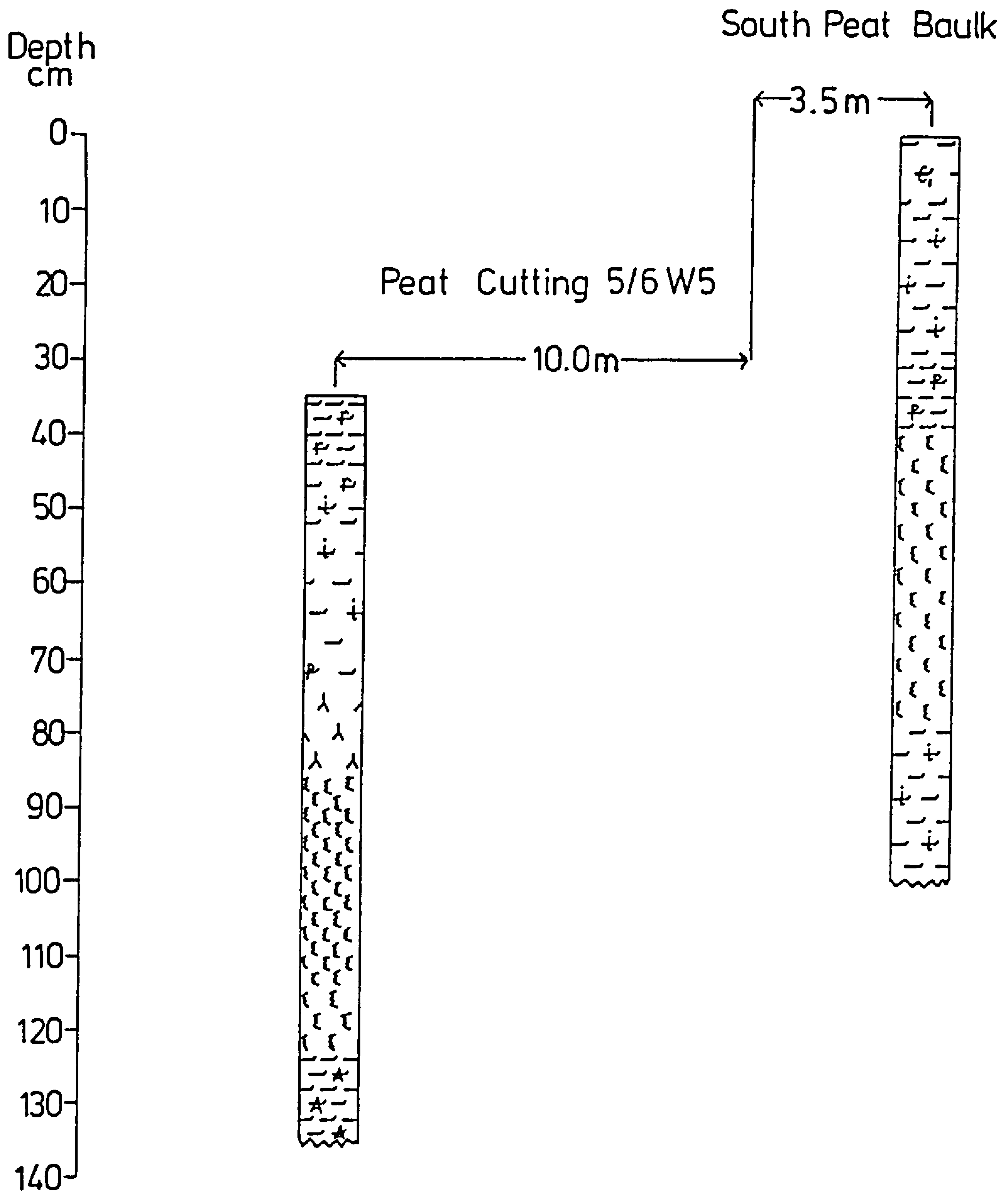


Fig. 4.7 Peat stratigraphy of surface cores from peat cutting 5/6W5 and its adjacent southern peat baulk.

4.3.6.2 Sub-surface stratigraphical features

1. Cutting 5/6W5

The surface peat deposit consisted of a 15 cm layer of moderately humified *Sphagnum recurvum* remains; this was present above *S. imbricatum* peat.

2. The peat baulk

A 10 cm band of strongly humified *Sphagnum compactum* peat occurred above moderately humified *S. imbricatum* remains at the surface of the baulk.

4.3.7 Stratigraphy of cores from canals 1-6 and the Main Canal of the Southern Dutch Canal System (Fig. 4.8a, b)

4.3.7.1 Gross stratigraphical features

The central portions of the cores (above the basal wood peat and below 77 cm) variously contained deposits of herbaceous peat (*sensu* Troels-Smith 1955), as well as the remains of *Sphagnum* sect. *Sphagnum*, *Phragmites*, *Campylopus* and wood in addition to peat types described from the 4/5W4 transect (4.3.2.1, no. 2). Otherwise, the gross stratigraphy was similar to that of the cores from the 4/5W4 transect.

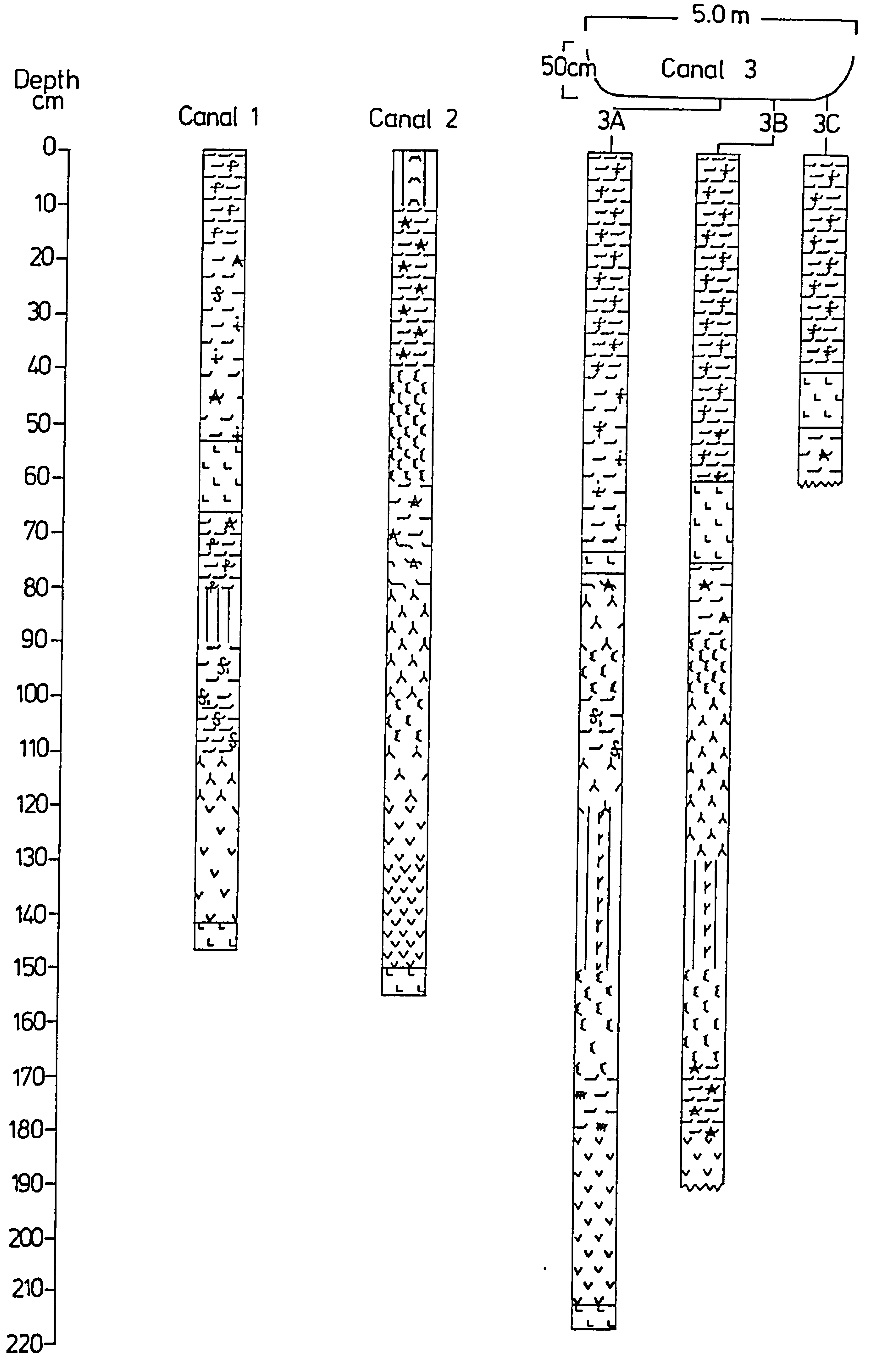


Fig. 4.8a Peat stratigraphy of cores from canals 1, 2 and 3 of the Southern Dutch Canal System.

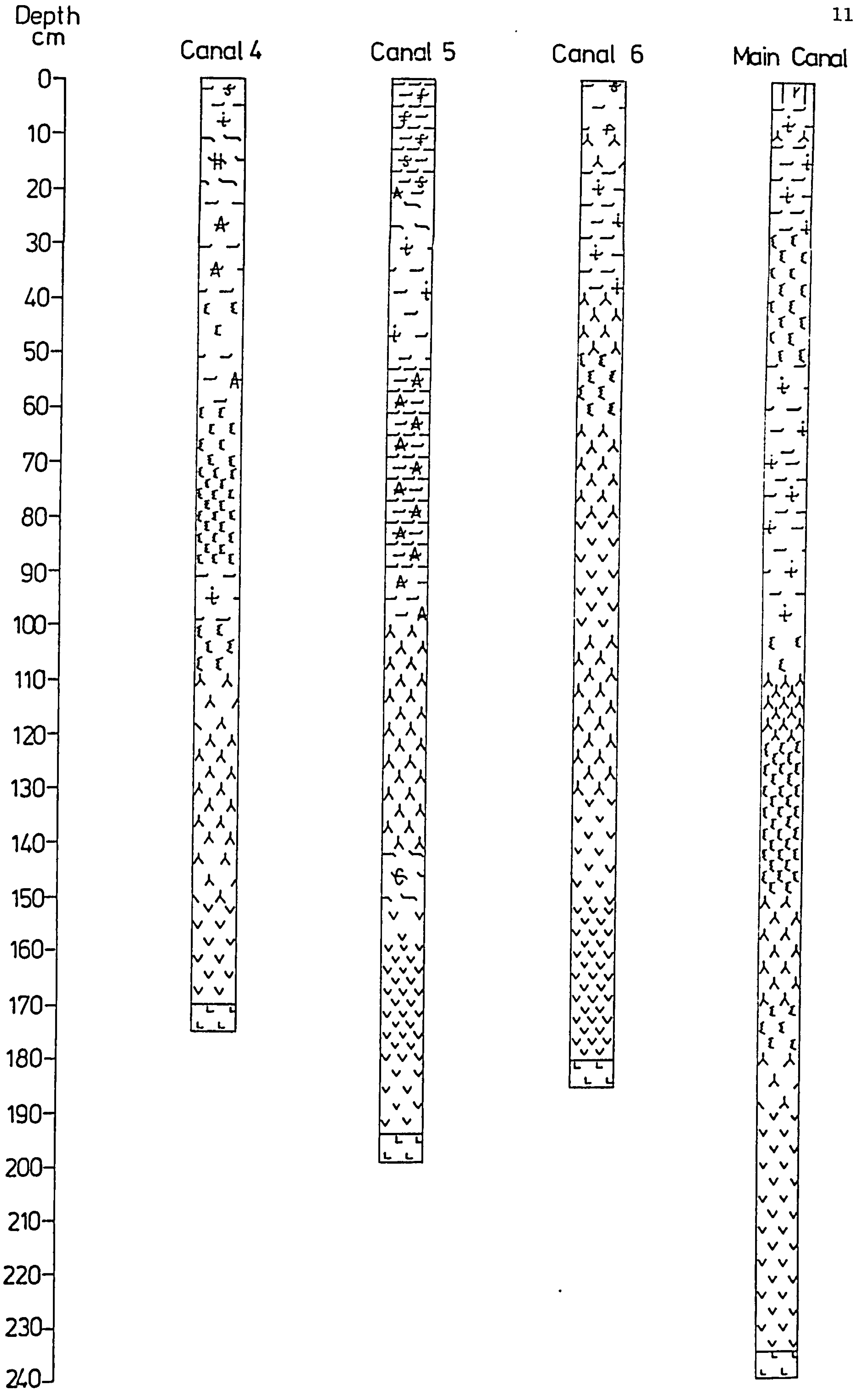


Fig. 4.8b Peat stratigraphy of cores from canals 4, 5, 6 and the Main Canal of the Southern Dutch Canal System.

4.3.7.2 Sub-surface stratigraphical features

1. Layers of clay, variable in thickness, were present in the cores from canals 1 and 3; clay was not present in the cores from the other canals. In canal 1 the clay occurred at a depth of 53-66 cm; in canal 3 the clay was at depths of 73-77 cm (3A), 60-75 cm (3B) and 40-50 cm (3C).

2. Canal 1

Above the clay layer in canal 1 a shallow (4 cm), strongly humified, deposit of *Sphagnum imbricatum* peat was present; above these remains, towards the top of the core, peat layers of *S.* sect. *Acutifolia*, *S. imbricatum* and *S.* sect. *Subsecunda* occurred; the surface deposit consisted of a weakly humified deposit of *S. recurvum*, 17 cm in thickness.

3. Canal 2

Between 10-40 cm moderately humified remains of *Sphagnum* sect. *Acutifolia* were present above *Scheuchzeria palustris* peat; the top 10 cm of the core contained *Eriophorum vaginatum* peat.

4. Canal 3

The upper portions of the three cores from canal 3 contained weakly humified *Sphagnum fimbriatum* peat; in 3A this occurred above the moderately humified remains of *Sphagnum imbricatum* which overlaid the clay; in 3B and 3C the *S. fimbriatum* peat occurred immediately above the clay.

5. Canal 4

Between 20-40 cm below the surface, a layer of *Sphagnum* sect. *Acutifolia* peat overlaid *Scheuchzeria palustris* peat; above the *Sphagnum* sect. *Acutifolia* remains deposits of Hypnoid and *S. imbricatum* peat occurred; the surface peat layer consisted of a 5 cm deposit of *S. squarrosum* remains.

6. Canal 5

The surface peat consisted of a 12 cm deposit of *Sphagnum fimbriatum* which occurred above *S. squarrosum* peat; at 20-30 cm *S.* sect. *Acutifolia* peat and bryophyte peat (*sensu* Troels-Smith 1955) occurred above the remains of *S. imbricatum*.

7. Canal 6

Between 10-17 cm, above a deposit of *Sphagnum imbricatum* peat, the core contained the remains of ericaceous plants; above 10 cm a surface layer of *S. squarrosum* peat overlaid *S. recurvum* peat.

8. Main Canal

Between 10-12 cm, a shallow layer of ericaceous peat occurred above *Sphagnum imbricatum* peat; *S. imbricatum* remains also occurred above this ericaceous peat below the 4 cm surface deposit of *Phragmites* peat.

4.3.8 Stratigraphy of cores from JA, EP and a modern peat cutting (Fig. 4.9)

4.3.8.1 Gross stratigraphical features

The gross stratigraphy of these peat cores was similar to that of the cores from the 4/5W4 transect.

4.3.8.2 Sub-surface stratigraphical features

1. JA

Between 7-20 cm, moderately humified remains of *Sphagnum magellanicum* occurred above *Scheuchzeria palustris* peat; above this *Sphagnum magellanicum* peat, ericaceous remains occurred below the shallow (2 cm) surface deposit of *Juncus effusus* remains.

2. EP

A relatively shallow layer of peat was present in EP, the Experimental Plot (see also Fig. 6.29). At a depth of 3-20 cm a layer of moderately humified *Sphagnum imbricatum* remains occurred above *Scheuchzeria palustris* peat and below the shallow surface deposit of *Campylopus* peat.

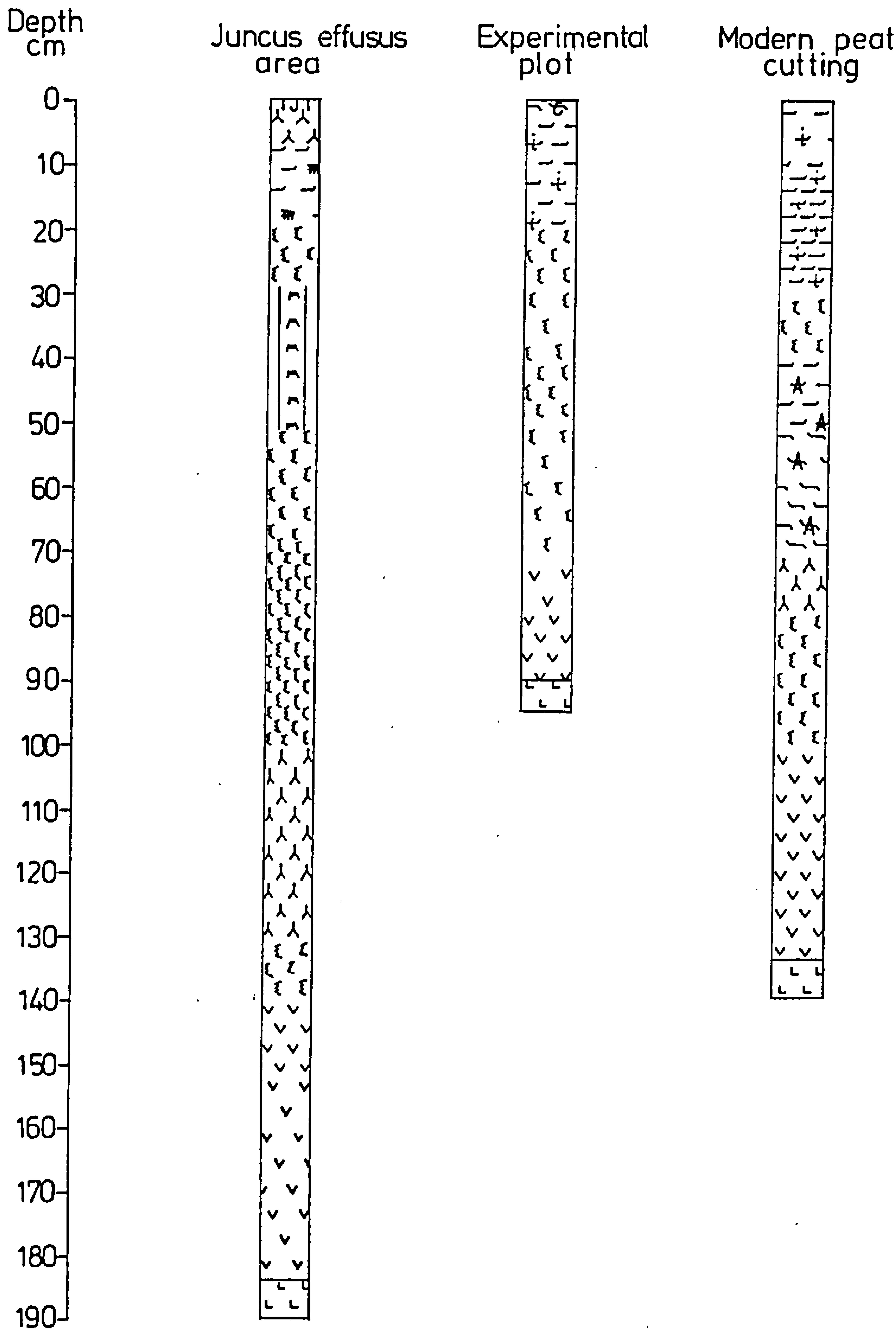


Fig. 4.9 Peat stratigraphy of cores from JA, EP and a 'modern' peat cutting.

3. Modern peat cutting

A deposit of *Sphagnum imbricatum* peat occurred from the surface of the core to a depth of 30 cm; this overlaid *Scheuchzeria palustris* peat. The *Sphagnum imbricatum* peat is the deposit currently being extracted by Fisons Ltd.

4.4 STRATIGRAPHICAL DEVELOPMENT OF THE MIRE

4.4.1 Problems in interpretation of the peat stratigraphy

Owing to the removal of some peat from most of Thorne Moors, the stratigraphy does not show the complete development of the mire. Further, whilst it is almost certain that the baulks of the pNNR have never been cut for peat (Chapter 2), it is likely that the drainage of these baulks (caused by the excavation of ditches and the removal of peat from adjacent cuttings) will have affected the composition and nature of their superficial peat horizons (4.5). In addition, subsequent burning and erosion of the dry peat baulks have probably removed and altered the character of some surface peats (5.6). In the following section, therefore, only the relatively early stages in the natural development of the mire are considered.

Comparable depths in the profiles do not necessarily represent contemporaneous surfaces; this is because of:

1. Variation in a) the amount of peat removed by cutting and b) the depth of peat which has developed over the cutting surface, in cores where the relative level of the sample sites is unknown.

2. Differential decay and compression.

3. Possible heterogeneity in the undisturbed mire surface.

4. Possible variation in the topography of the underlying clay.

4.4.2 Mire development

The wood peat at the base of the cores which penetrate the underlying clay (subsequently referred to as 'complete' cores), is probably the remains of the forest which covered the area just over 3000 years ago, during the Bronze Age (cf. de la Pryme 1701; Turner 1962; Buckland & Kenward 1973; Buckland 1979).

Remains of *Scheuchzeria palustris* above the wood peat in many of the cores, also observed by Margaret Pigott (Pigott 1956), may reflect the wet conditions which characterized the early sub-Atlantic period, zone VIIIa (Buckland 1979). At Hatfield Moors, where peat formation began during the early Atlantic period (zone VII), Smith (1958) observed a phase of increased surface wetness marked by remains of *Scheuchzeria palustris* close to the zone VIIb/VIIIa boundary; this 'flooding horizon' (*sensu* Smith 1958) may be contemporaneous with the main initiation of peat formation on Thorne Moors (cf. Buckland 1979).

Above the depth at which the lowest remains of *Scheuchzeria palustris* occurred, the cores contained a variety of peat types including *Sphagnum imbricatum, S. cuspidatum, S.* sect. *Acutifolia, S.* sect. *Subsecunda,* ericaceous peat and herbaceous peat; these suggest the existence of an ombrotrophic mire surface with some microtopographical heterogeneity.

A second phase during which conditions were relatively wet on the mire surface may be indicated by *Scheuchzeria palustris* and *Sphagnum cuspidatum* peats in the upper and middle portions of the cores; these remains occurred, for example, above 165 cm in the cores from the 4/5W4 transect (Fig. 4.3) at a depth below which *Scheuchzeria palustris* was absent from all cores. Dr J Turner (personal communication) obtained a date of 1855 ± 110 B P from material collected from a band of *S. palustris* remains in an exposed peat face, situated at a depth of 74-76 cm above the underlying clay. This corresponds to a depth of about 160 cm in the cores from the 4/5W4 transect and may indicate the approximate age of these remains. These upper *Scheuchzeria* peats probably correspond to a flooding horizon in the peat at Hatfield Moors which Smith (1958) considered may date from the end of the Roman occupation.

Although there is some evidence for the existence of flooding horizons, the occurrence of *Scheuchzeria palustris* at most levels above the wood peat and below 60 cm in the cores from the 4/5W4 transect suggests that this plant was a regular and persistent constituent of the flora of the undisturbed mire.

4.5 THE RECOLONIZATION OF CUT-OVER AREAS

4.5.1 Detection of the cutting surface

The depth of peat which represents the base of the abandoned peat cuttings of the Dutch Canal System (last cut 63-113 years ago), subsequently referred to as the 'cutting surface', is not obvious from the peat stratigraphy. It cannot, for example, be detected by the sudden disappearance of the remains of plants which no longer occur at Thorne Moors; this is shown by the presence of *Sphagnum imbricatum* remains immediately above the layers of clay, almost certainly dumped by the Dutch at the start of peat cutting (4.5.3), in the cores from canals 1 and 3 (Fig. 4.8a). Features which have been used in an attempt to detect the cutting surface include the presence of the remains of plants which were not major constituents of the flora of the undisturbed bog (4.4) and changes in the humification and frequency of macrofossils.

4.5.2 Recolonization of the cuttings and baulks of the pNNR

4.5.2.1 Peat cuttings of the pNNR

In core C from cutting 4/5W4 (Fig. 4.3) the cutting surface probably occurs at a depth of approximately 25 cm from the surface of the cutting and 60 cm from the surface of the peat baulk. 60 cm of peat, therefore, was cut away by the Dutch (although as peat has been removed by burning and erosion and the baulks are likely to have subsided since 1920 (4.6 and 5.6) the amount of peat removed was probably greater than 60 cm). This horizon corresponds to a decrease in the frequency of *Sphagnum imbricatum* remains and to a colour change observed in the field: from brown peat below 60 cm, to black peat above. It is possible, therefore, that *S. imbricatum*, a plant currently rare in Britain but abundant in Post-glacial peats (Green 1968), may have recolonized cut-over areas in the pNNR. This moss certainly occurred at, or very near, the surface in other cores from the pNNR; for example, cores A and E from cutting 4/5W4 (Fig. 4.3).

Sphagnum magellanicum, which like *S. imbricatum* is no longer present at Thorne Moors, may also have recolonized cut-over areas. Remains of this plant occurred 14 cm below the surface in cutting 4/5W5 (Fig. 4.6).

By contrast, however, it is unlikely that *Scheuchzeria palustris* recolonized the Dutch peat workings. Remains of this plant were not found near the surface in the pNNR cuttings and it was not seen on The Moors after 1870 (Chapter 3), when the Dutch started peat cutting. In addition, *Scheuchzeria palustris* is known to be a plant which is extremely susceptible to drainage (Tallis & Birks 1965).

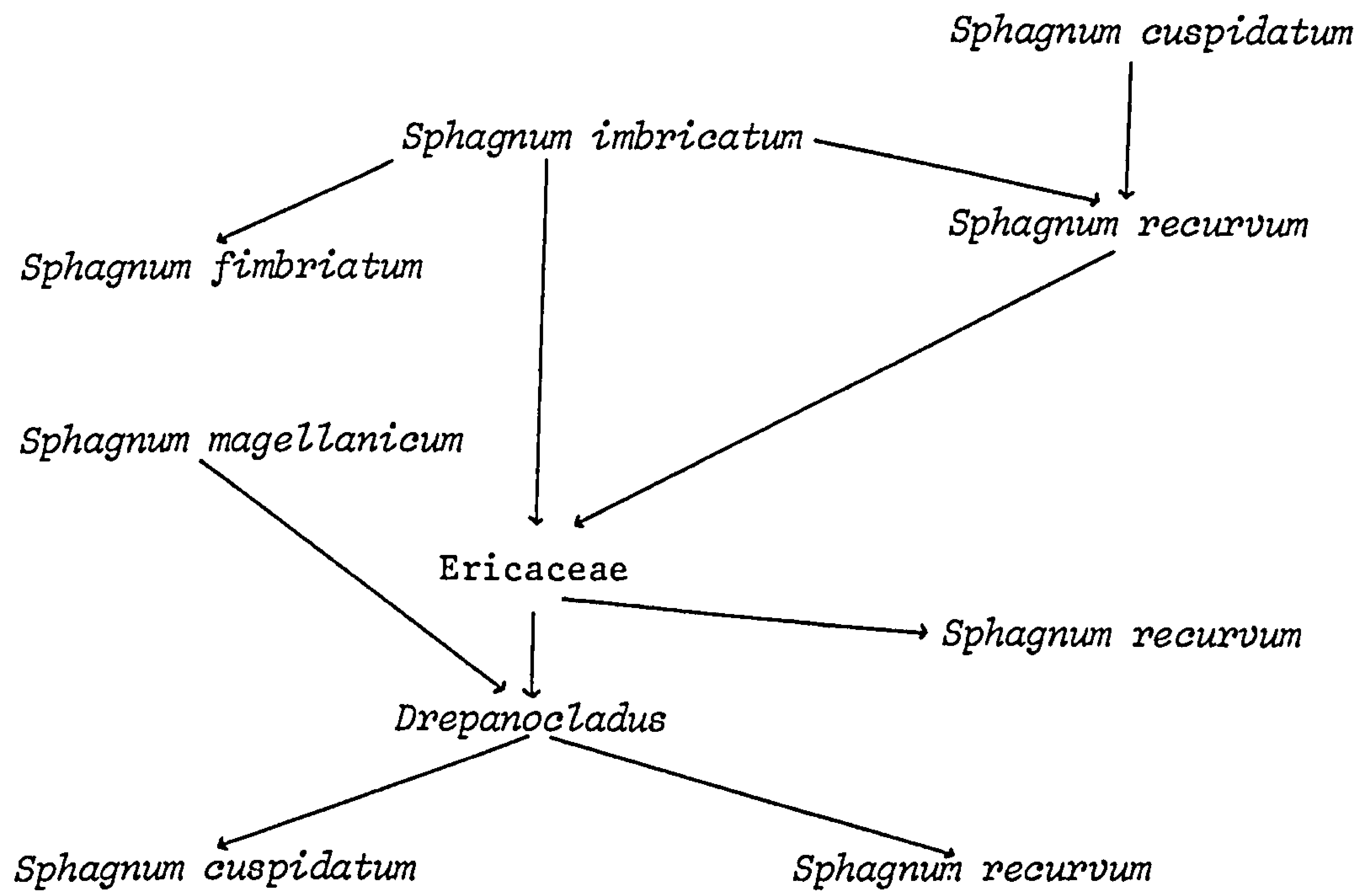


Fig. 4.10 Observed pathways of recolonization in the peat cuttings of the pNNR.

Sphagnum imbricatum and *S. magellanicum* were replaced by the vegetation shown in Fig. 4.10. The remains of *Sphagnum fimbriatum*, *S. recurvum* and *Drepanocladus* spp. occurred only at, or near, the surface of the peat cores. This indicates that these mosses, characteristic of the present vegetation but not that of the undisturbed mire, colonized the area relatively recently. Reasons for the disappearance of *Sphagnum imbricatum* and *S. magellanicum* and the subsequent recolonization by species such as *S. recurvum* are considered in Chapters 7 and 8.

The ericaceous peat at the surface of cores from 1/2W5 and 2/3W5 (Fig. 4.4) may represent the vegetation which recolonized these cuttings subsequent to the re-cutting of the area between canals 1 and 2 and section 2/3W (Chapter 2). These cuttings, therefore, may be at an earlier stage of recolonization than others in the pNNR.

The ditches in the cuttings (Fig. 4.3) have probably been full of water since their excavation and it is unlikely that any vegetation has colonized their bases. The surface peat in cores from the ditches, therefore, probably represents the remains of plants originally present in the surface water above the ditch (e.g. *Sphagnum recurvum* and *Drepanocladus* spp.) and remains which have fallen into the ditch from adjacent, higher cuttings.

4.5.2.2 Peat baulks of the pNNR

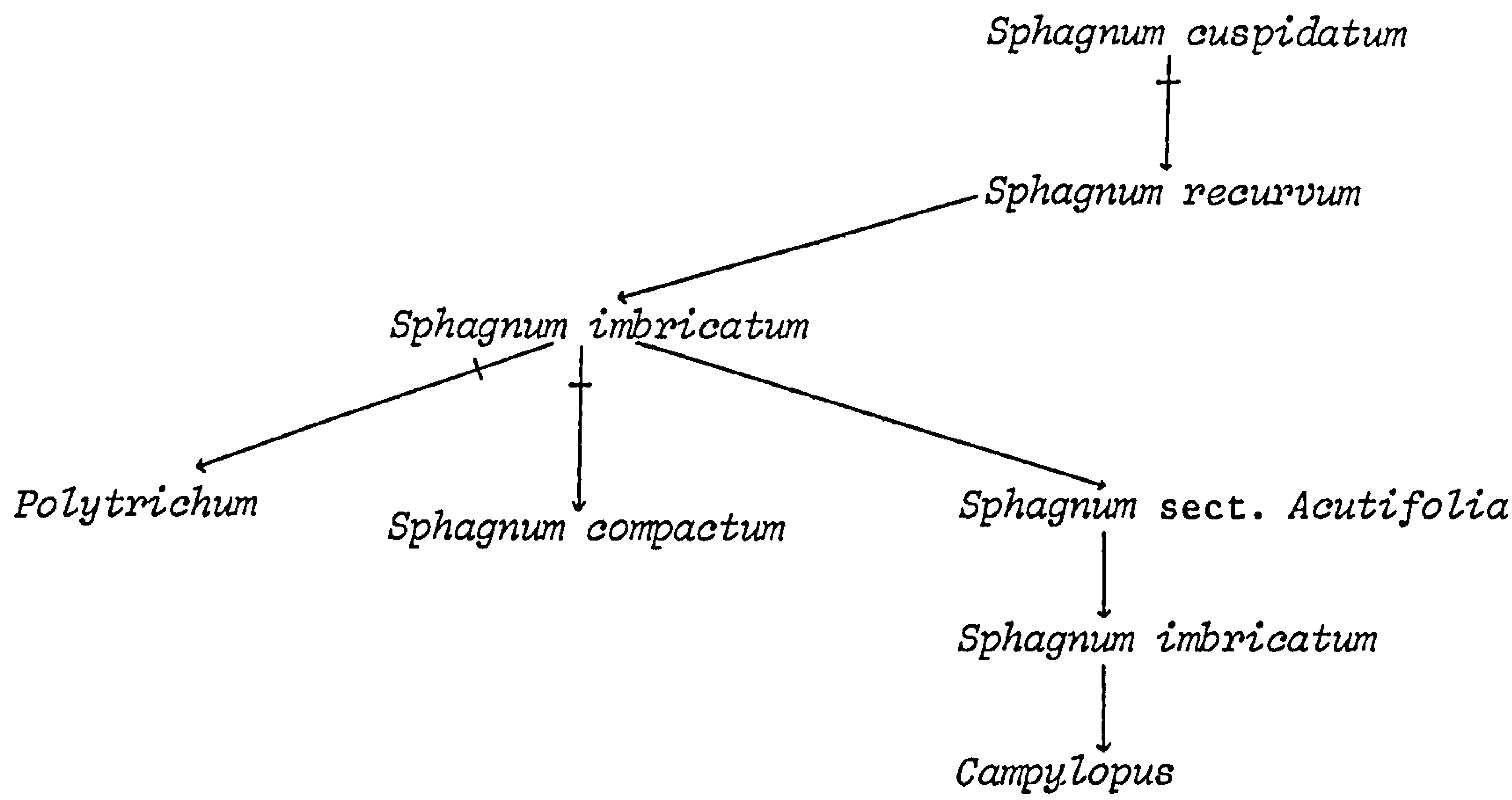


Fig. 4.11 Recent vegetational changes in the peat baulks of the pNNR. Lines on arrows represent probable stage of peat cutting.

The presence of the remains of *Sphagnum compactum*, a bryophyte characteristic of wet heaths rather than ombrotrophic mires, at the surface of the baulks (Fig. 4.11) adjacent to cuttings 4/5W4 (Fig. 4.3) and 5/6W5 (Fig. 4.7), may reflect the gradual drying of the peat baulks through their drainage and the removal of peat from the nearby cuttings.

The succession of peat types in the baulk adjacent to cutting 4/5W5 (Fig. 4.6) may also reflect the change towards drier conditions. *Sphagnum cuspidatum* was progressively replaced by species which may tolerate increasingly dry conditions: *S. recurvum*, *S.* sect. *Acutifolia*, *S. imbricatum* (Green 1968) and, eventually, *Campylopus* (Fig. 4.11).

4.5.3 The vegetation which recolonized the Dutch Canals (Fig. 4.8a, b)

The clay in cores from canals 1 and 3 was probably dumped by the Dutch at the start of peat cutting in an attempt to 'line' the canals and so increase the amount of water held by them (Chapter 2). It is certainly known that there were problems in retaining water in the Canal Systems (Goode 1973). Clay may also be present in parts of the other canals, not sampled during this investigation.

The presence of remains of *Sphagnum imbricatum* above the clay in cores from canals 1 and 3 (core 3A) supports the suggestion that *S. imbricatum* recolonized cut-over surfaces abandoned around 1920 (4.5.2.1) and disappeared from the site somewhat later. *S. imbricatum* may have recolonized the base of the canals after 1920 when they were partially drained (2.7). Although these remains could conceivably be explained by the dropping of a turf from a barge into the canal above the clay, it is unlikely that this would account for both layers of *S. imbricatum* peat in canal 1 as well as the remains in core 3A. *S. imbricatum* peat was also present very near the surface in cores from canal 4 and the Main Canal.

As in the cuttings, the surface peats in the canals consisted of the remains of plants which were not apparently characteristic of the undisturbed mire. These include *Sphagnum squarrosum*, *S. recurvum* and *S. fimbriatum*.

4.5.4. The vegetation which recolonized the *Juncus effusus* area (JA), the Experimental Plot (EP) and a modern peat cutting (Fig. 4.9)

In the *Juncus effusus* area the upper limit of the *Sphagnum magellanicum* peat, which was subsequently replaced by the remains of ericaceous plants at a depth of 7 cm, probably represents the cutting surface at this site. The shallow surface deposit of *Juncus effusus* remains suggest that this peat cutting became colonized by *J. effusus* only relatively recently.

In the Experimental Plot the cutting surface occurs very near the top of the peat core,probably at a depth of 3 cm where *Campylopus* recolonized *Sphagnum imbricatum* peat. In the modern peat cutting, however, the cutting surface is at the surface of the peat core because no vegetation has yet recolonized this area.

4.5.5 Conclusions

1. The depth of the cutting surface cannot be determined with certainty in the peat cuttings.

2. *Sphagnum imbricatum* and possibly *S. magellanicum*, not present at the site, probably recolonized cut-over surfaces abandoned around 1920.

3. It is extremely unlikely that *Scheuchzeria palustris* recolonized cut-over surfaces abandoned around 1920.

4. Many species characteristic of the present vegetation colonized the area relatively recently.

5. There is no evidence to suggest that the peat baulks were ever cut for peat.

6. Clay was used to 'line' some canals by the Dutch; this was probably an attempt to increase the amount of water retained by the canals.

4.6 THE DEPTH OF THE PEAT

In 1920 Peacock observed that 'In its more central portions .... the peat of the Waste was once (in 1874) from twenty to fifteen feet deep'; i.e. c. 5 m (Peacock 1920). The depth of peat recorded from below a peat baulk, however, an area probably never cut for peat, was 2.36 m (core F, Fig. 4.3). This reduction in the depth of the peat may be explained by the fact that the raised bog at Thorne originally had a liquid core which has disappeared through the drainage of the area over the last 100 years (Rogers & Bellamy 1972). Such a core may have acted as a buffer against seasonal or longer term fluctuations in precipitation; even in periods of drought, therefore, the surface of the cupola would have remained saturated (Morrison 1955). Support for this suggestion comes from Peacock (1920) who stated that 'In 1875 it was estimated that the winter rise and summer fall of the bog was about six feet, in an abnormally wet season in the 'sixties, eight feet'.

Alternatively, it is possible that the depth of peat in the pNNR, which is near the south-west margin of the complex, was always more shallow than that in more central areas.

Peat wastage may also have caused a reduction in the depth of the peat; this occurs when the water table is below the surface, as in the peat baulks (Hutchinson 1980). Peat wastage or subsidence of the peat at Thorne is considered in 5.6.

CHAPTER 5

HYDROLOGICAL INVESTIGATIONS

5.1 INTRODUCTION

5.1.1 The hydrology of mires

Most hydrological studies of sites bearing peat have been carried out on intact mire systems (e.g. Chapman 1965; Goode 1970; Ingram 1982), peatlands undergoing erosion (e.g. Conway & Millar 1960; Tallis 1973a) or peatland areas reclaimed for agriculture (e.g. Baden & Eggelsmann 1968; Burke 1972, 1975). There is comparatively little information available on the hydrology of cut-over peatlands which have their water tables maintained, often artificially, for the purposes of nature conservation (Schmatzler & Tüxen 1980; van der Molen 1981).

It has been suggested that an intact raised mire comprises two layers of substratum, namely a core of humified peat known as the 'catotelm', which occupies most of the deposit, overlain by a thin (25-50 cm) 'acrotelm' or 'active layer' (Lopatin 1949; Ivanov 1953, 1981); it may conveniently be described as 'diplotelmic' (Ingram 1978). The acrotelm is the peat-forming layer; it mainly consists of growing plant material, especially *Sphagnum*, which undergoes alteration by humification below, where it becomes transformed into the partly colloidal material or the catotelm (Ingram 1982). Water table levels and fluctuations in raised mires are controlled by, and depend on, the physical properties of these two layers (Ivanov 1981). The pattern of hydraulic conductivity, or ability of the peat to transmit water, is of particular importance. From the top to the base of the acrotelm, towards the top of the catotelm, the hydraulic conductivity decreases by up to 4 orders of magnitude. This means that when precipitation is reduced or absent the mire is prevented from becoming dry because horizontal seepage stops completely when there is a fall in level. In addition, excess rainwater is disposed of relatively rapidly without any significant rise in level because water runs off the mire to surrounding areas. The thickness of the acrotelm and the maximum depth of the water table are, therefore, roughly the same, seldom exceeding c. 0.5 m (Ivanov 1981).

The applicability of the two-layer hypothesis to cut and drained mires is not clear (Ingram 1978); it is likely, however, that the acrotelm will have been removed or destroyed such that the system is no longer able to maintain and regulate its water table.

5.1.2 Specific objectives

In order to assess some of the hydrological differences between cut-over areas at Thorne and intact mire systems, the fluctuation and level of the water table were investigated in a number of peat cuttings, a canal, and a dry peat baulk. Specific reasons for doing this were:

1. In the pNNR it was intended to assess the effectiveness of the dams in the ditches and drains which aim to 'seal off' the area hydrologically. Intermittent water table measurements were recorded in 32 peat cuttings and in one of the Dutch canals.

Continuous water table measurements were made in a peat cutting with a relatively high water table in the area of the pNNR without peat baulks (2/3W3), and a peat cutting in the area of the pNNR where baulks alternate with the cutting bays (4/5W5).

2. The behaviour of the water table in a peat baulk was investigated because of the potential of baulks to act as 'hydrological buffer zones' around nature reserves. In addition it was hoped that this study might indicate some of the changes which have occurred in the peat resultant on the drainage and subsequent drying of the baulks. Continuous water table measurements were made in one peat baulk in the Dutch Canal System; the water table was also periodically recorded in a transect across a peat baulk and the cutting adjacent to it.

3. In JA (the *Juncus effusus* area) particular interest was in the effect of the drain which forms the northern boundary of this cutting and in the possibility that the area receives water from the surrounding cuts. Continuous and intermittent water table measurements were made in JA.

4. In EP (the Experimental Plot), a shallow peat cut, not so well 'sealed off' hydrologically as the pNNR, it was intended to assess the influence of the deep Southern Boundary Drain. Continuous and intermittent water table measurements were made in this cutting.

At all study sites it was intended to assess the relationship between the water level and the vegetation.

The water budget as applied to a specific mire can be expressed as:

$$P + I = E + R \pm \Delta S$$

where P = precipitation, I = inflow, E = evapotranspiration, R = run-off and Δ S = change in storage. A complete assessment of the water budget was not feasible. The individual components of this budget, however, are commented on wherever possible.

All water table measurements were related to the precipitation recorded at Crowle, Humberside (Nat. Grid Ref. SE 474409), approximately 6 km from the study site. Monthly rainfall totals are given in Appendix 3.

5.2 MATERIALS AND METHODS

5.2.1 Monthly water table in peat cuttings

Water table in the pNNR was investigated by means of 32 sampling tubes located along 4 transects (1 perpendicular to the other 3) in a series of peat cuttings, and 1 transect along the length of canal 4 (Fig. 5.1). Sample tubes were located within the central section of each peat cutting, in the centre of a floristically and topographically 'uniform' area of approximately 25 m^2, selected using random numbers. Water table was also measured in cuttings JA and EP in sample tubes located by this method. Sample tubes were positioned in the centre of canal 4.

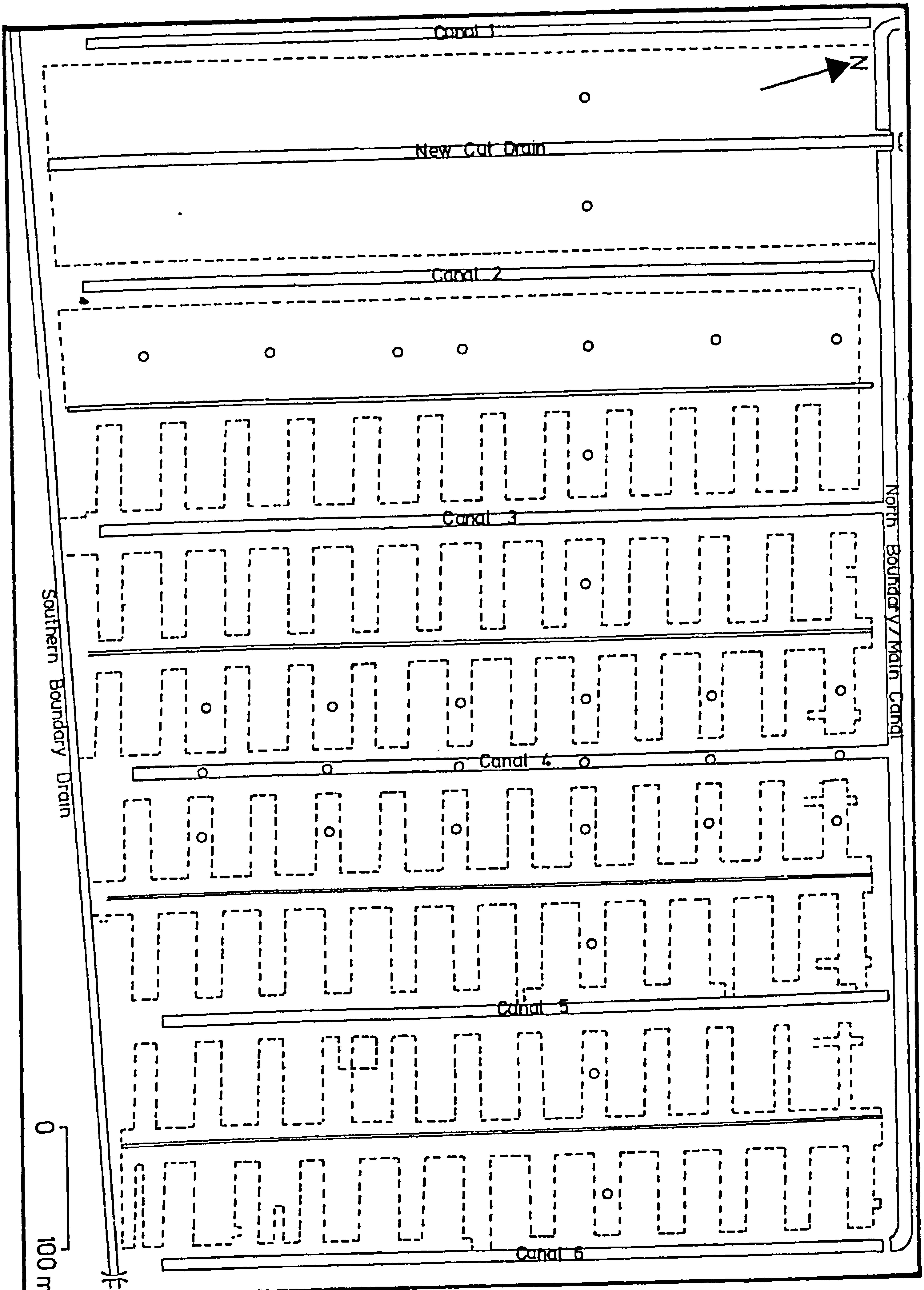


Fig. 5.1 Location of sampling tubes (o) for measurement of water table in peat cuttings. Sampling tubes were also located in JA and EP (see Fig. 5.3).

The sampling tubes (Fig. 5.2) were 50 cm lengths of ABS soil pipe (10 cm internal diameter) with numerous holes drilled in the side and a PVC lid. They were buried to within 5 cm of their length, an attempt being made to minimise disturbance to the peat substratum. Peat debris remaining within the tube subsequent to installation was removed by hand. The sample tubes were installed two months before any readings were taken to permit equilibration.

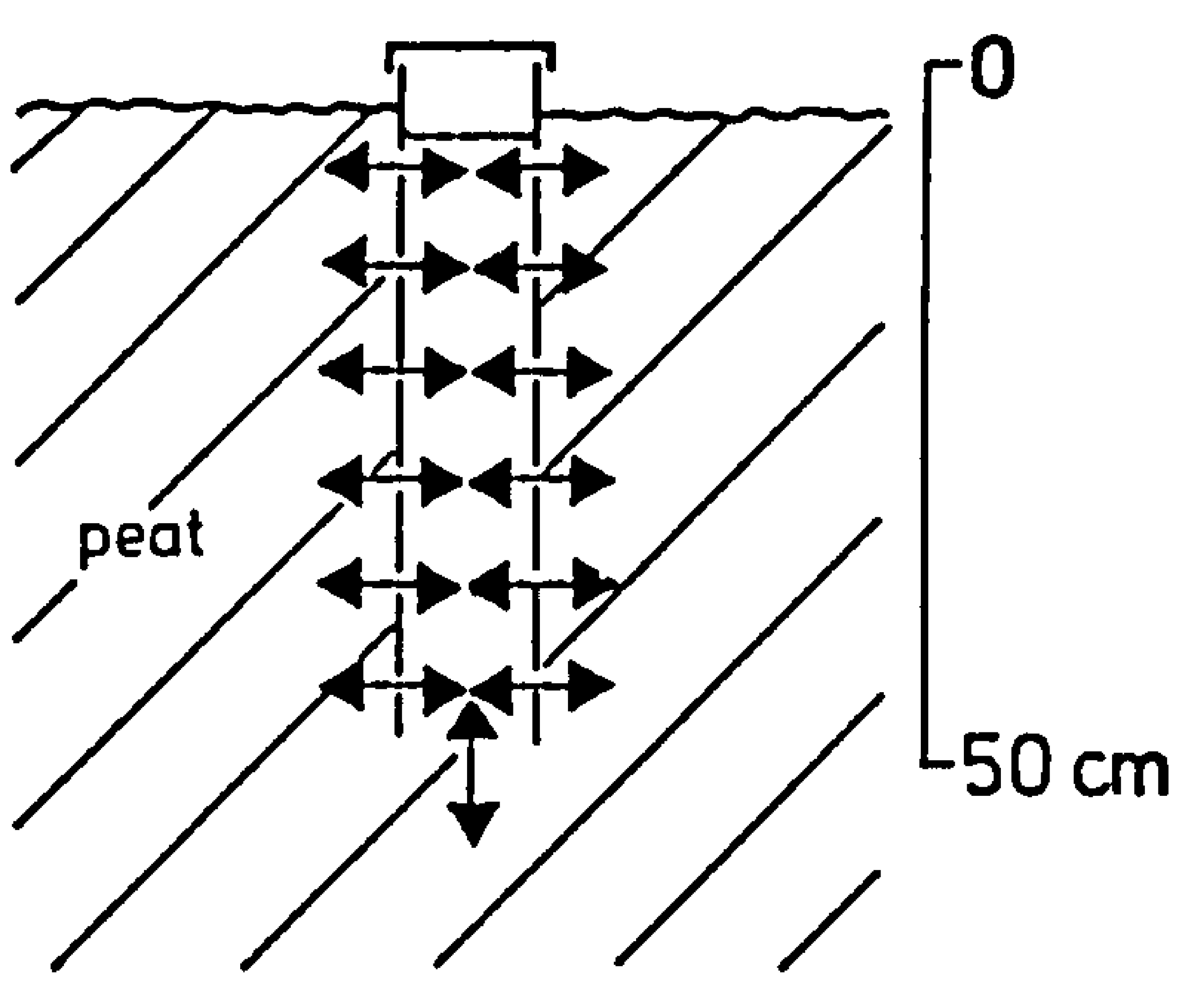


Fig. 5.2 A sampling tube *in situ*.

The water level was measured from the top of each sampling tube using a flexible steel rule graduated in mm. The distance from the top of the tube to the peat surface was also measured and the water table in relation to the peat surface was calculated from these two measurements. In the peat cuttings measurements were taken at approximately monthly intervals over a period of 16 months from April 1980 to August 1981. Measurement of water table in the 3/4E transect was terminated in October 1980, because during the winter, even when starting at first light it was impossible to take all the readings in one day. Between February and May 1981, in 2/3W3 and JA where the water table was very high, the height of the water level above the top of the sampling tube had to be estimated (because of a personal temporary physical limitation) to the nearest cm from a distance of 3-5 m, the nearest dry point. In canal 4 measurements were taken at approximately monthly intervals over a period of 16 months from November 1980 to March 1982.

5.2.2 Continuous monitoring of water table by automatic water level recorders

Three Kempton R16 automatic vertical water level recorders were available for making continuous, accurate records of water table. During the first period of operation the equipment was positioned in peat cuttings JA, 2/3W3 and 4/5W5. After just over one year two of the recorders were moved; one to peat cutting EP and the other to the peat baulk directly south of cutting 4/5W5, where they remained for a further year. The apparatus in cutting 4/5W5 remained in position throughout the whole monitoring period (Fig. 5.3).

The recorders in JA and 2/3W3 were located in the centre of the cuttings. The former was run from 22 April 1980 to 5 August 1981; the latter from 7 May 1980 to 3 June 1981. In 4/5W5 the recorder was positioned within the central section of the peat cutting, away from the area of 'peat rubble'; this recorder was run from 7 May 1980 to 5 August 1982. The recorder in EP was located towards the northern end of the cutting and operated from 5 August 1981 to 5 August 1982. On the peat baulk south of cutting 4/5W5 the recorder was installed c. 2.5 m from the edge of the baulk in line with the recorder in 4/5W5 and at right angles to the length of the cutting (Figs. 5.4 and 5.15). The recorder at this location, from now on referred to as SB, operated from 30 July 1981 to 5 August 1982. The two monitoring periods of approximately a year will subsequently be described as year 1 and year 2 respectively. The water level recorders will be referred to by the names of the cuttings (or baulk) in which they were situated.

Water table is monitored by the recorders by means of a float (with counterweight) operating a pen arm in the vertical plane, in conjunction with a revolving chart drum actuated by a monthly clockwork mechanism. The chart drum is 25 cm high. As the range of fluctuation at any site was unknown at the time

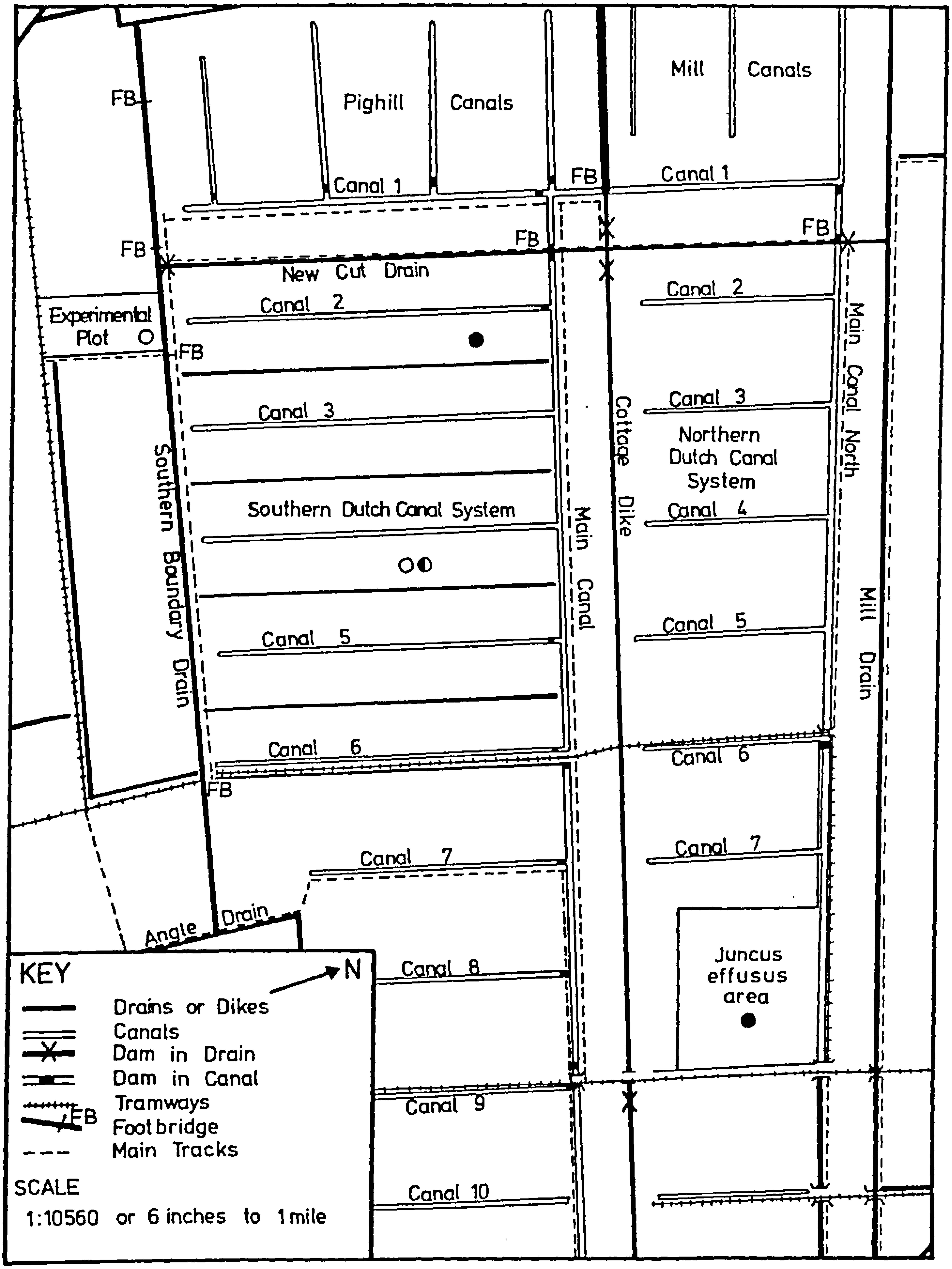


Fig. 5.3 Location of water level recorders during year 1 (●) and year 2 (○). The recorder in cutting 4/5W5 (◐) remained in position throughout the whole monitoring period.

of installation, a 1 in 5 gear was used so that all recorded levels were subsequently multiplied by 5. The equipment accurately registers water table changes of 5 mm (1 mm on the charts). On the horizontal scale 12 mm corresponds to a period of 24 hours; the time a particular water level was registered can, therefore, be determined to within 4 hours.

Much consideration was given to the design of the stands to support the recorders. It was decided that it would be preferable to use a stand which would move with the overall expansions and contractions of the surrounding peat (and so register water table relative to peat surface) rather than one totally embedded in the underlying mineral material. To this end the recorders located in the wet cuttings were mounted on a PVC platform (45 x 45 x 1.6 cm) whose 4 corners were attached to 2 m lengths of ABS soil pipe (external diameter 10 cm). The float and counterweight were enclosed in a 1 m PVC perforated tube (internal diameter 10.7 cm), sunk approximately 75 cm into the peat, directly below the recorder. The stands supporting the recorders were inserted approximately 1 m into the peat. Only in the case of EP, where the peat is shallow, was the underlying clay penetrated. To penetrate the dry peat baulk recorder SB was mounted on a stand supported by 4 'legs' of galvanised dexion slotted angle,2 m in length. Even so, some difficulty was experienced in inserting this stand and it was necessary to excavate a hole 1 m deep and the same size as the stand platform (45 cm x 45 cm), prior to installing the stand. The float and counterweight were not enclosed by a PVC tube in this case as there was no means of supporting such a tube.

The data obtained from the first few days of operation were discarded, as it was considered that the float and water table needed time to equilibrate after installation.

To investigate possible vertical movement of the recorder stands in the cuttings, the length of one leg of each stand above the water table was measured, every month when the charts were changed, during year 1. These readings were compared with changes in water table registered by the recorders and by adjacent sampling tubes.

5.2.3 Water table in a peat baulk and adjacent peat cutting

Water table in a baulk and adjacent cutting in the centre of the pNNR was investigated by means of a transect of sampling tubes located across cutting 4/5W5 and the nearby southern baulk. The transect (known as CB) was 54 m in length and positioned at right angles to the long axis of the baulk and cutting (Fig. 5.4) incorporating the water level recorders 4/5W5 and SB. Sampling tubes were installed every 2 m, 11 in 4/5W5, 15 across the baulk and one in 4/5W6 (Fig. 5.15). At SB it was unnecessary to install a tube as the water table reading was obtained from the hole over which the SB recorder was mounted.

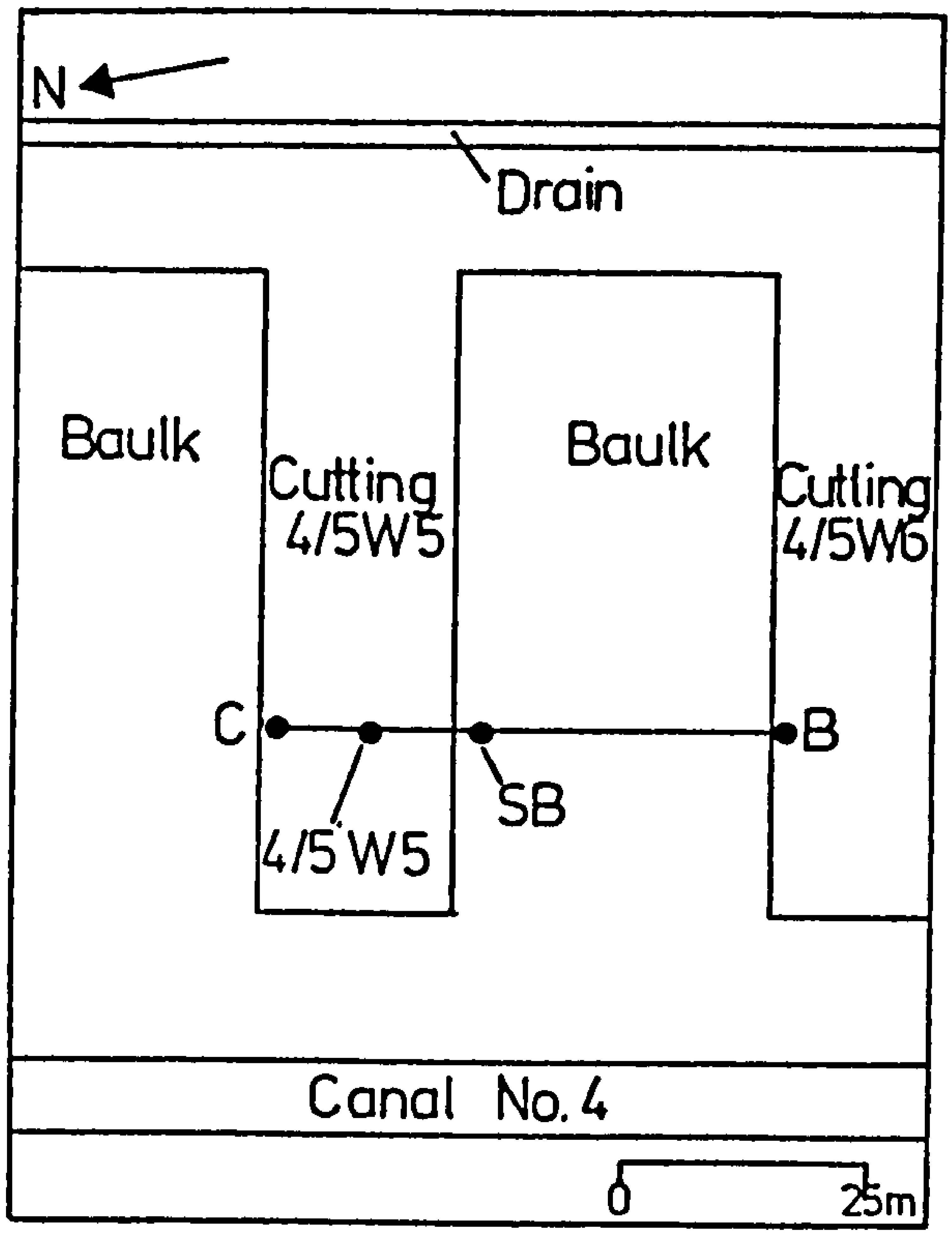


Fig. 5.4 Location of transect CB.

The sampling tubes were 75 cm lengths of capped, perforated ABS soil pipe (internal diameter 3 cm). The tubes were inserted by applying pressure from above, removed and re-inserted following clearance of peat debris from the pipe bore. All tubes were buried to within approximately 5 cm of their length. They were left for one month for equilibration prior to measurement.

In the cuttings the water level was measured from the top of each sampling tube using a flexible steel rule graduated in mm. The water table relative to the peat surface was calculated from this measurement.

On the peat baulk the water table was determined by the apparatus shown in Fig. 5.5. A metal rod (diameter 2 mm, length M), one end of which was inserted into a cork, was introduced into the sampling tube. A PVC plug was used (Fig. 5.5) to support and centralise the apparatus, and relevant measurements were made with a flexible steel rule. After determining the water level at which the cork floats in the laboratory, the water table was calculated. The reading obtained by this method is likely to be a slight over-estimate of water table because the cork displaces its own volume of water.

Water table measurements were taken at approximately monthly intervals from November 1981. Although a monitoring duration of one year was planned, the investigation was prematurely terminated because of the severe fire on 2 June 1982 which melted all the sampling tubes, and substantially altered the shape of the peat baulk. The transect was levelled when the water table was above the surface in the peat cutting. The shape of the peat surface in the cutting was determined by measuring water depth at one metre intervals along the transect. The baulk was levelled by means of a Quicksett level, utilizing the water table in the cutting as a local datum.

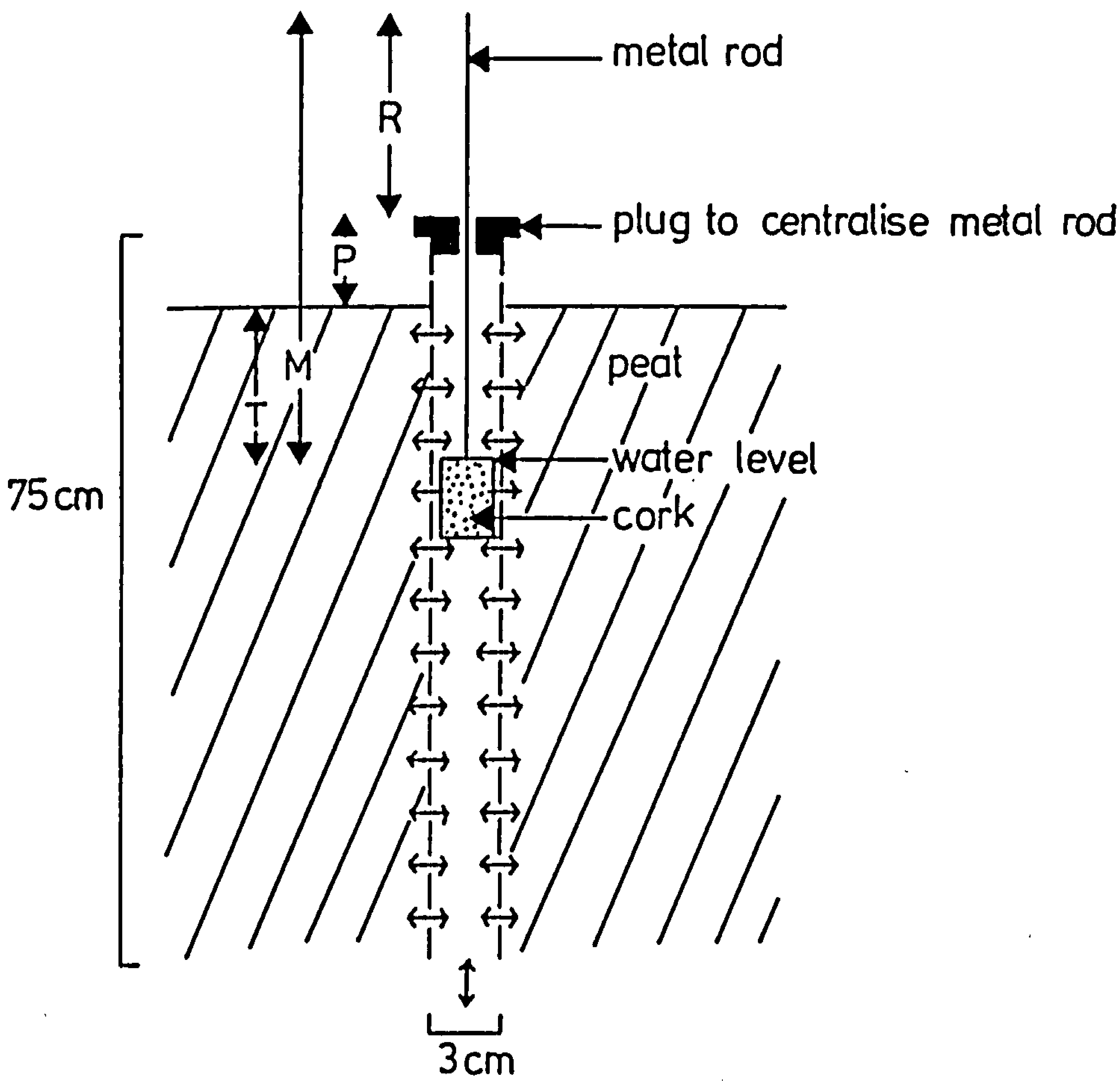


Fig. 5.5 Apparatus for determination of water table in a peat baulk. Water level below peat surface (T) was calculated by subtracting (R + P) from M.

5.3 GENERAL FEATURES AND PROBLEMS OF INTERPRETATION OF THE WATER TABLE DATA

5.3.1 General features of the water table data

The continuous water table records obtained during years 1 and 2 are shown in Figs. 5.7 and 5.8 respectively; the daily, mean weekly and mean monthly water tables are represented graphically in conjunction with daily, total weekly and total monthly precipitation values in each case. Changes in water table registered by means of the sampling tubes, the water level recorders and the legs of the water level recorder stands are shown in Fig. 5.6. Table 5.1 shows characteristics of the yearly water table levels. Extracts from the original chart data are shown in Figs. 5.9-5.12.

Intermittent water table records measured in the sampling tubes are represented graphically in Figs. 5.13 and 5.14. The monthly water table in 4/5W5 and the adjacent, southern, peat baulk, determined from the transect CB (Fig. 5.4) is shown in Figs. 5.15 and 5.16. Because of their complex nature and as several features can be identified from these records, the results are all presented together here. Reference back to the relevant diagrams is needed in discussing specific points; however, some general features may be identified here:

1. There was a marked seasonal variation in the water table at all study sites.

Fig. 5.6a

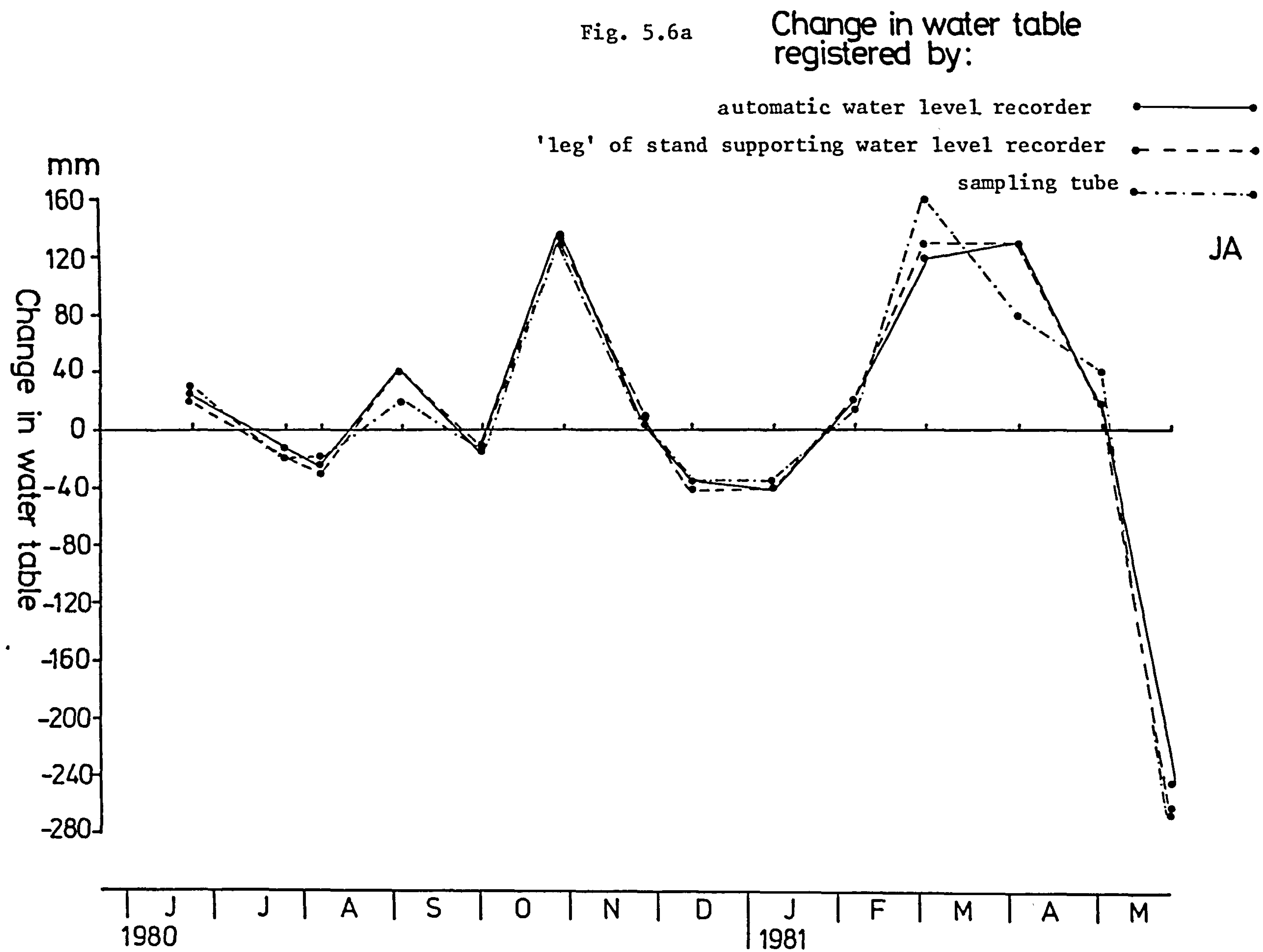
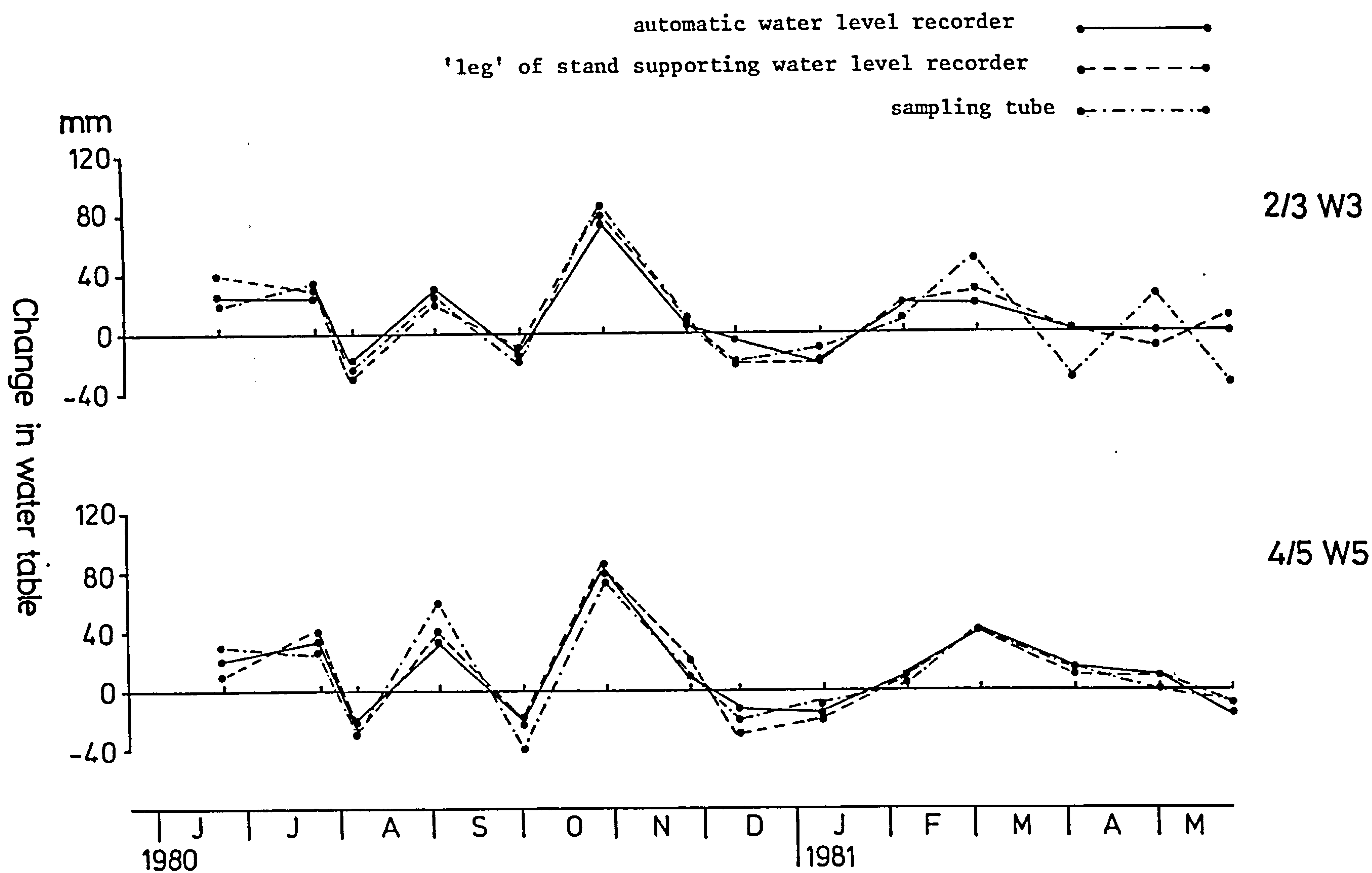

Change in water table registered by:
automatic water level recorder
'leg' of stand supporting water level recorder
sampling tube
JA
mm
160
120
80
40
0
-40
-80
-120
-160
-200
-240
-280
Change in water table
J
J
A
S
O
N
D
J
F
M
A
M
1980
1981

Fig. 5.6b Change in water table registered by:



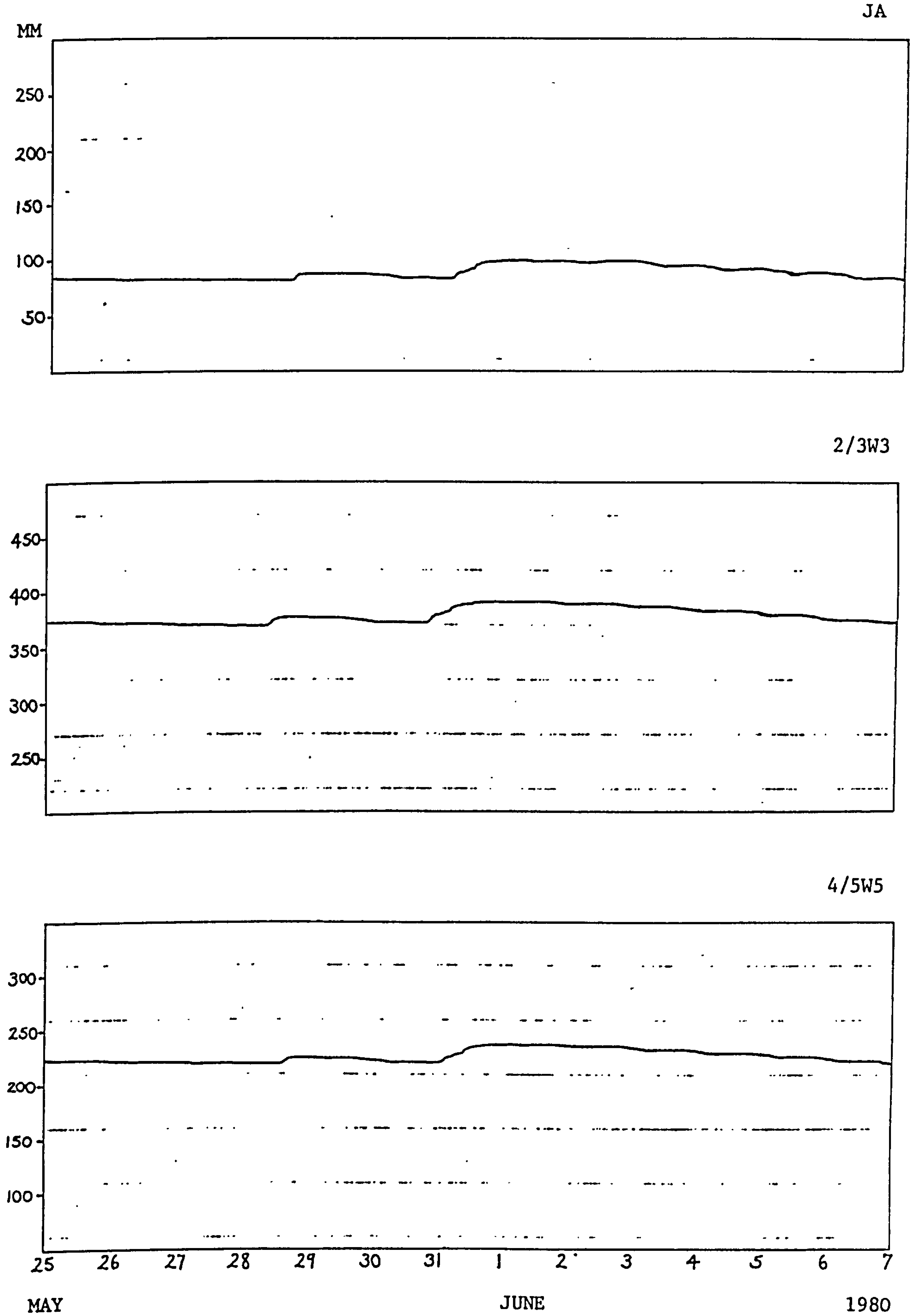


Fig. 5.9 Water table relative to peat surface (registered by automatic water level recorder) between 25 May-7 June 1980.

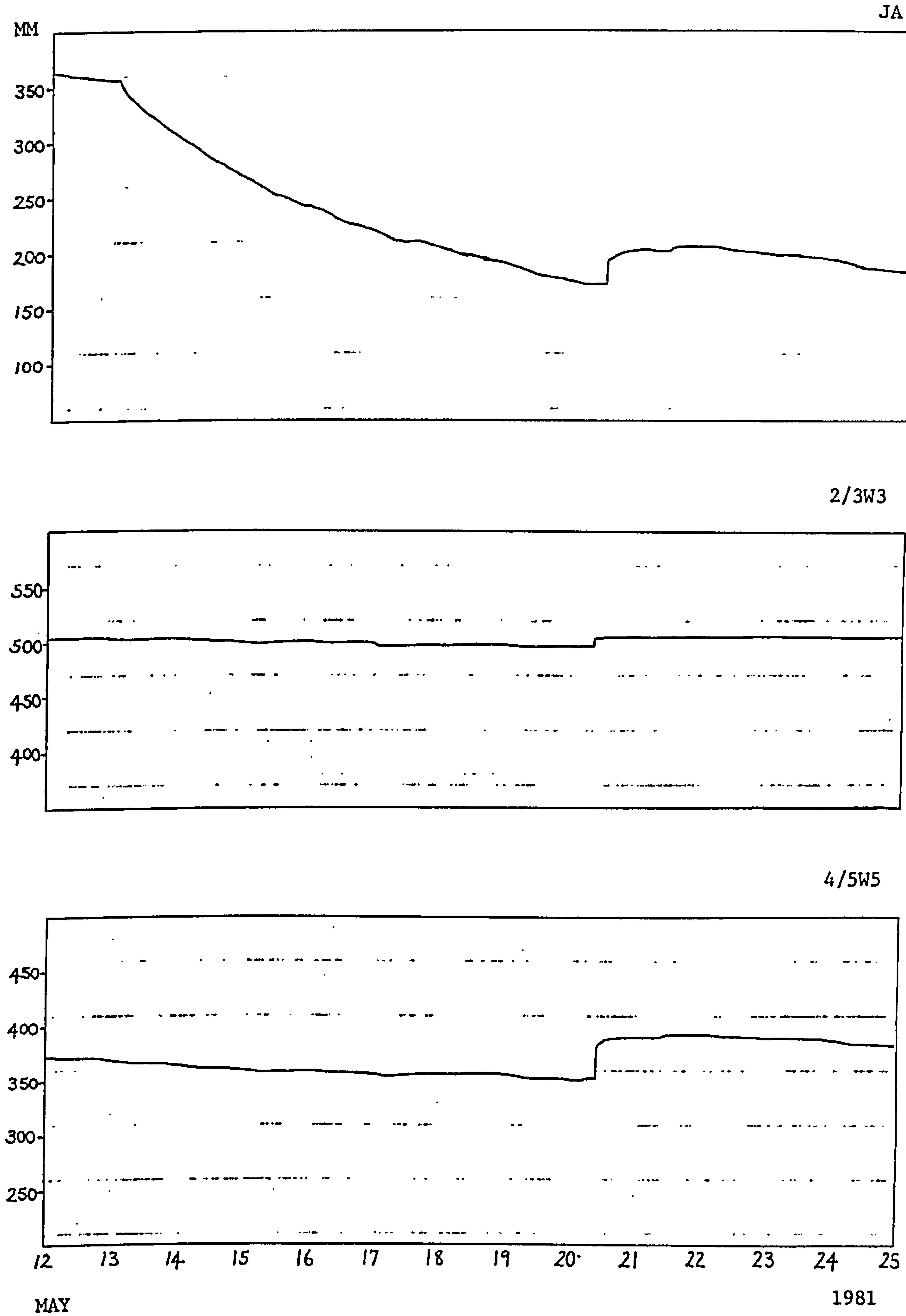


Fig. 5.10 Water table relative to peat surface (registered by automatic water level recorder) between 12-25 May 1981.

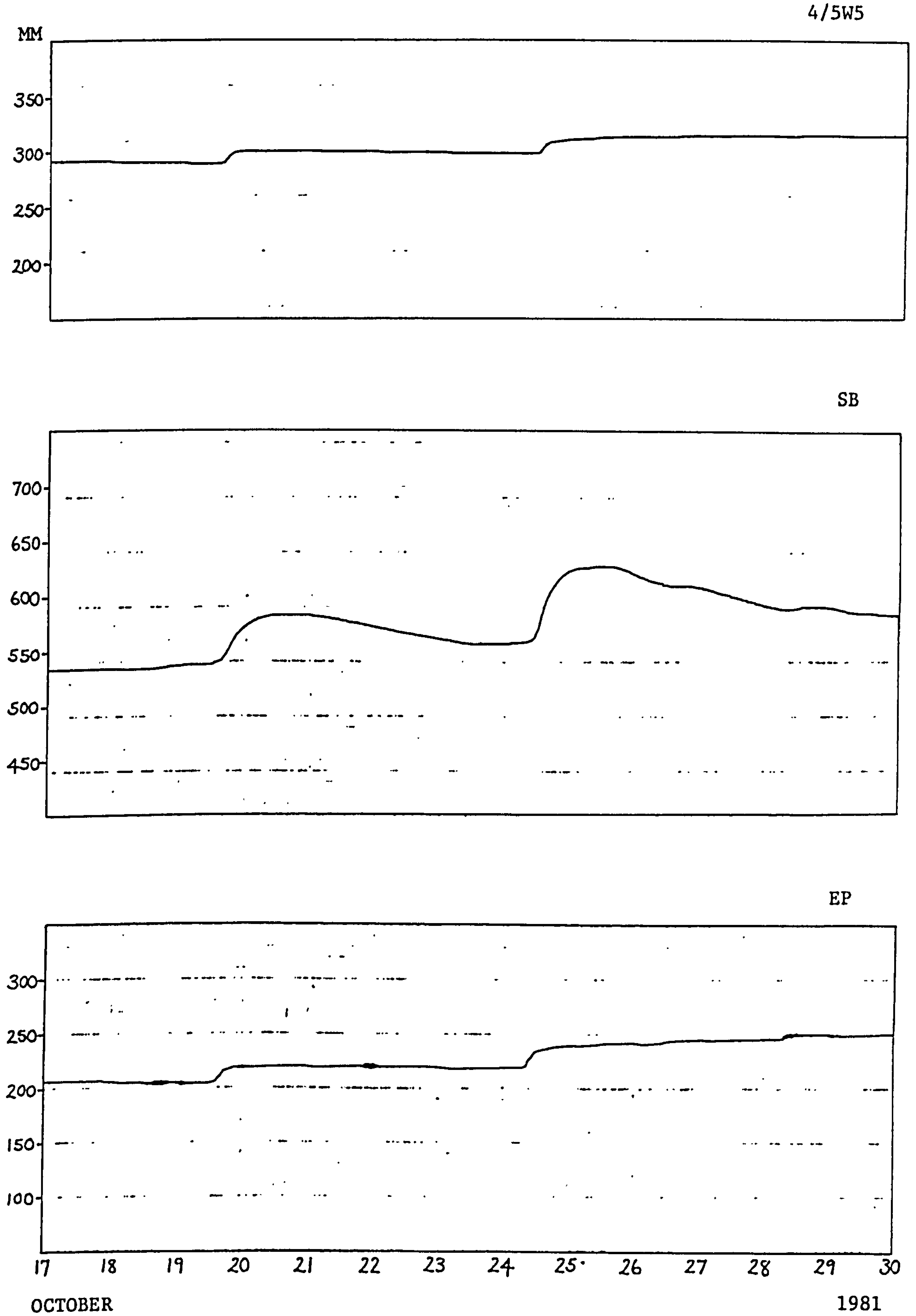


Fig. 5.11 Water table relative to peat surface (registered by automatic water level recorder) between 17-30 October 1981.

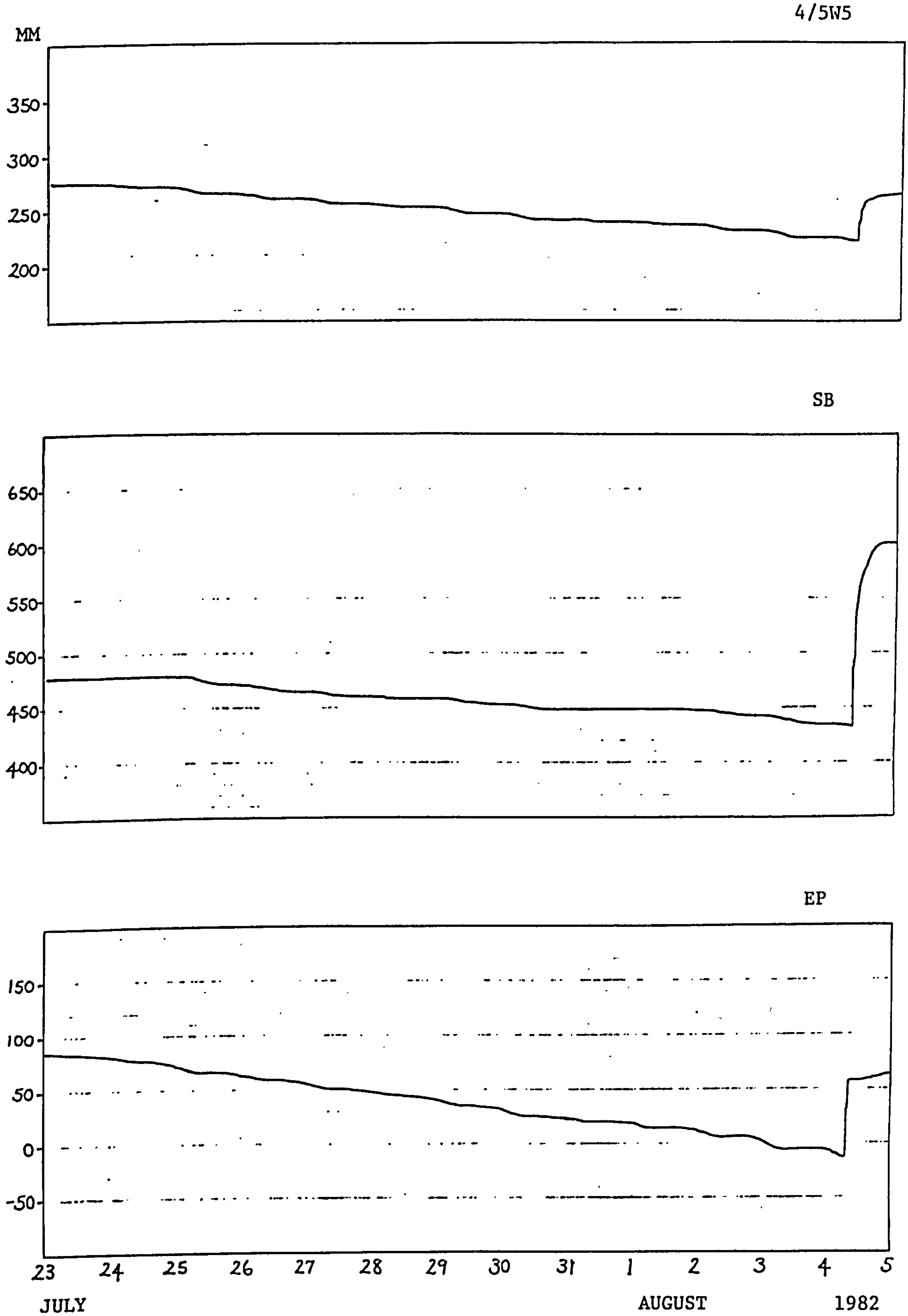


Fig. 5.12 Water table relative to peat surface (registered by automatic water level recorder) between 23 July-5 August 1982.

Fig. 5.13a Water table (measured in sampling tubes) in peat cuttings between April 1980-August 1981.

Fig. 5.13b Water table (measured in sampling tubes) in peat cuttings between April 1980-August 1981.

Fig. 5.13c Water table (measured in sampling tubes) in peat cuttings between April 1980-August 1981.

Fig. 5.13d Water table (measured in sampling tubes) in peat cuttings between April 1980-August 1981.

Fig. 5.14 Water table (measured in sampling tubes) in canal 4 between November 1980-March 1982.

Fig. 5.15a Water table relative to peat surface in transect CB between November 1981-May 1982. Note exaggeration of vertical scale.

Fig. 5.15b (see Fig. 5.15a).

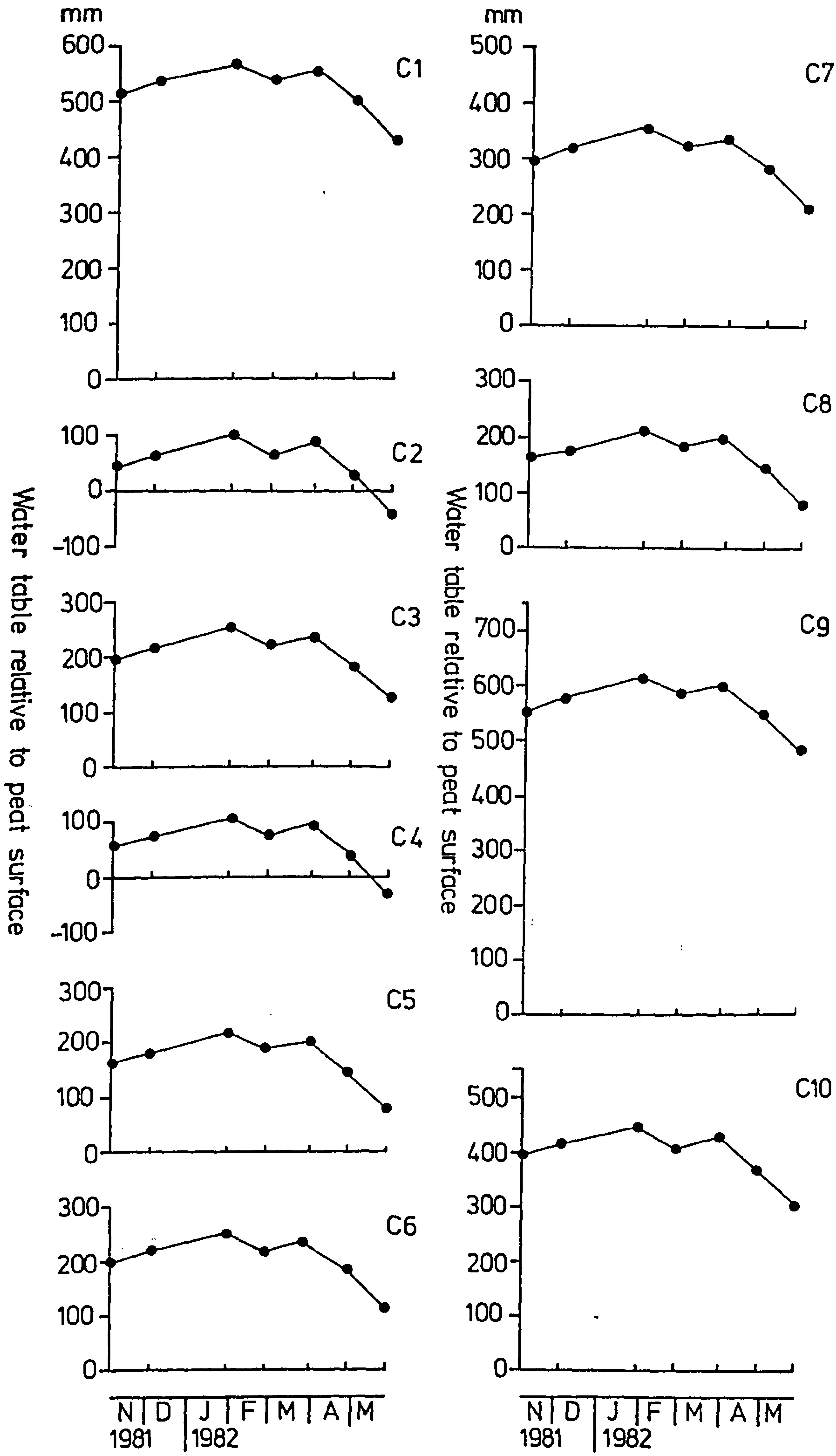


Fig. 5.16a Water table in sampling tubes of transect CB between November 1981-May 1982.

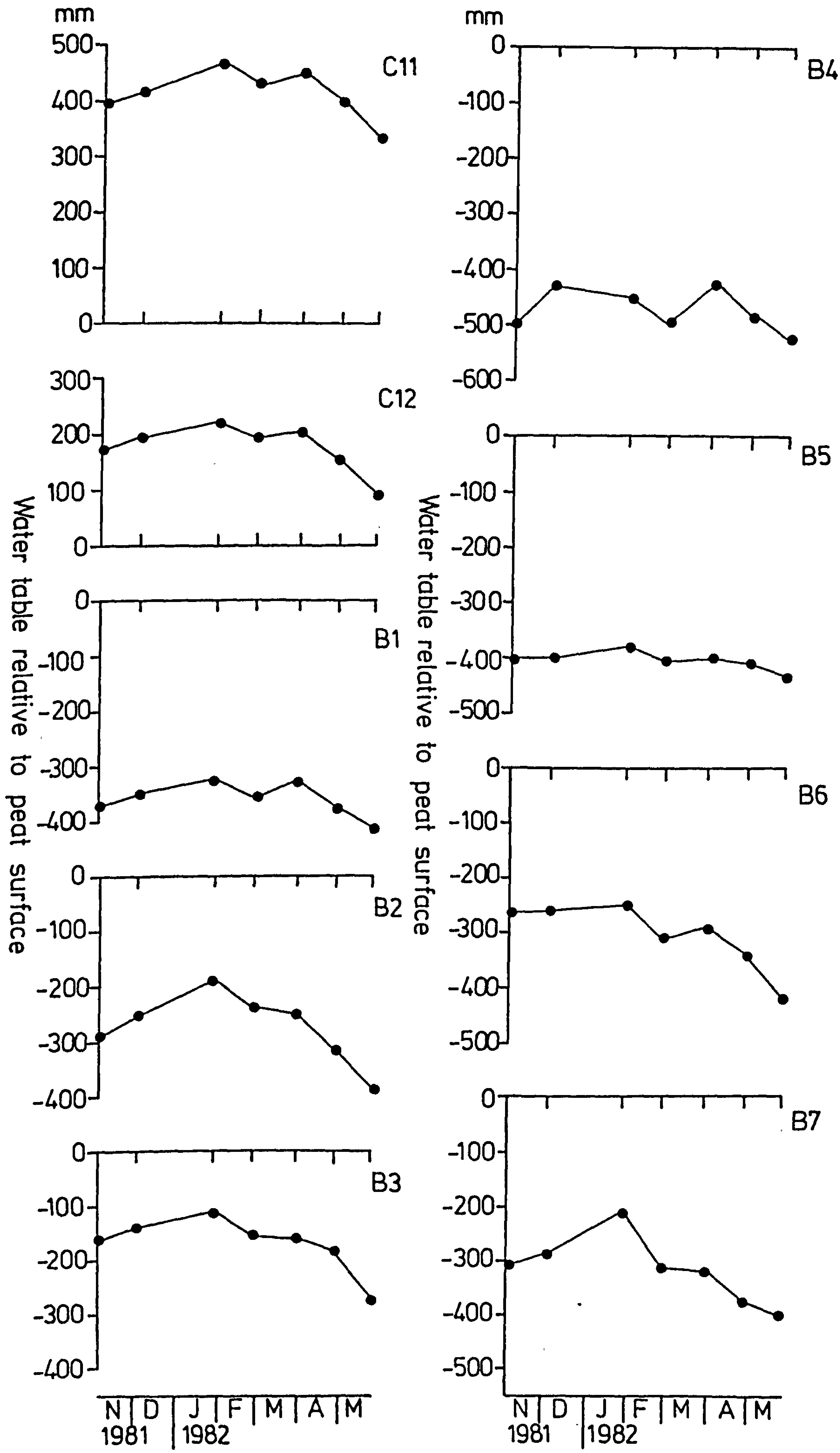


Fig. 5.16b Water table in sampling tubes of transect CB between November 1981-May 1982.

Fig. 5.16c Water table in sampling tubes of transect CB between November 1981-May 1982.

Table 5.1 Characteristics of yearly water table levels in peat cuttings monitored by automatic water level recorders. All values are in mm.

Year	Water level recorder	Mean	Median	Mode	Lowest water table	Highest water table	Range
1	JA	196	175	180	60	430	370
1	2/3W3	473	485	510	365	510	145
1	4/5W5	333	345	350	215	415	200
2	4/5W5	301	310	320	180	400	220
2	SB	560	560	580	420	790	370
2	EP	179	200	220	-55	370	425

Values for year 1 are based on water table levels recorded over one year between 1 June 1980 and 31 May 1981; those for year 2 are based on water table levels between 6 August 1981 and 5 August 1982.

2. The continuous water table records show that all sites exhibited long and short term fluctuations in water level.

3. The height of the water table was greater, and the fluctuation of the water table was less, in the cuttings of the pNNR than in the other study sites.

4. The behaviour of the water table in the peat baulk was very different from that observed in the peat cuttings.

These main features of the data are analysed and discussed in subsequent sections.

5.3.2 Limitations and problems in the interpretation of the water table data

Owing to the difficulty in determining levels across the area (Chapter 1) the relative heights of the study sites, apart from 4/5W5 and adjacent baulk, were not accurately established.

5.3.2.1 Continuous water table records

1. Movement of the water level recorder stands

Discrepancies between water table changes registered by the charts of the water level recorders and by the sampling tubes (Fig. 5.6) suggest that, for limited periods, the water table was either over- or under-estimated by the water level recorder, probably because of vertical movements of the recorder stands. The crude nature of the data, however, must be taken into account. It is impossible to establish from these data the degree of expansion and contraction of the peat surface. Discrepancies in water table changes monitored by these methods may be, at least partially, the result of differential movement of the peat mass at the site of the recorder and the site of the sampling tube. Differences may reflect errors in measurement, particularly in the case of the recorder stand, the length of which was difficult to measure accurately.

2. Short term changes in water table

Short term fluctuation in water level may be a response to rainfall. However, the response to rain may be quicker than Figs. 5.7 and 5.8 suggest. This is because the daily water table represents the level at approximately midday, whereas the daily precipitation measurements were taken at 0900 GMT, on the following day. Changes in water table occurring after midday are therefore not shown until the next day.

In considering the response of the water table to rainfall, the fact that the Crowle rainfall station is 6.0-6.5 km away from the recorders should be also taken into account; the amount of rain falling into the cuttings may have been slightly different from that shown in Figs. 5.7 and 5.8.

3. The effect of ice

The rather high mean monthly water table recorded for January 1982 (Fig. 5.8) at all sites was probably because the floats were held at relatively high levels when the water froze during mid-January. The water also froze in late December 1981; these periods are shown as spells of steady water table in the cuttings. In EP the ice held the float at an artificially high level; this added 70 mm to the water table range at this site.

4. The effect of the fire

Apart from melting some of the sampling tubes (5.2.3) the fire which occurred on 2 June 1982 burnt through the cable attaching the float to the counterweight in recorder SB. The water table between 2-25 June (the time taken to replace the lost counterweight) has been estimated as the mean between these two dates and is therefore represented as a straight line in Fig. 5.8b.

5. The water level recorded by SB

The behaviour of the water table in the hole over which recorder SB was mounted is unlikely to represent exactly the changes in water table which occurred within the peat baulk as the measurement of water table in a pit may not precisely reflect the water table within the peat, when the water table is below the surface. It is likely that the water table in the surrounding peat will be maintained at a slightly higher level owing to impeded drainage (Ingram 1982). Set against this, however, is the fact that in the immediate vicinity of the peat surrounding the pit an area of draw-down may be created causing water to flow into the pit. The size and shape of the hole are likely to have affected the water level. Rycroft, Williams & Ingram (1975), considering the use of seepage tubes to investigate the hydraulic conductivity of peat, observe that the dimensions of a cavity in peat affect the rate of water movement into that cavity because water may be conducted by peat at a different rate in the horizontal and vertical planes. It is also likely that, after rain, the water table in the hole will have risen before the water table in the peat baulk because of the time necessary for water to percolate through the peat to reach the water table.

5.3.2.2 Intermittent water table records

The measurement of water level in short sampling tubes may not exactly reflect the true water table in relation to the underlying mineral material (c. 2 m below the peat surface). The tubes are held at the peat surface and should, therefore, move with the peat surface if expansion or contraction of the peat takes place. It was considered, however, that an estimate of water table in relation to peat surface would be of greater value in assessing the effect of water levels on the composition of the vegetation. The remarks made on measurement of water table in wide cavities (sampling tubes of 10 cm internal diameter) apply here. The main reason for using sampling tubes of these dimensions was that they were also used for collection of water samples for chemical analysis (6.2). In the CB transect the use of narrower tubes (internal diameter 3 cm) will lessen the effect owing to a higher water table being maintained in the surrounding peat than in the sample tube, because of impeded drainage.

The apparently uneven water surface in the peat cutting measured from the CB transect (Fig. 5.15) may be due to measurement errors or reflect the fact that the surface of the peat altered in shape slightly between the beginning of the investigation and the time when the transect was levelled (March 1982) because of the continual trampling of the area.

5.4 SEASONAL FLUCTUATIONS IN THE WATER TABLE

5.4.1 Response of the water table to rain

5.4.1.1 Continuous water table records

1. Gross changes in water level

Comparison of the mean weekly and monthly water table and the total weekly and monthly precipitation suggests that bulk changes in water level are a response to rainfall. The water table in early October 1980 (Fig. 5.7), for example, may be related to the low rainfall of September 1980. The highest levels in the cuttings during year 1, recorded in March and April 1981, correspond to the high rainfall value of March. Similar relationships can be advanced for other periods in 1980 and 1981, and for year 2 (Fig. 5.8).

In 4/5W5 the mean water table of year 2 was 301 mm, 32 mm less than that recorded for year 1 (Table 5.1). This difference, and the lower modal value of year 2, probably reflect the relatively low precipitation of the first half of 1982 (Appendix 3), compared with the greater than average precipitation totals of 1980 and 1981.

2. Short-term responses to rain

Inspection of Figs. 5.7-5.12 suggests that the response of the water table to precipitation was rapid in all the cuttings. For example, the 30 mm of rain which fell on 20 May 1981 (Fig. 5.10) produced an immediate rise in water table in the three cuttings.

There was a consistent variation in the magnitude of the short-term response to rainfall. During year 1 the recorder at site 2/3W3 always registered a lesser increase in water table than found at JA and 4/5W5. The 28 mm of rain which fell on 30 June 1980, for example, produced a rise in water table of 35 mm in 2/3W3 and 50 mm in both 4/5W5 and JA. During year 2 site EP consistently showed a greater increase in water table subsequent to rain than site 4/5W5.

The magnitude of the response to rain varied with the time of year; greater increases in water table occurred during the summer months. The 13 mm of rain which fell on 4 August 1982 caused the water table to increase by 40 mm in 4/5W5 and 80 mm in EP (Fig. 5.12), whereas the 13 mm of rain which fell on 24 October 1981 produced an increase in water table of 10 mm in 4/5W5 and 20 mm in EP (Fig. 5.11).

5.4.1.2 Intermittent water table records

In the peat cuttings gross changes in water table were related to rainfall. The gradual summer increase in water level of 1980, for example, corresponds to heavy rainfall during June and August 1980 (Fig. 5.13).

In canal 4 (Fig. 5.14) there appears to have been a delay in the response to rainfall. For example, during September 1981 the level at all sampling locations was low, despite relatively high rainfall in August and September. An increase was, however, registered in October.

5.4.1.3 Factors affecting the response of the water table to rain

1. Short-term responses to rain

Any given amount of rainfall will tend to produce a greater rise in water level when the water table is originally below the peat surface than when it is above the peat surface. This is accounted for by the fact that it is only the spaces or 'voids' (Ingram 1967) between the peat particles that can accommodate the water. The absorption of water by the drier areas of JA and 4/5W5 and their surrounding peat baulks may explain why these cuttings consistently, after rain, registered greater increases in water table than 2/3W3. There are no peat baulks in the immediate vicinity of 2/3W3 and this cutting has a high water table continuously above the peat surface. In EP the mean water table was much lower than that in 4/5W5. This may explain why at all times EP registered a greater increase in water table than 4/5W5 and why, in all cuttings, the response was greater during the summer when the water table is low than during the winter.

2. The delay in the response to rain in canal 4

The canal is relatively long and narrow and surrounded on both sides by dry peat baulks at least 5 m wide. Water takes longer to infiltrate drier peat than more moist peat (Keane & Dooge 1972) and so it is likely that there would be some delay before the water table level in the baulk responded to rain. The observed effect, therefore, may arise from this delay in the equilibration of the water table in the baulk and canal, after rain.

5.4.1.4 Conclusions

1. Gross changes in water level in all peat cuttings appear to be closely related to rainfall.

2. The response to rainfall at all sites except canal 4 was immediate.

3. The consistent difference in the magnitude of the response to rain observed in the study sites was considered to relate to the relative proportions of peat above and below the water table.

5.4.2 Seasonal decline in water level

5.4.2.1 Seasonal decline in water level at the study sites

During the summer of 1980 all the recorders registered several consecutive periods of steady reduction in water table subsequent to each fall of rain (Figs. 5.7 and 5.9). Although comparable amounts of rain fell during the winter of 1980/81, the water table remained at a higher level than during the summer. This presumably reflects greater evapotranspiration during the summer months. The diurnal pattern of loss can be clearly seen in Figs. 5.9 and 5.12.

The decline in water table in the peat cuttings may be described by the mean gradient of the fall in water table over equivalent rain-free periods. During the summer of year 1, between 2-7 June 1980, the mean gradient of the fall in water table in 4/5W5 was 2.5 (i.e. the mean rate of fall was 2.5 mm per day), whereas during the winter, between 26-31 December 1980, the mean gradient of the fall in water table was 1.5 in this cutting.

The cuttings showed differences in the rate of decline of the water table. Between 2-7 June 1980 (Fig. 5.9) the mean gradient of the fall in water table was 2.0 in JA and 2/3W3 and 2.5 in 4/5W5. Between 6-16 May 1982 the mean gradient of the fall in water table was 3.0 in 4/5W5 and 6.0 in EP. The differences between the rate of decline of the water table at the study sites were consistent. At site 2/3W3, for example, a greater decline in water table was always registered than at 4/5W5: between 14-19 May 1981 (Fig. 5.10) the mean rate of fall was 2 mm per day in 4/5W5 and 1 mm per day in 2/3W3.

A seasonal decline in water table was also shown by the intermittent water table records.

5.4.2.2 Factors affecting the seasonal decline in water level

A seasonal relationship between water table in mires and rainfall has been observed by many workers (e.g. Bartley 1960; Chapman 1965). The loss through transpiration by vegetation is greatest during the summer.

The differences in the rate of decline of the water table in different parts of Thorne Moors may perhaps be attributable to the height of the water table in the cuttings, lower rates being associated with higher water levels. The mean water table in 2/3W3, for example, was greater than that in 4/5W5. Nichols & Brown (1980) found that under similar conditions the rate of evaporation from a *Sphagnum* moss surface was approximately twice that from a free water surface. The highest rate of evaporation was found when the water table was c. 5 cm below the surface. Although the vegetation in neither of these cuttings consists of a complete *Sphagnum* lawn, it is likely that the difference in the rates of fall between sites 2/3W3 and 4/5W5 may be because the higher water table of 2/3W3 covered a greater proportion of the vegetation than in 4/5W5. In EP a greater exposure of peat and vegetation due to an even lower water table may explain the relatively high observed rates of reduction in level.

5.4.2.3 Conclusions

Seasonal decline in water levels were considered by comparing mean gradients of the fall in water table:

1. The decline in water level was greatest during the summer probably because of losses through evapotranspiration.

2. At any one time the sharpest decline in water level occurred in peat cuttings with the greatest exposure of peat and vegetation; losses through evapotranspiration may therefore relate to the level of the water table.

5.5 HEIGHT AND FLUCTUATION OF THE WATER TABLE

5.5.1 Height of the water table

The continuous water table records show that mean and modal water tables were higher in the pNNR (2/3W3 and 4/5W5) than in JA and EP. Within the pNNR the water level in 2/3W3 was higher than that in 4/5W5 (Table 5.1).

There was much local variation in the height of the water table in relation to the peat surface in the central (Fig. 5.13) and outer (Figs. 5.15 and 5.16) sections of the cuttings in the pNNR. For example in 4/5W1 (Fig. 5.13) the level never fell below 90 mm, whereas in 2/3W8 the level was continuously below 60 mm above the peat surface.

It has been observed (Chapter 1) that there may be a very slight rise in height to the south and west of the pNNR area. This is borne out by the water table results: in cutting 5 the sampling tubes indicated deeper water for longer periods in an eastwards progression. Likewise, in canal 4 (Fig. 5.14) and in the 2/3W transect, although the water table in 2/3W7 and 2/3W8 was generally slightly lower than in 2/3W10 and 2/3W12, there was an overall trend towards drier conditions to the south.

Drains may exert some influence on the water table in some of the cuttings. For example the New Cut may help maintain the water level in 1/2W5 at a relatively low level (Fig. 5.13).

5.5.2 Fluctuation of the water table

5.5.2.1 Continuous water table records

The range of fluctuation of the water table was least in the pNNR and greatest in JA and EP (Table 5.1). This is emphasized by the fact that the largest differences between the mean weekly and mean monthly water table curves occur in JA (Fig. 5.7) and EP (Fig. 5.8). Within the pNNR the range of fluctuation was greater in 4/5W5 than in 2/3W3.

The large range of fluctuation exhibited by JA was partly the result of a rise in water table (approximately 200 mm) in February and early March 1981, when increases of no more than 80 mm occurred elsewhere. On 13 May 1981 the water table rapidly fell (Fig. 5.10). Between 14-19 May the water table dropped by 110 mm. The mean gradient of the fall in water table between these two dates was 22.0; the mean rate of fall was, therefore, 22 mm per day. At the same time the mean gradients of the fall in water table in 4/5W5 and 2/3W3 were 2.0 and 1.0 respectively (Fig. 5.10).

5.5.2.2 Intermittent water table records

In the pNNR cuttings the range of water table fluctuation (excluding the 3/4E transect which was measured over a period of less than one year), was fairly similar, ranging between 115 mm and 170 mm above the surface over the period investigated - a difference of 55 mm. The range of fluctuation was lowest towards the centre of the area of the pNNR where peat baulks separate the cutting bays (the lowest range of 115 mm occurring in 3/4W5) but this may not be significant.

5.5.3 Features affecting the level and fluctuation of the water table

5.5.3.1 The level of the water table in the pNNR

The high water levels and the overall similarity in the pattern and fluctuation of the water table in the pNNR suggest that the whole area responds similarly to changes in water relations.

The variety of depths to which peat was cut is considered to be the main reason for the observed local differences in the height of the water table. Deposits of peat 'rubble' also introduce further variation together with the vegetational microtopography. Mining subsidence may have had local or general effects on the water level.

Because of the difficulties in establishing precise levels in the area (5.3), it is not easy to comment on the relative effects of drains and elevation differences on water levels observed. However, it is unlikely that the New Cut is responsible for the relatively low water level in 1/2W5 (Fig. 5.13). This drain is dammed at both ends and if it were exerting an influence, the water table in 1/2E5, on the eastern side of the New Cut (Fig. 5.1), would be expected to be generally lower than that observed. Drains to the west of canal 1 are probably too far away (c. 50 m) to exert any detectable draw-down effect on the water level in 1/2W5 (cf. Boelter 1972). In addition, dry peat baulks, c. 5 m wide, run along both sides of canal 1; it is considered, therefore, that the low water table recorded in 1/2W5 reflects the relatively high altitude of the area. The effectiveness of dry peat baulks in maintaining high water tables is further considered in Chapter 10.

5.5.3.2 Comparison with undisturbed mires

With regard to the aims of conservation management in the pNNR area, it is relevant to compare the level and range of the water table with that observed in undisturbed bogs. Goode (1970), working on the Silver Flowe, N.W. Scotland, found that water table levels varied around the peat surface over a range of 150 mm in the pool networks on the crown of the bog and increased to 250 mm towards the periphery. At Coom Rigg Moss, Northumberland Chapman (1965) found that the lowest summer water table was -230 mm and that run-off occurred at -80 mm, suggesting a maximum fluctuation of 150 mm. Although these bogs may differ somewhat from Thorne Moors before it was cut and drained, such values suggest a comparable, if somewhat higher, range of fluctuation at Thorne (145 mm in 2/2W3; 200 mm in 4/5W5). By contrast it is clear that the measured mean water levels at Thorne Moors (473 mm in 2/3W3; 333 mm in 4/5W5) are substantially above those recorded in undisturbed sites. The upper limit of the water table, and, therefore, to some extent, the amplitude of fluctuation are determined by the heights and permeabilities of dams in ditches and drains. The management problems which this situation creates are discussed in Chapter 10.

5.5.3.3 Level and fluctuation of the water table in JA

The increase in water table of approximately 200 mm which occurred during February and early March 1981 was quite different from anything measured elsewhere on the Moors. It was probably explained by the activities of Fisons Ltd. Subsequent to the relatively low rainfall of December 1980 and January 1981, the water table in peat workings to the east of JA was apparently raised in late February 1981, by Fisons Ltd., (to reduce fire risk) by damming the drain which forms the eastern extension of Main Canal North and which runs into Mill Drain (Fig. 5.3). As a result, water backed up into JA, the northern boundary of which comprises this drain. After the heavy rainfall of March 1981, the dam was breached on 13 May 1981 (Fig. 5.10); this caused the water table to fall quickly. Were it not for the fact that some water may run on to this cutting from elsewhere the mean water table (196 cm) would probably have been lower.

5.5.3.4 Level and fluctuation of the water table in EP

The main contributory factor to the high range (425 mm) and the low mean water level (179 mm) appears to have been the low water table levels recorded throughout the summer of 1982.

These were lower than values recorded in other parts of the site and may be explained by various features: The area is not so thoroughly 'sealed off', by dams in drains and peat baulks as the pNNR, from the effects of surrounding drains. Also the sluice at the west end of the Southern Boundary Drain may have been open during this time causing additional drainage of the peat.

5.5.4 Conclusions

1. The variation in the water level relative to the peat surface in the pNNR probably reflects general and local variations in peat height, with no clear evidence for draw-down associated with the New Cut.

2. The dams in drains and ditches which aim to seal off the pNNR area hydrologically are considered to be effective:

a. The water table fluctuated less in the pNNR than in the other study sites.

b. The water level in the pNNR was much higher than in the other study sites.

c. The overall similarity in the magnitude and pattern of water table variation in the cuttings and canal investigated in the pNNR suggests that the whole area responds similarly to changes in water relations.

3. The range of water table fluctuation in the pNNR is somewhat higher, and the mean water levels are substantially higher, than those recorded in undisturbed mires. This is

because the upper limit of the water table, which in intact mires is determined by the level at which run-off occurs, is at Thorne dictated by the height and permeability of dams in ditches and drains.

4. In JA the level and fluctuation of the water table were partly explained by the activities of Fisons Ltd. Most of the time the drain which forms the northern boundary of this cutting maintained the water table at a relatively low level.

5. In EP the relatively low mean water table was probably mostly due to the influence of the southern Boundary Drain.

5.6 THE WATER TABLE IN THE PEAT BAULK

5.6.1 The response of the water table to rain registered by recorder SB

5.6.1.1 Gross changes in water level

Comparison of the total monthly precipitation values with the mean monthly water table (Fig. 5.8) and the fluctuation of the water table (Fig. 5.16) suggest that gross changes in water level in the peat baulk were related to rainfall.

5.6.1.2 Short-term responses to rain

The short-term response to rain was rapid. A much greater increase in water table occurred in SB subsequent to rain than in 4/5W5. For example, the 13 mm of rain which fell during 24 October 1981 produced an increase in water table of 70 mm in SB, but only 10 mm in 4/5W5 (Fig. 5.11). The magnitude of this response seemed to vary with the time of year; the 13 mm of rain which fell during 4 August 1982 caused the water table in SB to increase by 170 mm (Fig. 5.12).

As well as exhibiting a much higher rise in water table subsequent to rain than in 4/5W5, Fig. 5.11 shows that the overall pattern of response to rain in SB was also very different from that occurring in 4/5W5. Fig. 5.11 shows the response of the water table to rain on two occasions. In 4/5W5 the water table responded immediately (rising by 10 mm) to the 12 mm of rain which fell on 19 October 1981 and then stabilized until 24 October when 13 mm of rain caused a further increase. By contrast, although the response to the 12 mm of rain on 19 October was immediate in SB, the water table continued to rise for 24 hours, to increase by a total of 50 mm; over the next 3 days the water table fell steadily until 23 October (when a fall of 1 mm of rain may have prevented a further decline in water table). The 13 mm of rain which fell on 24 October produced a similar pattern of response to that of 19 October: the water table rose over a period of 24 hours by 170 mm; the subsequent fall was influenced by the 1 mm of rain which fell on each of 26, 28 and 29 October.

5.6.1.3 The net response of the baulk water table to rain

Observation of the response of SB to an isolated fall of rain suggests that the difference between the level before rain and the stabilized level afterwards was a little greater than the change registered by 4/5W5 in the same time. For example, the level in SB on 5 April 1982 was 550 mm; subsequent to the 11 mm of rain which fell between 5-7 April the level stabilized to 540 mm on 13 April. The overall change in level in 4/5W5 was from 320 mm on 5 April to 315 mm on 13 April. Between 5-13 April, therefore, the water table in 4/5W5 decreased by 5 mm and that in SB decreased by 10 mm. After stabilization of the water table subsequent to rain, Fig. 5.8 shows that the behaviour of the water table in SB was very similar to that in 4/5W5, until the next fall of rain.

The very high response to rain exhibited by SB is reflected by the recorded range (370 mm).

5.6.2 Water table fluctuation in the sampling tubes

The fluctuation of the water table was generally greater in the peat baulk than in the adjacent peat cutting (Figs. 5.15 and 5.16).

The sampling tubes in the baulk exhibited variety in the pattern of fluctuation of the water table (Fig. 5.16). This is reflected in differences in the shape of the water table profiles of Fig. 5.15. In the vicinity of the ditches, for example, the fluctuation of the water table was lower than that in some of the other sampling tubes. In B14, for example (located in a ditch - see Fig. 5.15), the water table fluctuated over a range of 180 mm whereas in B13 (located 2 m from a ditch - see Fig. 5.15) the water table fluctuated over a range of 240 mm (Fig. 5.16).

5.6.3 Interpretation of the response of the water table to rainfall

5.6.3.1 The response of the water table to rain registered by recorder SB

1. Inferred properties of the peat comprising the baulk

The behaviour of the water table in the hole over which recorder SB was mounted permits some inferences to be drawn on the properties of the peat surrounding the hole. The high amplitude of water table oscillation in SB may reflect the very low permeability of the surrounding peat. In less permeable peats, voids form a smaller proportion of the total volume than in more permeable examples. A given addition of water, therefore, produces a greater rise in level in less permeable peats than in more permeable peats; the same applies to a fall.

The peat which comprises this baulk may have a low permeability, and therefore, a low hydraulic conductivity (Ingram 1967) because it has been drained. Drying of the peat may have caused an increase in humification and the utilization of the peat baulks for peat extraction may have contributed to compaction and subsidence of the peat. The relationship between humification and hydraulic conductivity has been investigated by many workers (Baden & Eggelsmann 1963; Boelter 1965) who have found marked decreases in hydraulic conductivity with increasing humification. Humification is a complex process difficult to quantify or measure objectively. In attempting to relate hydraulic conductivity to simpler, physically based properties of peat Boelter (1970) found that bulk density (which increases with increasing decomposition) showed an inverse relationship with hydraulic conductivity. An increase in bulk density may also reflect subsidence of peat. Armstrong & Watson (1974) found that, following the drainage of a South Australian fen, the bulk density of the peat increased threefold whilst the thickness of the peat reduced to approximately one quarter, over a period of 32 years. Stephens and Speir (1970) observed that the rate of subsidence was proportional to the depth to which the water table was lowered, following drainage of organic soils in the USA. The inferred low hydraulic conductivity of the baulk, therefore, may reflect compaction, subsidence and an increase in humification owing to the drainage and subsequent drying of the peat.

2. The surface of the peat baulk

The effects of drying in causing an increase in humification and subsidence are likely to be greatest towards the outer surface of the peat baulks at Thorne. Investigation of erosion gullies on Featherbed Moss in the S. Pennines by Tallis (1973a) revealed that drying of surface peat layers caused an impermeable peat skin to develop, which accentuated overland flow. If such a skin has developed at Thorne it is possible that rainwater may tend to run over the surface of the peat into the surrounding cuttings, the ditches in the baulk (Fig. 5.15) and the SB hole. Such a skin is also likely to increase the time which rainwater (that does not run off) takes to penetrate the underlying peat, resulting in a corresponding delay in the response of the underlying water table to rain, as suggested elsewhere (5.4.3).

3. Interpretation of the pattern of response to rain

It seems likely that the high initial increase and subsequent high fall in water table reflect the low hydraulic conductivity of the peat surrounding the hole. Water running over the peat baulk surface and into the SB hole may have contributed to the high increase in level. The fact that the rise was greater during the summer (Figs. 5.11 and 5.12) may be because the peat adjacent to, and above, the water table at the lower summer water level has an even lower hydraulic conductivity than that adjacent to and above the water table at the higher winter levels. The level at which the water table eventually stabilizes may approximately represent the net response of the baulk water table to the rain. The time required for stabilization is probably that taken by the water table in the baulk and hole to equilibrate, and may relate to the time for the rain water to infiltrate the peat baulk and reach the water table.

4. Future changes in the peat baulk

It is likely, owing to further drying, that the peat of the baulks will continue to settle and become more compact resulting in further changes in the hydrophysical properties of the peat. The changes resultant on desiccation of peat may be irreversible; for example, the proportion of water taken up by a sample of dried peat is considerably less than that held by the peat before it was dried (Hooghoudt 1950).

5.6.3.2 The response of the water table to rain registered by the sampling tubes

The generally high fluctuation of the water table in the baulk is likely to relate to the fact that the oscillations occurred in peat which may be extremely impermeable.

The observed variety in the pattern of fluctuation probably results from various causes. The response to rain (monitored in B2 by the SB recorder) at the sample sites, for example is likely to have varied, the exact response of each sampling tube probably being affected by the nature of the peat (e.g. hydraulic conductivity) in its vicinity. The lower fluctuation in the vicinity of the ditches may be because the water table near the ditches reacts sluggishly to shifts in the water balance compared with that further away (Dr H A P Ingram, personal communication). Further differences in fluctuation may have been caused by the position of the sampling tube in the baulk; for example, those sampling tubes situated near ditches on the baulk may have received some water flowing over the relatively impermeable peat surface.

5.6.4 The height of the water table in the baulk and adjacent cutting

5.6.4.1 The water table records

The water level was generally higher in the peat baulk than in the peat cutting (Figs. 5.8, 5.15 and 5.16); the lowest water level recorded in SB (420 mm) was higher than the highest level recorded in 4/5W5 (400 mm).

The water level in the baulk and cutting gradually fell during the early summer of 1982. Between January and May the maximum downward water table displacement was greater in the baulk than in the cutting.

5.6.4.2 Factors affecting the height of the water table in the baulk and adjacent cutting

The water table in the baulk is likely to have been maintained at a generally higher level than in the cutting by capillarity and the retention of precipitation through impeded drainage (Ingram 1982), as in intact bogs.

1. The decline in water table between January and May 1982

The ditches in the baulk are unlikely to have received water directly from the baulk except perhaps in January 1982 and December 1981 when they contained standing water, some of which may have eventually flowed into the surrounding cuttings.

It is likely that some water losses in the baulk occurred through evapotranspiration. Such losses from the baulk were probably less than from the adjacent cutting. In spite of the presence of birch trees which must account for some losses, the relatively impermeable nature of the peat and the likely existence of an impermeable skin are likely to reduce water loss by this means.

Some water may have been lost by flow from the peat baulk to the peat cutting because of the steep hydraulic gradient (cf. B1 and C11, Fig. 5.15). In this context it is relevant to consider the side of the baulk as one side of a ditch. The effectiveness of ditches in the drainage of peat varies according to the hydraulic conductivity of the peat through which the water flows. The position of the water table in the environs of a ditch is determined by the hydraulic conductivity of the peat and the hydraulic gradient between the bog and the ditch (itself related to the dimensions of a ditch). Boelter (1972) for example, demonstrated that a ditch causing the water table to lie in highly humified peat had little influence on the water table beyond 5 m from the ditch; however a (shallower) ditch which caused the water table to lie in less decomposed peat led to a detectable draw-down effect 50 m from the ditch. Although the steep hydraulic gradient between C11 and B1 (Fig. 5.15) suggests some recharge from the baulk to the cutting, the steep gradient also implies a low hydraulic conductivity (Dr H A P Ingram, personal communication), so that the actual rate of this recharge may be rather small. The capacity of the baulk to retain water suggests that, in this sense, the peat of the baulk displays similar characteristics to the catotelm of undisturbed bogs (Ingram 1978); in intact bogs horizontal seepage may cease completely when the water table falls to the top of the catotelm (Ivanov 1981).

2. Water storage capacity of Thorne Moors

Chapman (1965) observed that the water storage capacity at Coom Rigg Moss, Northumberland, was equivalent to the amount of water that could be accommodated by the peat between the lowest summer water table and the level at which run-off occurred. At Thorne Moors, water is accommodated in both the baulks and the cuttings; the storage capacity is related to the difference between the lowest and highest recorded levels, the latter probably being determined by the height and permeability of the dams in ditches and drains. These observations are in accord with those of Burke (1972, 1975) who found that drainage of blanket peat at Glenamoy, Ireland was accompanied by an increase in storage capacity. In this case the increased storage capacity was accompanied by a greater, more uniform water output which at Thorne is prevented by the dams in ditches and drains.

Baden & Egglesmann (1968) investigated the hydrological budget of a raised bog area of N.W. Germany and established that the storage capacity of a drained 'raised bog grassland' was much greater than that of an adjacent, heather-covered raised bog. By contrast, Conway and Millar (1960), who compared run-off in small peat covered catchments in the Northern Pennines, concluded that a small catchment, severely burnt and traversed by drains (both artifical and formed by peat erosion), had no storage capacity; however an intact *Sphagnum*-covered catchment had a water storage capacity of several centimetres in its surface layers. It may be that any storage capacity created by the drainage of the former catchment was subsequently removed by the erosion and burning to which the area was subject. Tallis (1973a) points out that the new storage capacity produced by a drop in the water table in eroded areas of the S. Pennines, is likely ultimately to decrease because of burning. At Thorne, the fire which occurred on 2 June 1982 undoubtedly removed some of the storage capacity of the area.
In addition to losses through burning, the continued progression of subsidence and compaction will probably further reduce the capacity of the drier peat areas, particularly the baulks, to store water.

5.6.5 Conclusions

1. The behaviour of the water table in the hole over which recorder SB was mounted suggests that the peat has a low permeability and a correspondingly low hydraulic conductivity. This may be a result of the drainage and subsequent drying of the baulks, causing an increase in humification, compaction and subsidence.

2. A particularly impermeable surface skin may have developed on the outer surface of the peat baulk.

3. Long term drying of the peat baulk may have caused, and may continue to cause, irreversible changes to the hydrophysical properties of the peat.

4. The variation in the magnitude and pattern of water table fluctuation across the peat baulk may relate to the position of the sample sites on the peat baulk and local differences in the nature of the peat.

5. The water level was higher in the peat baulk than in the adjoining peat cutting.

6. The rate of recharge from the baulk to the cutting was probably rather low.

7. The capacity of the baulk to retain water (through its low hydraulic conductivity) indicates that the peat of the baulk displays some characteristics of the catotelm of undisturbed bogs.

8. As in other drained bogs, an increased storage capacity at Thorne has been produced by the past drainage of the area; the subsequent hydrological isolation of the pNNR by means

of dams in ditches and drains has further increased this capacity.

9. The storage capacity is likely ultimately to decrease through losses owing to burning and through the continued progression of subsidence, decomposition and compaction of those areas above the water table.

5.7 DURATION LINES

5.7.1 The use of duration lines to describe the water regimes of the peat cuttings

The continuous water table data obtained during years 1 and 2 are represented as duration lines in Figs. 5.17 and 5.18. Duration lines show the number of days, in one year, a certain water table is exceeded, over the recorded range. Many continental workers (e.g. Niemann 1963, 1973; Grootjans & Tenklooster 1980) have used duration lines to describe the water regimes of plant communities; they have also been used to characterize further sociologically- and ecologically-definable vegetation units (Klötzli 1969). The water table duration lines of the five cuttings investigated emphasize and summarize previously noted differences in water regimes. Overall differences in level, such as the altogether higher water tables of 2/3W3 and SB, and the generally lower water tables of JA and EP, are displayed by the height of the curve. The range is related to the number of points on each curve. The relatively low range recorded in 2/3W3 (145 mm), for example, is represented by far fewer points than that

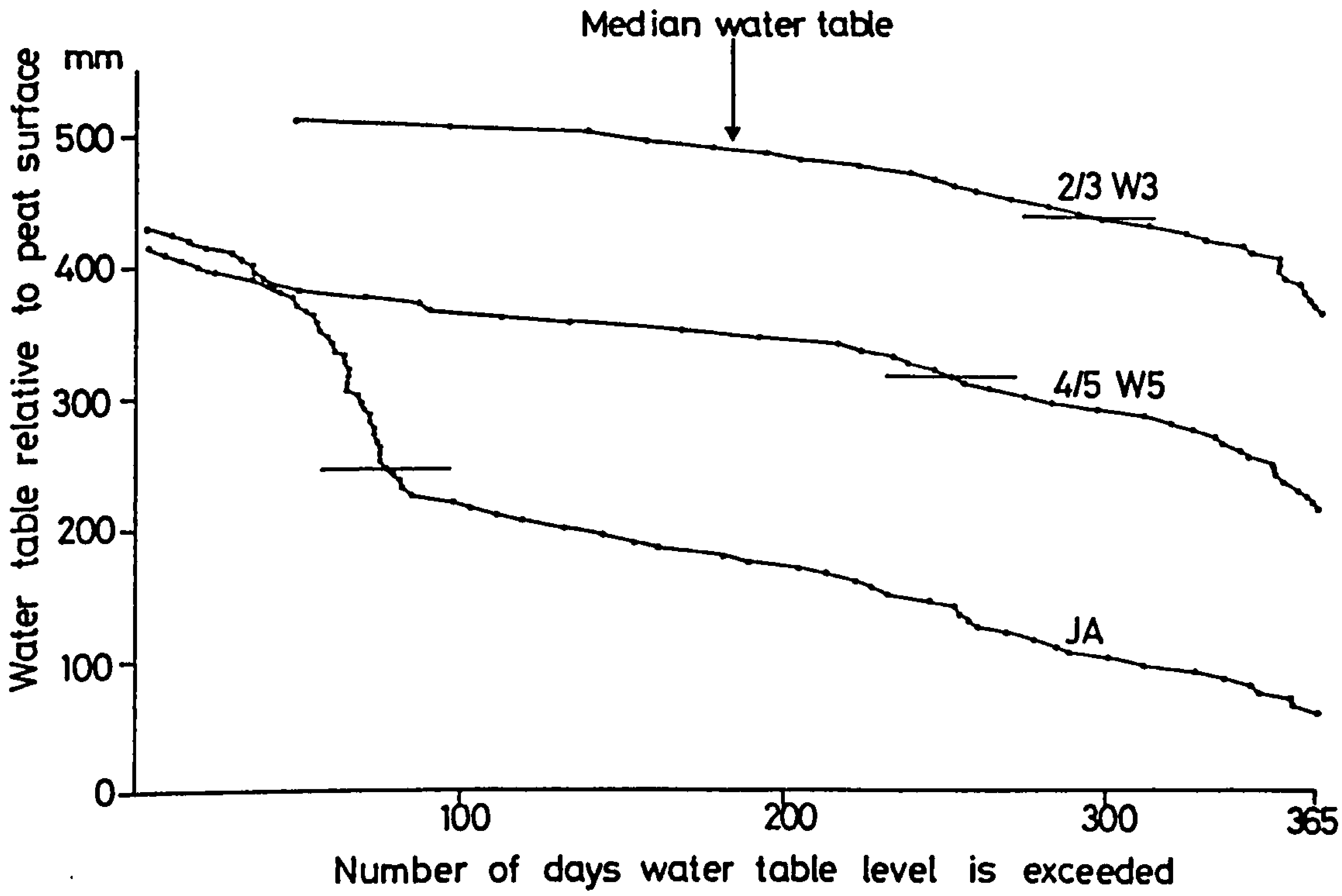


Fig. 5.17 Representation of water table levels recorded during year 1 between 1 June 1980 and 31 May 1981 as 'duration lines'. Short horizontal lines mark the mid-point of the range.

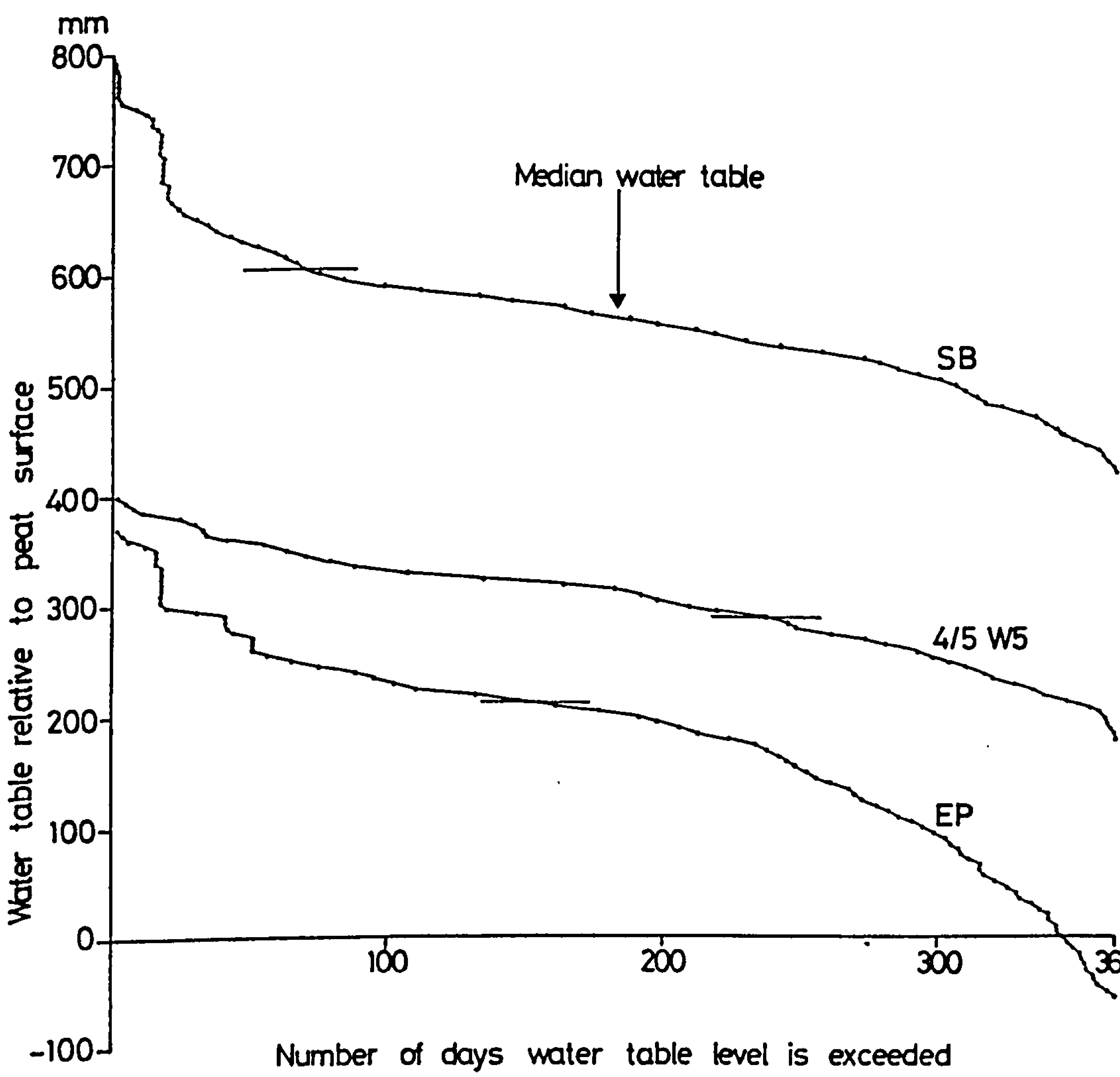


Fig. 5.18 Representation of water table levels recorded during year 2 between 6 August 1981 and 5 August 1982 as 'duration lines'. Short horizontal lines mark the mid-point of the range.

of JA (where the range was 370 mm) because the water table tended to remain at the recorded levels for longer. The clusters of points at the ends of the curves denote the extremely high and low levels recorded. The higher levels observed in JA, many of which occurred on one day only, correspond to the substantial fluctuation of early 1981 (5.5.2.1). The upper, completely vertical sections of the EP line represent the sudden shifting upwards of the float owing to the formation of ice in mid January 1982 (5.3). The modal water table occurs on one of the two points furthest apart on the curve, or between these two points. The modal water table of 350 mm in 4/5W5 (year 1), for example, was exceeded on 168 days; 355 mm was exceeded on 133 days. The difference between these two points represents the number of days (35) on which the water table remained at the modal level.

5.7.2 Shape of the duration lines

Water table changes in the peat cuttings are characterized by the shape of the duration lines. A convex duration line is produced when the water table remains mostly in the upper half of its fluctuation range (i.e. median > mean). A water table remaining mostly in the lower half of its fluctuation range gives rise to a concave line (i.e. median < mean).

At Thorne Moors, the duration lines for sites 2/3W3 and 4/5W5 (during years 1 and 2) are convex whereas for sites JA, SB and EP they are concave. The water table remained mostly in the upper half of its fluctuation range, therefore, only in the wet cuttings of the Dutch Canal System, presumably because of the 'sealing off' of the area by dams in ditches and drains. The overall similarity in shape of the line for site 2/3W3 and the lines for site 4/5W5 for years 1 and 2 probably also reflects their similar location. The shape of the curve for the SB site below the mid point of its range is very similar to the corresponding section of the curve for site 4/5W5. This supports the previous suggestion that, after stabilization of the water table subsequent to rain, the behaviour of the water table in SB is very similar to that in 4/5W5. The section of the curve for SB above the mid point of the range, which gives rise to its overall concave shape, results from the extremely high short-lived responses to rain. The concave shape of the duration line for site JA arises mostly because of the short period of high water table in early 1981. In EP the relatively rapid reduction of the water table during the summer months is the main reason for a principally concave duration line.

5.7.3 Conclusions

1. The water regimes of the cuttings in the pNNR were characterized by convex duration lines (the water table remained mostly in the upper half of its fluctuation range); the water regimes of sites JA and EP gave rise to concave duration lines (the water table remained mostly in the lower half of its fluctuation range). This suggests that the dams in drains and ditches which aim to isolate the pNNR hydrologically are effective.

2. The high, relatively short-lived response to rain in SB accounts for the concave duration line of the water regime.

5.8 THE RELATIONSHIP BETWEEN WATER TABLE AND THE VEGETATION

Full descriptions of the vegetation of the study sites are given in Chapter 3.

5.8.1 The peat cuttings

5.8.1.1 The peat cuttings of the pNNR

Characteristics of the water table (Fig. 5.13; Table 5.1) are related to the vegetation noda of some of the sample sites in Table 5.2. Noda generated by classification AC are used to describe the vegetation of the sample sites because the height of the water table in relation to the peat surface within each cutting varies too greatly to facilitate the use of classification MS. The number of noda represented in Table 5.2 is limited because sampling tubes were located within the central section of each peat cutting. The water table in the outer sections of cutting 4/5W5 was measured in transect CB (Figs. 5.15 and 5.16). Characteristics of the water table measured in the relevant sampling tubes are shown with the vegetation noda of three sample sites in Table 5.3. The peat cuttings are considered in order of increasingly high water tables in this section, as in Table 5.2. The distribution of the vegetation noda within the pNNR is described in Chapter 3.

Table 5.2 Vegetation and water table (mm) of peat cuttings in the pNNR, JA and EP. Vegetation noda are those generated by classification AC (Chapter 3).

peat cutting	lowest water table	highest water table	water table range	nodum number	nodum name
1/2W5	-125	40	165	2	*Calluna-Sphagnum recurvum*
2/3W8	-105	60	165	2	"
2/3W5	- 90	65	155	2	"
2/3E5	- 60	80	140	2	"
2/3W1	- 55	110	165	2	"
2/3W10	- 45	105	150	2	"
2/3W12	- 40	100	140	2	"
3/4W5	- 25	90	115	2	"
5/6E5	20	150	130	2	"
4/5W5	- 75	85	160	10	*Vaccinium-Andromeda*
4/5E5	100	265	165	10	"
1/2E5	- 15	145	160	6	*Calluna-Erica*
3/4E5	5	135	130	8	*Erica-Eriophorum vaginatum-S. fimbriatum*
5/6W5	40	170	130	4	*E. angustifolium-Sphagnum*
2/3W7	-55	100	155	3	*E. vaginatum-S. recurvum-Vaccinium*
2/3W3	140	310	170	3	"
					vegetation
JA	60	430	370	-	*Juncus effusus; S. recurvum*
EP	- 55	370	425	-	*Calluna; Eriophorum angustifolium; E. vaginatum; Betula pubescens*

Table 5.3 Vegetation and water table (mm) of the outer sections of cutting 4/5W5 and 4/5W6 measured in transect CB (see Figs. 5.15 and 5.16).

sampling tube	lowest water table	highest water table	water table range	nodum number	nodum name
C1	430	565	135	5	*Andromeda-S. recurvum*
C2	- 40	100	140	5	"
C3	125	250	125	5	"
C10	305	445	140	5	"
C11	335	465	130	5	"
C12	90	220	130	-	-

Calluna-Sphagnum recurvum (nodum 2): Cuttings with the lowest recorded water tables in the pNNR are dominated by *Calluna*. The presence of *Campylopus paradoxus* and *Pohlia nutans* is also consistent with the relatively low water tables which appear to characterize this nodum (Watson 1981). *Rhododendron ponticum* and *Pteridium aquilinum*, generally associated with drier conditions, occur sporadically. *Sphagnum cuspidatum* is absent. In all cuttings, however, the water table is for some part of the year above the peat surface, allowing the growth of *S. recurvum*. Vegetation of nodum 2 occupies the central sections of several peat cuttings in the pNNR; that it occurs in the outer sections of some cuttings in the south and west of the area supports the suggestion that there is a slight rise in height in this direction.

Vaccinium-Andromeda (nodum 10): The height of the water table was very different in the two cuttings characterized by the *Vaccinium-Andromeda* nodum (Table 5.2). This vegetation type, also dominated by *Eriophorum angustifolium* and *Eriophorum vaginatum*, can clearly withstand a range of water table conditions from 75 mm below the peat surface to 265 mm above.

Calluna-Erica (nodum 6): This vegetation type is dominated by *Calluna* and *Erica tetralix*. The dominance of *Calluna* may be accounted for by the fact that the water table occasionally drops below the peat surface. Vegetation of this nodum occurs in 2/3W8 and in the southern portion of the 5/6W transect, perhaps indicating, as with the *Calluna-S. recurvum* nodum (2), the drier conditions to the south and west of the pNNR.

Erica-E. vaginatum-S. fimbriatum (nodum 8): The presence of this vegetation type in the wet conditions of 3/4E5 demonstrates the tolerance of *E. vaginatum* to a water table well above the peat surface at Thorne. This nodum, also characterized by dominant *Erica tetralix* and *S. fimbriatum* is a frequent constituent of the wetter, outer sections of the peat cuttings.

E. angustifolium-Sphagnum (nodum 4): The water table remains well above the surface in 5/6W5 which contains vegetation of this type. This may account for the presence of *S. recurvum*, *S. fimbriatum* and *S. cuspidatum* as well as *Drepanocladus revolvens*. Nodum 4 occurs in the northern portion of the pNNR.

E. vaginatum-S. recurvum-Vaccinium (nodum 3): Vegetation of this nodum appears to be associated with a high water table. As with the *Erica-E. vaginatum-S. fimbriatum* nodum (8) this vegetation type is dominated by *E. vaginatum;* it also frequently occurs in the outer, wetter, sections of the cuttings. *Vaccinium oxycoccus* is normally associated with drier conditions than those found in 2/3W7 and 2/3W3; it may tolerate this high water table because it tends to root in adjacent drier areas.

Andromeda-S. recurvum (nodum 5): Fig. 5.15 shows that although the water table is extremely high in the outer sections of 4/5W5 there is some microtopographical variation. *Andromeda* may survive here and in the outer sections of other peat cuttings because it roots in 'islands' of peat 'rubble' or dead vegetation such as that present at C2 (Fig. 5.15).

The water table was not monitored in sites characterized by vegetation of noda 7 (*Sphagnum fimbriatum-S. cuspidatum*) and 9 (*S. fimbriatum-S. recurvum*). Sites containing these types of vegetation occur mainly in the outer, wetter, sections of the peat cuttings.

5.8.1.2 *Juncus effusus* area (JA)

Optimum conditions for the germination and establishment of *Juncus effusus* appear to include a water table which fluctuates about the level of the soil surface (Lazenby 1955). It is considered likely that this plant became established when the water level was relatively low. Indeed, *Juncus effusus* was noted to have achieved its present dominance in the area during the dry summer of 1976 (personal communication, Mr Eversham, employee of Fisons Ltd.). The mature plant appears to be able to withstand the variety of water table conditions observed in the area (Fig. 5.7a; Table 5.2).

5.8.1.3 Experimental plot (EP)

EP, a peat cutting abandoned relatively recently, is primarily colonized by *Eriophorum vaginatum* and *E. angustifolium* with *Calluna vulgaris*. The presence of *Calluna*, particularly, is compatible with the relatively low water table in this cutting (Table 5.2); the *Eriophorum* spp. can withstand a range of water table conditions.

5.8.2 The peat baulks

The water table is always below the surface in the peat baulks (Figs. 5.8c, 5.15 and 5.16). They are primarily characterized by the *Pteridium-Campylopus* nodum (1) although some parts of the baulks are colonized by vegetation of nodum 2 (*Calluna-S. recurvum*).

The species which characterize the *Pteridium-Campylopus* nodum (1), such as *Pohlia nutans*, *Polytrichum juniperinum*, *P. piliferum* and *Campylopus*, are normally associated with dry heathlands (Watson 1981). The restriction of this vegetation type to the peat baulks suggests that its distribution may be accounted for by the fact that the water table is well below the surface. The *Calluna-S. recurvum* nodum (2), characteristic of the drier portions of the cuttings, presumably occurs in those parts of the baulks where the water table is nearer the surface.

5.8.3 Canal 4

Table 5.4 shows features of the water table measured in the sampling tubes located in canal 4 (Fig. 5.14) with the canal vegetation nodum of each sample site.

Table 5.4 Vegetation and water table (mm) of canal 4. Full descriptions of the canal vegetation noda are given in 3.5.

sampling tube	lowest water table	highest water table	water table range	canal nodum number
C41	- 35	150	185	C1
C411	- 5	175	180	C4
C49	110	250	140	C4
C47	85	250	165	C2
C43	85	260	175	C2
C45	265	470	205	C2

The presence of some of the plant species which characterize nodum C1 and occur at C41 is consistent with the *relatively* dry conditions observed there. This nodum, for example, contains much *Rhododendron ponticum*, *Polytrichum commune* and *S. fimbriatum*. *Scrophularia nodosa*, *Carex acutiformis* and *C. nigra*, plants of damp woods or fens, occur. It also contains, however, some *Potamogeton polygonifolius*, *Equisetum fluviatile* and *Phragmites australis*, plants usually associated with swamps and shallow water. Microtopographical variation within the canals may account for the coexistence of some of these species.

The wetter conditions of C411 and C49 may be reflected in the greater dominance of plants such as *Juncus bulbosus*, *Lycopus europaeus*, *Potamogeton polygonifolius*, *Drepanocladus revolvens* and *Sphagnum squarrosum* which characterize nodum C4. The coexistence of these species with *Calluna* and some *Rhododendron ponticum* also suggests a degree of microtopographical variation.

Like nodum C4, nodum C2 is characterized by plants associated with wet conditions which may reflect the high water tables measured in C47, 3 and 5. These include dominant *Phalaris arundinacea*, *Typha latifolia* and *Ranunculus flammula* with *Cladium mariscus*, *Glyceria maxima* and *Sparganium erectum*.

5.8.4 Conclusions

1. The distribution of the vegetation in the cuttings and on the baulks of the pNNR is consistent with the behaviour of the water table at these sites.

2a. The dominance of *Juncus effusus* in JA may be explained by the level and fluctuation of the water table in the area.

b. The plant species currently established in EP are likely to be able to tolerate the range of water table conditions observed in EP.

3. In canal 4 the distribution of the vegetation cannot entirely be explained by differences in the water table.

CHAPTER 6

THE CHEMISTRY OF THE PEAT WATERS

6.1 INTRODUCTION

Some investigations into the water chemistry of peatlands have included cut, drained or otherwise degraded areas as a small proportion of the total sample sites (e.g. Gorham 1956a; Gorham & Pearsall 1956). There is very little information, however, on the water chemistry of re-vegetated peat cuttings (Proctor 1974; Giller 1982), particularly in ombrotrophic mires.

The aim of this investigation was to assess and compare the water chemistry of peat cuttings at Thorne Moors with the water chemistry of intact ombrotrophic mires. In addition it was hoped to gain information on seasonal fluctuations in the chemical composition of the peat waters.

The water chemistry was investigated in seven study sites (Fig. 6.1). Specific reasons for choosing these were:

1. In the pNNR it was intended to assess variation in water chemistry across the length and breadth of the area in cuttings where baulks separate the cutting bays (sites 5. 4/5W5 and 6. 5/6E5) and in the area of the pNNR without peat baulks (sites 2. 2/3W1, 3. 2/3W5 and 4. 2/3W8).

2. In the *Juncus effusus* area (site 1. JA) particular interest was in the possible chemical input from the drain which forms the northern boundary of this cutting.

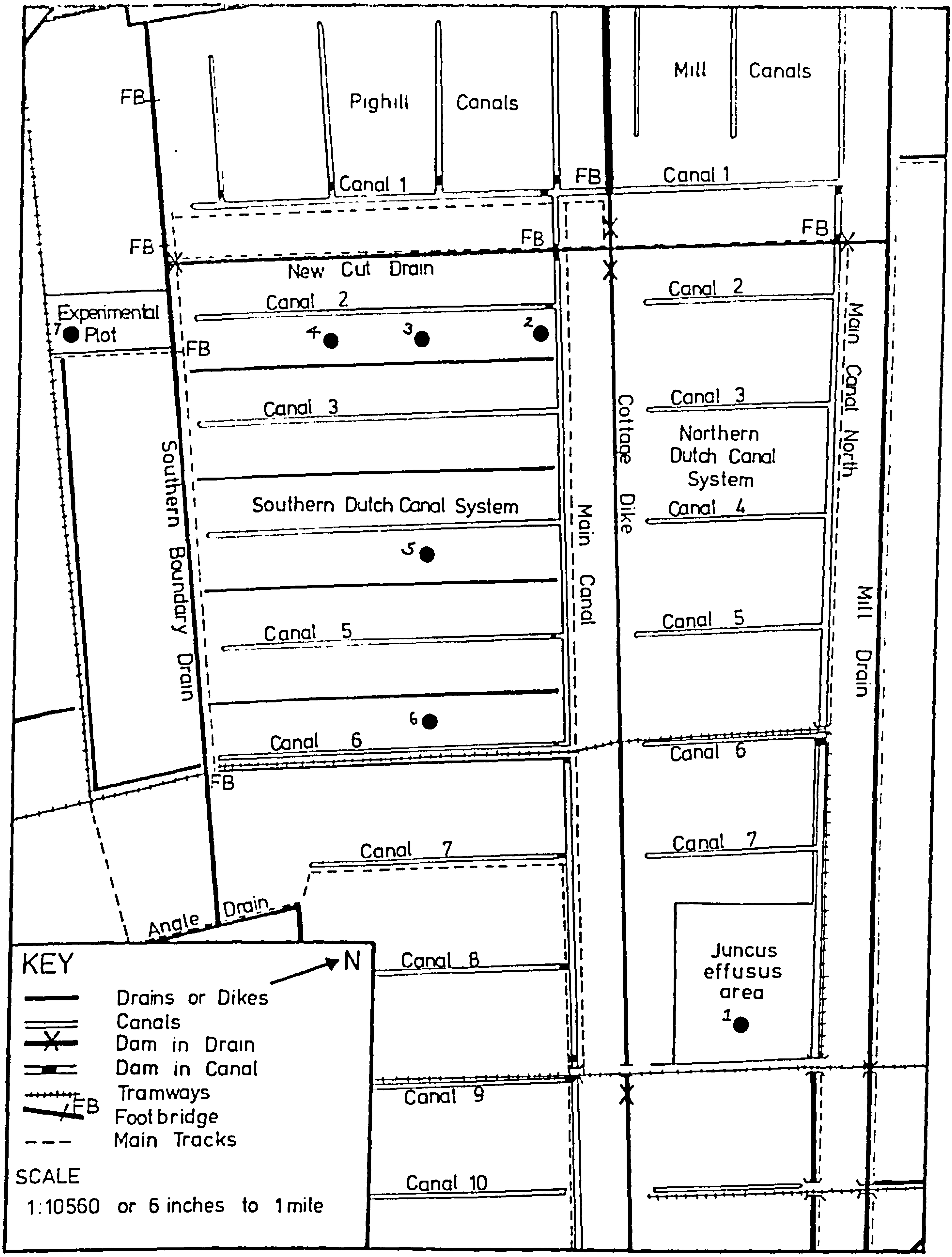


Fig. 6.1 Location of major study sites.

3. In the Experimental Plot (site 7. EP), a shallow peat cutting, the possible influence of the underlying clay was investigated.

At all study sites the relationship between the water chemistry and the vegetation was assessed.

6.2 MATERIALS AND METHODS

6.2.1 Water sampling

At each study site five sampling points were located in the centre of a floristically and topographically 'uniform' area of approximately 25 m^2 selected using random numbers. In the pNNR, study sites were located within the central section of each peat cutting. Water samples were collected from tubes (5.2.1) inserted into the peat at the sampling points.

The use of tubes inserted into the peat allows sampling of the interstitial water of the peat matrix at the rooting depth of the vegetation under investigation (Summerfield 1974; Giller 1982), when the water table is up to 50 cm below the peat surface. It should be noted that the ionic concentration of peat waters is likely to be much greater than that of open surface waters (Sjörs 1950). It is recognized that the peat waters may exhibit a chemical stratification (Sjörs 1950) which will be masked by this sampling method. In order to make comparisons between the study sites, however, it was deemed necessary to obtain an overall estimate of the ionic concentrations prevailing in the surface 50 cm. The stratification of the peat waters formed part of a separate investigation (6.7).

The sampling tubes were installed two months before samples were taken to allow equilibration. Water samples were collected from the tubes at approximately 2-monthly intervals between March 1980 and January 1981. On each sampling occasion a single water sample was taken from each tube in a 250 ml polyethylene bottle. The water samples were filtered and stored at $5^{o}C$ within 24 hours of collection. Chemical analyses were completed within ten days.

6.2.2 Methods of chemical analysis and data processing

Details are given in Appendix 4.

6.3 WATER CHEMISTRY OF THE PEAT CUTTINGS

6.3.1 Approach in presentation and discussion of results

The concentration of ions in the samples taken over a period of one year exhibited much variation. It was decided, therefore, to present in detail the results and base the main discussion on the chemical analysis of samples taken on one occasion only: 10 July 1980. Giller (1982) found that concentrations of ions were generally greater during the summer months owing to lower water levels. Differences between the study sites are likely to be more apparent at this time. Seasonal fluctuations in the concentrations of ions are considered in 6.4.

For each chemical variable the results of a one-way analysis of variance (Appendix 4) are summarized. The F-ratio and probability are given with the mean value of the variable for each site. The lines underneath the means indicate homogeneous subsets generated using Duncan's New Multiple Range Test ($P < 0.05$). The Bartlett Box-F test indicates the heterogeneity of error variances. Where this is significant the subsets can be regarded only as indicative of differences between the study sites. The values are based on means of five replicates.

6.3.2 pH

F ratio = 3.689 $P < 0.05$ Bartlett Box - F $P < 0.05$

Site	6	4	1	3	5	7	2
	5/6E5	2/3W8	JA	2/3W5	4/5W5	EP	2/3W1
Mean	3.82	3.90	3.91	3.94	4.09	4.14	4.47

The pH of 2/3W1 was relatively high, otherwise there is poor separation of the study sites in respect of pH. The generally low pH values probably reflect the acid nature of the peat. The presence of some *Sphagnum* at all the study sites except EP may be contributing to the high acidity of the sites. Clymo (1964) has shown that *Sphagnum* species are able to lower the pH of their environment by the ability of the cell walls to exchange cations for hydrogen ions (Clymo 1967).

6.3.3 Major cations

6.3.3.1 Calcium

F ratio = 3.572 P < 0.05 Bartlett Box - F N.S.

Site	6	5	1	7	2	3	4
	5/6E5	4/5W5	JA	EP	2/3W1	2/3W5	2/3W8
Mean mg/l	6.44	6.54	7.64	7.72	8.38	8.68	9.44

The study sites of the 2/3W transect (2, 3 and 4) had significantly higher concentrations of Ca^{2+} in the peat waters than the other two sites in the pNNR (5 and 6). This may reflect the chemical composition of water from a nearby canal (6.6) or drain (6.5).

Concentrations of calcium in JA and EP were intermediate between the higher levels of 2, 3 and 4 and the lower levels of 5 and 6.

6.3.3.2 Magnesium

F ratio = 17.373 $P < 0.001$ Bartlett Box - F   N.S.

Site	2	1	6	5	3	4	7
	2/3W1	JA	5/6E5	4/5W5	2/3W5	2/3W8	EP
Mean mg/1	1.18	1.96	2.68	2.74	3.66	3.98	4.64

The sites are separated into two groups. As with calcium, magnesium concentrations were greater in sites 3 and 4 than sites 5 and 6 in the pNNR; site 1, however, had relatively low levels of magnesium. The relatively high concentration of magnesium in EP, a shallow peat cut, may reflect the proximity of the underlying clay (Chapter 4; 6.7).

6.3.3.3 Sodium

F ratio = 0.476 N.S. Bartlett Box - F $P < 0.001$

Site	6	1	7	2	3	4	5
	5/6E5	JA	EP	2/3W1	2/3W5	2/3W8	4/5W5
Mean mg/l	7.20	8.20	8.80	9.00	9.70	10.20	11.25

There are no differences between the study sites in relation to concentrations of sodium. The levels may partly indicate the proximity of Thorne Moors to the North Sea (cf. Gorham 1955; Boatman 1961).

6.3.3.4 Potassium

F ratio = 17.395 $P < 0.001$ Bartlett Box - F N.S.

Site	5	1	6	2	4	3	7
	4/5W5	JA	5/6E5	2/3W1	2/3W8	2/3W5	EP
Mean mg/l	1.10	1.19	1.54	2.11	2.55	2.68	3.56

Sites in the 2/3W transect (2, 3 and 4) had greater concentrations of potassium than elsewhere in the pNNR (5 and 6). As with calcium and magnesium, the concentrations may reflect the chemical composition of water from one of the canals (6.6) or drains (6.5). The high concentration of potassium in EP may reflect the proximity of the underlying clay (6.7). Alternatively the high level here may represent contamination by bird droppings in the vicinity of the sampling tubes (cf. Allen *et al.* 1968; Gore 1968).

6.3.4 Iron

F ratio = 5.504 P < 0.001 Bartlett Box - F P < 0.001

Site	5	1	6	4	7	2	3
	4/5W5	JA	5/6E5	2/3W8	EP	2/3W1	2/3W5
Mean mg/l	2.46	4.98	6.98	8.62	9.48	12.28	18.56

There was much variation in the concentration of iron between replicate water samples at each study site, resulting in poor separation of the study sites into homogeneous subsets. Sites 2. 2/3W1 and 3. 2/3W5 had higher concentrations of iron than the other study sites. Site 5. 4/5W5 had the lowest concentration of iron. The concentrations of iron at least partly reflect the increased solubility of iron compounds at lower pH; below pH 4.8 iron is soluble in the ferric as well as the ferrous forms (Hem 1970).

6.3.5 Manganese

F ratio = 10.293 $P < 0.001$ Bartlett Box - F $P < 0.05$

Site	5	7	6	1	4	3	2
	4/5W5	EP	5/6E5	JA	2/3W8	2/3W5	2/3W1
Mean mg/1	0.11	0.14	0.15	0.20	0.23	0.26	0.31

As with iron, sites 2. 2/3W1 and 3. 2/3W5 had higher concentrations of manganese than the other study sites. Site 5. 4/5W5 had the lowest concentration of manganese.

6.3.6 Phosphorus

F ratio = 1.685 N.S. Bartlett Box - F $P < 0.05$

Site	2	4	5	3	6	1	7
	2/3W1	2/3W8	4/5W5	2/3W5	5/6E5	JA	EP
Mean mg/1	0.000	0.000	0.000	0.001	0.002	0.003	0.007

No dissolved phosphorus was detected in sites 2. 2/3W1, 4. 2/3W8 and 5. 4/5W5. Concentrations of dissolved phosphorus were very low in the other study sites, although levels in EP were somewhat higher than in JA and 6. 5/6E5. As with potassium, the relatively high concentration of dissolved phosphorus in EP may reflect contamination by bird droppings.

6.3.7 Nitrogen

Total inorganic N

F ratio = 8.006 P < 0.001 Bartlett Box - F P < 0.001

Site	5	2	1	4	3	6	7
	4/5W5	2/3W1	JA	2/3W8	2/3W5	5/6E5	EP
Mean mg/l	0.21	0.80	0.81	0.94	1.15	1.21	25.86

NH_4-N

F ratio = 17.525 $P < 0.001$ Bartlett Box - F $P < 0.001$

Site	5	2	3	1	4	6	7
	4/5W5	2/3W1	2/3W5	JA	2/3W8	5/6E5	EP
Mean mg/1	0.16	0.32	0.35	0.60	0.71	0.84	4.80

(NO_2+NO_3)-N

F ratio = 5.36 $P < 0.001$ Bartlett Box - F $P < 0.001$

Site	5	1	4	2	6	3	7
	4/5W5	JA	2/3W8	2/3W1	5/6E5	2/3W5	EP
Mean mg/1	0.12	0.22	0.30	0.48	0.80	0.80	21.06

With the exception of EP, there were no significant differences in the concentration of dissolved nitrogen at the study sites and levels were low. As with potassium and phosphorus the high concentration at EP may result from contamination. In submerged soils with low pH values NH_4-N tends to accumulate, because the mineralization of organic nitrogen stops at the ammonia stage owing to lack of oxygen to carry the process via nitrite to nitrate (Ponnamperuma 1972).

Table 6.1 $(NO_2 + NO_3)$-N as a proportion of total nitrogen at the study sites in water samples collected 10 July 1980

Site	1	2	3	4	5	6	7
	JA	2/3W1	2/3W5	2/3W8	4/5W5	5/6E5	EP
$(NO_2 + NO_3)$-N %	27	60	70	32	57	66	81

Table 6.1, however, shows that in all sites except 1. JA and 4. 2/3W8 $(NO_2 + NO_3)$-N forms a greater proportion of the total. The largely microbial interconversions between ammonium, nitrite and nitrate in soils are regulated by the redox potential, pH (Van Cleemput, Patrick & McIlhenny 1975) and temperature (Kaila, Soini & Kivinen 1954). The redox potential, closely related to inundation (Pearsall 1938), is likely to vary at the study sites (Chapter 5). This and other differences in the physical and chemical environment may account for the observed

variation in the proportion of $(NO_2 + NO_3)$-N at the study sites. In addition, the relatively high concentrations of $(NO_2 + NO_3)$-N at the study sites may reflect oxidation of the water samples before chemical analysis.

6.3.8 Major anions

6.3.8.1 Sulphate

F ratio = 1.432 N.S. Bartlett Box - F $P < 0.001$

Site	3	2	6	5	4	1	7
	2/3W5	2/3W1	5/6E5	4/5W5	2/3W8	JA	EP
Mean mg/l	0.48	2.88	11.85	18.61	18.81	24.34	29.85

There is no separation of the study sites into homogeneous subsets partly because of high intra-site variation in sulphate concentration.

6.3.8.2 Chloride

F ratio = 5.56 $P < 0.05$ Bartlett Box - F $P < 0.05$

Site	5	6	1	2	4	3
	4/5W5	5/6E5	JA	2/3W1	2/3W8	2/3W5
Mean	15.31	15.79	17.40	25.37	26.25	26.69
mg/l						

Sites in the 2/3W transect (2, 3 and 4) had greater concentrations of chloride than the other study sites. The relative levels of chloride reflect the relative levels of sodium quite closely at the study sites. The concentrations may indicate the proximity of the site to the sea, as with sodium. No data were available for site 7. EP because the water samples were inadvertently lost.

6.3.9 Electrical conductivity (K_{corr})

F ratio = 16.035 P < 0.001 Bartlett Box - F P < 0.001

Site	6	5	1	2	3	4	7
	5/6E5	4/5W5	JA	2/3W1	2/3W5	2/3W8	EP
Mean μS	97	101	121	128	138	152	349

The conductivity reflects the overall ionic concentration of the peat waters. The conductivity was greatest in EP. In the 2/3W transect (sites 2, 3 and 4) the values were higher than those of the other sites in the pNNR (5 and 6), but these differences were not significant.

6.3.10 Differences in the water chemistry of the study sites

6.3.10.1 Cluster analysis

Cluster analysis, using Ward's method (Appendix 4), was performed on the mean values of the chemical measurements from the peat waters of the study sites, to examine the overall relationships between the water chemistry at the study sites. A dendrogram displaying the classification of the peat waters from the study sites is shown in Fig. 6.2. The degree of similarity of the study sites is indicated by the value of the error sum of squares at which they were fused together.

6.3.10.2 Overall differences between the sites

The sites are segregated into three main clusters (Table 6.2). The most isolated cluster contains only one site, 7. EP. This site had relatively high concentrations of nitrogen, phosphorus and potassium which may reflect the chemical composition of a contaminant such as bird droppings. EP also contained high concentrations of iron and magnesium. A second cluster consists of the sites of the 2/3W transect (2, 3 and 4); these are separated from the other two sites of the pNNR (5. 4/5W5 and 6. 5/6E5) and from site 1. JA which comprise the third cluster. The 2/3W transect sites (2, 3 and 4) contained higher concentrations of calcium, potassium, iron, manganese and chloride than sites 1. JA, 6. 5/6E5 and 5. 4/5W5. Sites 3. 2/3W5 and 4. 2/3W8 also

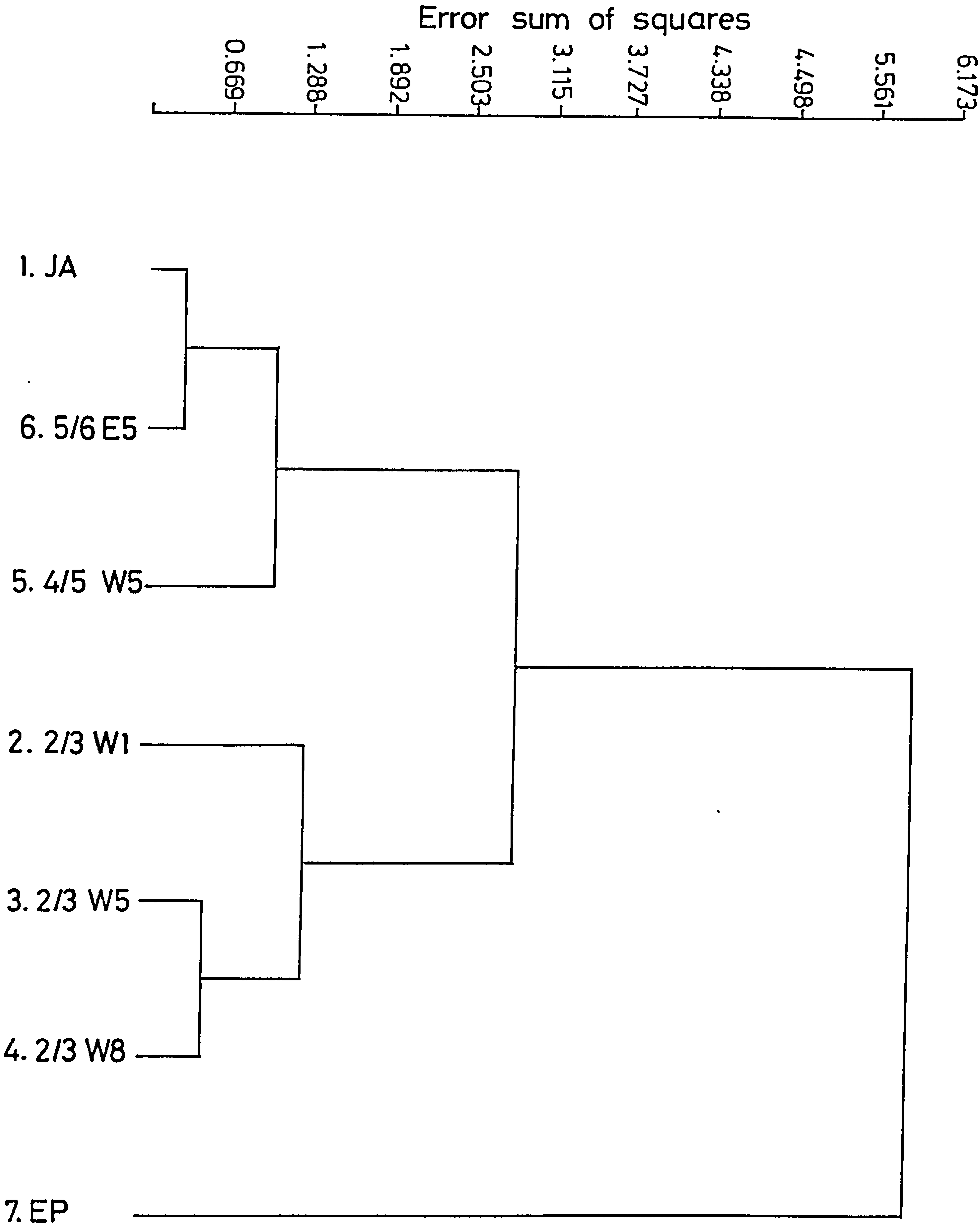


Fig. 6.2 Classification of peat waters of the study sites sampled on 10 July 1980 using Ward's method, based on measured chemical attributes.

Table 6.2 Mean values of chemical variables (mg/l) in clusters shown in Fig. 6.2.

cluster no.	pH	Ca	Mg	Na	K	Fe	Mn	P	$(NH_4+NO_2+NO_3)$-N	NH_4-N	(NO_2+NO_3)-N	SO_4	Cl	K_{corr}	no of sites	study sites
1	3.94	6.87	2.46	8.88	1.28	4.81	0.15	0.002	0.74	0.53	0.38	18.27	16.20	107	3	1, 6, 5
2	4.10	8.83	2.94	9.63	2.45	13.15	0.27	0.000	0.96	0.46	0.53	7.39	26.10	139	3	2, 3, 4
3	4.14	7.72	4.64	8.80	3.56	9.48	0.14	0.007	25.86	4.80	21.06	29.85	-	349	1	7

contained higher concentrations of magnesium than 1. JA and the other sites in the pNNR. The linearisation of the study sites in the dendrogram (Fig. 6.2) is consistent with the increasing conductivity values in clusters 1-3 (Table 6.2).

6.3.11 Comparison with the chemical status of intact ombrotrophic mires

Published data for chemical analyses of major cations in water from a variety of mires are given in Table 6.3. The pH values of the Thorne Moors peat cuttings were similar to, or a little greater than those of ombrotrophic mires in all sites, except 2. 2/3W1 where the pH was comparable to values recorded from poor fens. Concentrations of calcium, magnesium, sodium and potassium were higher than those which characterize ombrotrophic mires. The levels of calcium in water samples from Thorne Moors are more similar to those which characterize poor fens. Sodium and magnesium concentrations were similar to those recorded in the N. Cheshire 'schwingmoors' where cation concentrations may reflect the influence of ground water and run-off on to the mire surface from the sides of the surrounding basins and drainage ditches (Tallis 1973b). Potassium concentrations at Thorne Moors were intermediate in value between those recorded in poor fens and those recorded in the N. Cheshire 'schwingmoors'. The total major cation concentration at Thorne Moors is a little greater than that recorded from poor fens.

Table 6.3 Major cation (excluding H^+) concentrations (mg/1) of selected mire communities, partly after Tallis (1973b).

Ombrotrophic mires	pH	Na	K	Ca	Mg	Total
Moorhouse, N. England. May 1954 (Gorham 1956b)	3.7	4.6	0.1	1.3	1.1	7.1
Tarn Moss, N. England. July 1973 (Proctor 1974)	3.9	4.1	0.2	2.2	0.6	7.1
Ireland. (Bellamy & Bellamy 1966)	3.9	5.6	0.2	0.7	0.8	7.3
Cairn Gorm, Scotland. (Gorham 1957)	3.9	9.5	0.4	1.2	2.0	13.1
Silver Flowe, Scotland. May-Sept (Boatman *et al.* 1975)	-	2.6	0.5	0.5	1.4	5.0
Sweden. (Witting 1947)	3.9	1.6	0.1	0.8	0.3	2.8
Sweden. (Witting 1947)	3.8	2.0	0.3	0.9	0.6	3.8
Sweden. (Sjörs 1950)	3.8	2.1	0.4	0.8	0.6	3.9
Poor fens						
Malham Tarn, England. July 1973 (Proctor 1974)	3.9	5.1	0.2	4.0	0.6	9.9
Recolonized peat cutting, Middle Fen, Malham, England. July 1973 (Proctor 1974)	5.6	3.5	0.5	11.0	0.4	15.4
Sweden. Intermediate poor fen (Sjörs 1950)	4.4	1.8	0.4	1.2	0.4	3.8
Sweden. Intermediate fen (Sjörs 1950)	4.8	1.8	0.4	12.0	0.4	14.6
'Schwingmoors', N. Cheshire, England. (Tallis 1973b)						
Abbots Moss. March 1969	-	12.0	7.9	9.0	3.2	32.1
Flaxmere. June 1972	4.5	10.5	8.4	9.4	2.9	31.2

continued/......

Table 6.3 (continued)

	pH	Na	K	Ca	Mg	Total
Thorne Moors, S. Yorkshire, England.(July 1980)						
Site 1. JA *Juncus effusus* area	3.9	8.2	1.2	7.6	2.0	19.0
Site 6. 5/6E5 re-vegetated peat cutting	3.8	7.2	1.5	6.4	2.7	17.8
Site 5. 4/5W5 "	4.1	11.2	1.1	6.5	2.7	21.5
Site 2. 2/3W1 "	4.5	9.0	2.1	8.4	1.2	20.7
Site 3. 2/3W5 "	3.9	9.7	2.7	8.7	3.7	24.8
Site 4. 2/3W8 "	3.9	10.2	2.6	9.4	4.0	26.2
Site 7. EP 'modern' peat cutting	4.1	8.8	3.6	7.7	4.6	24.7
Sweden. Transitional fen (Sjörs 1950)	5.8	1.2	0.4	18.0	0.2	19.8
Sweden. Extreme rich fen (Sjörs 1950)	7.7	4.6	0.8	36.1	10.9	52.4

There is little information available on concentrations of iron and manganese in water samples from ombrotrophic mires although Summerfield (1974) recorded concentrations of iron of 0.8 mg/l on 5 May 1970 from Wem Moss, Shropshire. In water samples from a flood plain mire in Norfolk (collected in October 1979), however, Giller (1982) recorded iron concentrations of 0.04-2.16 mg/l and manganese concentrations of 0.04-1.10 mg/l. The concentrations of iron recorded from Thorne Moors (2.46-18.56 mg/l) were therefore relatively high. The concentrations of manganese recorded from Thorne Moors (0.11-0.31 mg/l) were somewhat lower than those observed in the flood plain mire.

The low concentrations of nitrogen and phosphorus recorded at all the study sites except EP are in agreement with those reported from other ombrotrophic mires (cf. Boatman, Hulme & Tomlinson 1975; Gorham 1956b).

Of the major anions, sulphate concentrations (0.48-29.85 mg/l) are similar to and a little higher than those recorded by Gorham (1956b) from Moor House, N. England, who observed levels between 3.8 and 19.9 mg/l. However most of the sulphate concentrations measured at Thorne Moors are greater than the 6.25 mg/l of sulphate considered by Sjörs (1950) to characterize ombrotrophic mires in Sweden. A concentration of sulphate of 14.4 mg/l is regarded by Bellamy (1968) to indicate ombrotrophic conditions; this value is based on measurements from water samples collected from most regions of Western Europe and occurs at the mid point of the range of concentrations recorded at Thorne Moors.

Concentrations of chloride (15.31-26.69 mg/l) are higher than the values observed by Gorham (3.5-6.5 mg/l; 1956b) and the 10.6 mg/l which Bellamy (1968) considers typical of ombrotrophic mires.

The electrical conductivity measurements of the peat waters from Thorne Moors (97-349 μS) are somewhat greater than those recorded in ombrotrophic mires where values of less than 80 μS are typical (cf. Gorham 1956a,b; Gorham & Pearsall 1956).

6.3.12 Factors influencing the water chemistry of the peat cuttings

6.3.12.1 The basis of the subsequent investigations

In considering the results of the chemical analysis of the peat waters (6.3.2-6.3.9), various sources of enrichment were suggested to explain the observed differences in the water chemistry of the study sites. These included water from the drains and the Dutch canals and the influence of the underlying clay.

In order to examine the possibility that enrichment from one or more of these sources was the cause of the relatively high concentrations of ions present in the peat cuttings, and to assess the degree of influence of these sources on the study sites, the following investigations were carried out:

1. Chemical analysis of 47 water samples collected from drains in the site (6.5).

2. Chemical analysis of 34 water samples collected from the Northern and Southern Dutch Canal Systems (6.6).

3. Water samples along a transect in the pNNR were analysed for their chemical composition; the transect crossed three peat cuttings and two canals, one of which was connected to an adjacent cutting by a ditch (6.6).

4. In order to examine the chemical stratification of the peat waters samples of water were taken from below the peat surface at four sites: Canal 3, 4/5W4, JA and EP; these were subjected to chemical analysis (6.7).

The results of these investigations are presented following a consideration of the seasonal fluctuation in the chemical composition of the peat waters (6.4) at the main study sites.

Other factors may have contributed to the relatively high concentrations of ions recorded in the study sites; these are discussed below.

6.3.12.2 Black-headed gulls (*Larus ridibundus*)

At some times of the year (6.4) phosphorus concentrations in the peat cutting study sites were somewhat higher than those recorded in water samples collected on 10 July 1980. In the *Juncus effusus* area (site 1. JA) phosphorus concentrations were particularly high; for example 0.1 mg/l of phosphorus was recorded from this cutting on 14 March 1980, when concentrations in the pNNR study sites were no greater than 0.05 mg/l.

The periodic use of this cutting as a nesting site by a large colony of Black-headed gulls probably explains the relatively high concentrations of phosphorus (cf. McColl & Burger 1976). Rogers & Bellamy (1972) also recorded relatively high phosphorus concentrations in water from JA and from the swamp of *Juncus effusus* north of Mill Drain, also periodically occupied by Black-headed gulls.

Black-headed gulls appear to be quite specific in their choice of nest plant. In the Sunbiggin Tarn fens, for example (Holdgate 1955), these birds selected particularly the summits of *Carex elata* tussocks for nesting sites. At Thorne Moors, the birds nest only on *Juncus effusus* tussocks, never, apparently, on other tussock formers such as *Eriophorum vaginatum* (Mr B. Eversham, personal communication).

6.3.12.3 The effect of drainage

The drainage of a bog causes the inorganic sulphides accumulated under anaerobic conditions to oxidise rapidly to SO_4^{2-}. The net effect is to exchange a weak acid (H_2S) for a strong acid (H_2SO_4) which is almost completely dissociated at c. pH 5 (Bloomfield & Coulter 1973). The H^+ so released contributes to the acidification of drainage waters and also displaces cationic nutrients from ion exchange sites on the peat colloids (Odelien, Selmer-Olsen & Haddeland 1975). The overall effect is a decrease in the pH and an increase in the conductivity of the drainage water (Dr K Brown, personal communication).

It may be, therefore, that previous drainage of the peat cuttings and the current exposure of the drier parts of the cuttings and baulks to air are partly the cause of the relatively low pH, high conductivity and high cation and sulphate concentrations measured in the peat cutting study sites.

6.3.12.4 Clay

It is possible that some clay intended for lining the Dutch canals (Chapter 4) may have been dumped indiscriminately in peat cuttings. This, along with clay spoil excavated and dumped along some of the main drains as a result of the widening and deepening of these drains by Fisons Ltd. (Chapter 2), may have had an effect on water chemistry at the study sites and in other peat cuttings.

6.3.13 The relationship between the water chemistry and the vegetation

Full descriptions of the vegetation of the study sites are given in Chapter 3. The vegetation noda of the study sites generated by classifications AC and MS are shown in Table 6.4. Noda generated by classification MS, which classifies the species present in the 'main' and 'side' cuttings, are mainly used to discuss the vegetation of the study sites, rather than classification AC which analyses the vegetation present in the individual sections of the 'main' cuttings, because it was considered likely that the vegetation of the whole peat cuttings would be affected by the chemical conditions measured.

6.3.13.1 Plant species in the peat cuttings

Much of the vegetation reflects the fact that the chemistry of the peat waters has more in common with a weakly minerotrophic mire than with an ombrotrophic mire. Many of the commoner species are known to be able to tolerate a range of chemical conditions; for example, *Eriophorum angustifolium* (present in all vegetation noda) and *Polytrichum commune* (present in noda 2, 5 6 and 7) can occur in both poor and rich fens as well as in bogs in Britain (e.g. cf. Proctor 1974; Wheeler 1980b). *Juncus effusus* (which occurs in noda 2, 3, 6, 7 and 8) and *Aulacomnium palustre* (which occurs in noda 2, 7 and 9)

Table 6.4 Vegetation of water chemistry study sites. Noda generated by classifications AC and MS (Chapter 3) are listed.

sample site	Classification AC nodum number	Classification AC nodum name	Classification MS nodum number	Classification MS nodum name
2. 2/3W1	2	*Calluna-Sphagnum recurvum*	2	*S. recurvum-Cephalozia*
4. 2/3W8	2	"	2	"
3. 2/3W5	2	"	7	*Sphagnum-Drosera*
6. 5/6E5	2	"	2	*S. recurvum-Cephalozia*
5. 4/5W5	10	*Vaccinium-Andromeda*	3	*Vaccinium-Andromeda*
	Vegetation			
1. JA	*Juncus effusus; Sphagnum recurvum*			
7. EP	*Calluna; Eriophorum angustifolium; E. vaginatum; Betula pubescens*			

also occur in poor fens as well as bogs (cf. Gorham 1956a). Other species are more exclusive to fens; *Carex curta*, for example, which is present in the *Vaccinium-Andromeda* nodum 3, characterizes the poor-fen *Caricion curto-nigrae* alliance (Westhoff & den Held 1969) and *Phragmites australis* which occurs in the *Sphagnum recurvum-Cephalozia* nodum 2) is a plant of both poor and rich fens (e.g. cf. Proctor 1974).

Some cuttings (not included in the chemical studies) support *Potentilla palustris* (which occurs in the *Sphagnum-Drepanocladus* nodum 9) and *Molinia caerulea* (which occurs in noda 1: *Pteridium-Campylopus* and 8: *Sphagnum-Juncus-Molinia*). These are also fen species. Although *Molinia caerulea* does grow in oceanic ombrotrophic mires in parts of W. Britain, the occurrence of both these species at Thorne is a further indication of its affinities with poor fen.

The species of *Sphagnum* present in the cuttings at Thorne Moors are compatible with the observed chemical conditions. *S. recurvum*, the most widespread species which occurs in all noda, is known to be a species of wide tolerance as regards mineral status (cf. Skene 1915; Green & Pearson 1968; Tallis 1973b; Clymo 1973). *S. fimbriatum*, which occurs in all noda except 6 (*Polytrichum commune-Juncus*), and *S. squarrosum* which does not occur at the study sites but is present in noda 4, 9 and 10, are usually associated with poor fens and fen carr habitats; these species can also withstand a range of chemical conditions (cf. Clymo 1973; Proctor 1974). *S. subnitens* is not widespread on The Moors, being present only in the *Pteridium-Rhododendron-Sphagnum recurvum* nodum (4); it is known, however, to occur in a range of chemical conditions, from rich fens to ombrotrophic mires (e.g. Wheeler 1980b; Newbould & Gorham 1956). *S. cuspidatum* is usually associated with the dilute acid waters of ombrotrophic mires (e.g. Gorham 1956b). Concentrations of ions may be less in the peripheral, wetter parts of the cuttings of the pNNR, where this moss mostly occurs, than in the study sites (located in the central sections of the cuttings). *S. papillosum*, found in poor fens but mostly characteristic of ombrotrophic mires (e.g. Gorham 1956b), is present in noda 2, 3, 7 and 10. This species may withstand the relatively high ionic concentrations at Thorne Moors by having locally created chemical conditions suitable for its growth through the ability of its cell walls to exchange cations for hydrogen ions (Clymo 1964; 1967).

6.3.13.2 The differences between the vegetation of the study sites

At study sites 2. 2/3W1 and 4. 2/3W8, which both contain vegetation of nodum 2 (*S. recurvum-Cephalozia*), similar chemical conditions prevail (Table 6.4; Fig. 6.2). The relatively high concentrations of the major cations, particularly calcium, are compatible with the dominance of *S. recurvum* (cf. Clymo 1973) and the presence of *Phragmites australis* in this nodum.

Bryophytes such as *Cephalozia bicuspidata, Pohlia nutans* and *Campylopus paradoxus* which also characterize this nodum, can clearly withstand the chemical conditions which occur at the study sites.

Table 6.4 shows that site 3. 2/3W5, where the chemistry of the peat waters was similar to that of sites 2. 2/3W1 and 4. 2/3W8, is characterized by vegetation of nodum 7 (*Sphagnum-Drosera*). In addition to *S. recurvum* and *Cephalozia bicuspidata* which characterize and dominate the vegetation at sites 2 and 4 (nodum 2), nodum 7 is also dominated by *S. fimbriatum* and *Drosera rotundifolia*. The reason for this difference in the vegetation of these study sites is not clear. It may be noted, however, that classification AC (Table 6.4) indicates that the vegetation of the central section of each peat cutting, where the sampling tubes were located, at study sites 2, 3 and 4, is all of nodum 2 type (*Calluna-S. recurvum*). It may be, therefore, that in this case at least, the chemical conditions prevailing at the study sites have a local effect on the vegetation; the water chemistry in the outer sections of the peat cuttings at the study sites may be different from that of the central sections.

The chemistry of the peat waters was similar at study sites 5. 4/5W5 and 6. 5/6E5; they contain, however, vegetation of different types. The vegetation in 5. 4/5W5 consists of the *Vaccinium-Andromeda* nodum (3), characterized by the dominance of *V. oxycoccus, A. polifolia* and three species of

Sphagnum: S. recurvum, S. fimbriatum and *S. cuspidatum* whereas site 6. 5/6E5 contains vegetation of the *S. recurvum-Cephalozia* nodum (2). Some other factor may therefore be determining the composition of the vegetation in these two cuttings.

With respect to the vegetation and water chemistry of 5. 4/5W5 (nodum 3: *Vaccinium-Andromeda*); in comparison with those of the sites of the 2/3W transect [nodum 2 (*S. recurvum-Cephalozia*) in sites 2 and 4; nodum 7 (*Sphagnum-Drosera*) in site 3], it may be that the presence of *Vaccinium oxycoccus, A. polifolia* and *S. cuspidatum* in 4/5W5 reflect the relatively low concentrations of ions at this site. Certainly, in Britain, these plants are mainly associated with ombrotrophic mires (cf. Gorham & Pearsall 1956).

In site 1. JA the chemistry of the peat waters collected on 10 July 1980 was similar to that of the sites 5. 4/5W5 and 6. 5/6E5; at other times of the year, however, phosphorus concentrations were somewhat higher in site 1. JA (6.4). The occurrence of relatively high phosphorus concentrations (6.3.12.2) for most of the year may partly explain the dominance of *Juncus effusus* in this cutting.

The plant species present in EP (*Eriophorum vaginatum, E. angustifolium, Calluna vulgaris* and *Betula pubescens*) can clearly withstand the chemical conditions which prevail in this peat cutting. However, features of the chemistry of the peat waters, for example, the high concentrations of magnesium, may be inhibiting the colonization of *Sphagnum* species and other plants.

6.3.14 Conclusions

1. At all the study sites the pH of the peat waters was comparable with, or somewhat greater than, that which characterizes ombrotrophic mires.

2. Cation concentrations at all the study sites were greater than those recorded from ombrotrophic mires.

3. Of the major anions, sulphate concentrations at some of the study sites and chloride concentrations at all the study sites were greater than those which characterize ombrotrophic mires.

4. Concentrations of nitrogen and phosphorus were in agreement with those reported from ombrotrophic mires.

5. The vegetation reflects the fact that, in general, the chemical characteristics of the peat waters suggest minerotrophic rather than ombrotrophic conditions.

6. To a certain extent, the differences between the chemical conditions which prevail at the study sites are reflected in the vegetation of the study sites.

7. The differences between the vegetation of the study sites cannot entirely be explained by differences in the chemical factors measured.

6.4 SEASONAL FLUCTUATION IN CHEMICAL COMPOSITION OF THE PEAT WATERS

6.4.1 Introduction: presentation of results

The fluctuations in the chemical composition of water samples collected over a period of one year (6.3.1) are shown in Figs. 6.3-6.10. The mean and standard error of the five replicate samples collected at each of the seven study sites are displayed on the graphs. The samples were collected on the following dates:

14 March 1980
16 May 1980
10 July 1980
23 September 1980
10 November 1980
26 January 1981

The chemical composition of peat waters collected on 26 January 1981 was in some cases rather different from that of samples collected on 10 July 1980. The results of the January chemical analysis are presented here where the separation of the study sites into homogeneous subsets (6.3.1) for any chemical variable was strongly different from that which resulted from the July analysis (6.3). A dendrogram displaying the classification of peat waters from the study sites collected on 26 January 1981 is shown in Fig. 6.11.

6.4.2 pH

There was little fluctuation in the pH of the peat water over the sampling period in all study sites except EP (Fig. 6.3). At this site the pH decreased throughout the summer to a low value in autumn. Malmer (1962) found a lowering of the pH after summer and considered it to be due to the water table rising into peat where oxidising conditions had been prevalent throughout the summer. This may explain the trend observed in EP; the water table was not in contact with surface peat in the early summer and rose towards the end of the summer (Fig. 5.13d).

6.4.3 Major cations

6.4.3.1 Calcium

Concentrations of calcium (Fig. 6.4a) were generally somewhat lower during and towards the end of the summer than during the winter at the study sites. This is the opposite trend to that observed by Giller (1982) and by McColl (1969) who found that higher concentrations of the major cations corresponded to lower, summer water levels. The lower summer concentrations may reflect a biological demand for this nutrient during the growing season (cf. Prentki, Gustafson & Adams 1978); subsequent release from senescent plant material (cf. Planter 1970) may be reflected in the higher winter concentrations. The cause of the

Fig. 6.3 Chemical analysis of peat waters.

Fig. 6.4a Chemical analysis of peat waters.

high concentration found in EP during May is not clear; the fluctuation of cations in this cutting may reflect variation in the availability of minerals from the underlying clay (6.7).

Calcium

F ratio = 6.450 P < 0.001 Bartlett Box - F P < 0.001

Site	5	7	6	3	4	1	2
	4/5W5	EP	5/6E5	2/3W5	2/3W8	JA	2/3W1
Mean mg/l	5.36	7.62	7.66	7.84	8.72	9.04	12.44

The study sites of the 2/3W transect (2, 3 and 4) had higher concentrations of calcium in the peat waters than the other two sites in the pNNR (5 and 6) in the January as well as the July samples (6.3.3.1), although the concentration was only significantly higher in site 2. 2/3W1. A much greater concentration of calcium was measured from JA in the winter, however, than in the summer. This may be explained by the flooding of this cutting by calcium-rich water from Main Canal North (6.6).

6.4.3.2 Magnesium

Magnesium concentrations were highest in May and November at almost all the study sites (Fig. 6.4b). The high levels recorded in May may be related to the low water level in the study sites at this time (Chapter 5) whereas the November concentrations, as with calcium, may reflect release from senescent plant material. In EP the fluctuation in magnesium concentration was very similar to that of calcium.

6.4.3.3 Sodium

Fig. 6.4c shows that the variation in the concentration of sodium was similar at all the study sites over the sampling period. The highest levels measured in July (6.3.3.3), cannot be explained by concentration owing to a low water table because the water level was relatively high at this time of the summer (Chapter 5). It may be that the concentrations of sodium on the different sampling occasions represent the variable input of sodium from precipitation (cf. Boatman, Hulme & Tomlinson 1975).

Fig. 6.4b Chemical analysis of peat waters.

Fig. 6.4c Chemical analysis of peat waters.

6.4.3.4 Potassium

Throughout the sampling period, fluctuations in potassium concentrations (Fig. 6.4d) were similar to those of sodium (Fig. 6.4c). Potassium is extremely soluble and mobile (Summerfield 1974) and differences in concentration may therefore reflect variation in input, such as by precipitation and leaching from plant material, and losses (plant uptake and conversion into insoluble forms).

6.4.4 Iron

Concentrations of iron were low in site 1. JA and site 5. 4/5W5 and generally higher in site 3. 2/3W5. There was much inter-site variation, the study sites exhibiting little consistent seasonal variation (Fig. 6.5). Much variation in concentrations of iron has been reported by other workers; Summerfield (1974), for example, found on one occasion a maximum range of variation of 3.6-28.5 mg/l iron over a distance of 10 cm.

Fig. 6.4d Chemical analysis of peat waters.

Fig. 6.5 Chemical analysis of peat waters.

6.4.5 Manganese

Concentrations of manganese were very low over the whole sampling period (Fig. 6.6). There was some consistent variation at the study sites in that in site 1. JA and the pNNR study sites (with the exception of 6. 5/6E5) manganese concentrations were relatively high in July and low in November; the relatively high concentrations, however, do not correspond to either particularly high or low water levels (Chapter 5).

6.4.6 Phosphorus

Fig. 6.7 shows that phosphorus concentrations at other times of the year were much greater than those in July (6.3.6) and September. The low summer concentrations probably reflect the biological demand for this nutrient (cf. Tamm 1954).

The high January value (0.14 mg/l) for site 3. 2/3W5 arises from high and variable phosphorus concentrations from all the sampling tubes in this cutting; this suggests a contamination source outside but near the tubes. The anomalously high and variable phosphorus concentration recorded for May in site 7. EP suggests that the water in the sampling tubes was contaminated (from an unknown source) around this time (6.3.6); the concentration decreased rapidly over the summer, probably owing to uptake by plants.

Fig. 6.6 Chemical analysis of peat waters.

Fig. 6.7 Chemical analysis of peat waters.

With the exception of site 7. EP and the January value for site 3. 2/3W5, the phosphorus concentration was greatest in site 1. JA for most of the year. Black-headed gulls are probably the source of phosphorus in this cutting (see 6.3.14.2). Although some plants of ombrotrophic peatlands are known to have efficient internal nutrient re-cycling (e.g. *Eriophorum vaginatum*; Goodman & Perkins 1968), the capacity of *Juncus effusus* for this is not known. Some degree of 'leakiness' might be expected to contribute to high levels of nutrients in the substratum outside the growing season.

6.4.7 Nitrogen

With the exception of site 7. EP nitrogen concentrations were mostly low over the whole sampling period (Fig. 6.8a, b, c). As with phosphorus, subsequent to anomalous contamination in May (6.4.6), the concentration of nitrogen in EP decreased throughout the year (Fig. 6.8a).

Fig. 6.8a Chemical analysis of peat waters.

Fig. 6.8b Chemical analysis of peat waters.

Fig. 6.8c Chemical analysis of peat waters.

6.4.7.1 Form of nitrogen

Table 6.5 (NO_2+NO_3)-N as a percentage of total nitrogen at the study sites.

	1	2	3	4	5	6	7
	JA	2/3W1	2/3W5	2/3W8	4/5W5	5/6E5	EP
16 May 1980	45	75	61	69	78	40	47
10 July 1980	27	60	70	32	57	66	81
23 September 1980	42	48	30	64	55	14	29
10 November 1980	44	66	25	49	76	81	18
26 January 1981	50	83	61	100	0	100	37

Table 6.5 shows that the proportion of (NO_2+NO_3)-N not only varied at the study sites but also varied at each site on different sampling occasions. This, and the fact that the fluctuation in nitrogen concentrations showed little consistent variation, may be accounted for by wide variation in microbial interconversions between ammonium, nitrite and nitrate owing to differences in water table changes and redox potential at the study sites (see 6.3.7).

6.4.8 Major anions

6.4.8.1 Sulphate

Changes in sulphate concentration show some consistent variation at the study sites of the pNNR; in site 1. JA and 7. EP the values were higher and the fluctuation greater (Fig. 6.9a) than in the pNNR sites.

Sulphate

F ratio = 7.095 $P < 0.001$ Bartlett Box - F N.S.

Site	6	3	4	5	2	1	7
	5/6E5	2/3W5	2/3W8	4/5W5	2/3W1	JA	EP
Mean mg/l	10.08	10.85	18.91	22.75	27.07	41.09	54.43

In water samples collected in January the sulphate concentration in JA and EP was significantly higher than sites 6, 3 and 4 in the pNNR. The relatively high sulphate concentrations in these cuttings correspond to a relatively low water table in JA and EP compared with that in the other study sites (Fig. 5.13). To a certain extent, therefore, these differences may reflect the production of sulphate through greater aeration of the peat by a lower water table (6.3.14.3).

Fig. 6.9a Chemical analysis of peat waters.

6.4.8.2 Chloride

As with sodium, fluctuations in chloride may partly reflect variable input from precipitation (Fig. 6.9b).

6.4.9 Electrical conductivity (K_{corr})

The conductivity (Fig. 6.10) was somewhat greater in the summer when the water table was, on the whole, relatively low than in the winter when it was higher (Fig. 5.13). For example, in January, the conductivity at all the sites was lower

Conductivity

F ratio = 23.241 $P < 0.001$ Bartlett Box - F N.S.

Site	5	2	3	4	6	1	7
	4/5W5	2/3W1	2/3W5	2/3W8	5/6E5	JA	EP
Mean µS	75	101	102	103	108	112	149

than that recorded in July (6.3.9); it was particularly low in site 5. 4/5W5. This trend is similar to that observed by McColl (1969), Summerfield (1974) and Giller (1982) and suggests that, in spite of all the factors which may have contributed to the fluctuation of the chemical variables, the degree of dilution of the peat waters determines their overall ionic concentration.

Fig. 6.9b Chemical analysis of peat waters.

Fig. 6.10 Chemical analysis of peat waters.

6.4.10 The overall differences between the study sites in January

As in July (6.3.10) the sites are segregated into three main clusters, the most isolated of which contains only site 7. EP (Fig. 6.11 and Table 6.6). Although the linearisation of the study sites in the dendrogram is identical to that in Fig. 6.2, the sites of the 2/3W transect (2, 3 and 4) are not contained in the same cluster in January. Site 2. 2/3W1 is associated with the other two sites in the pNNR (5. 4/5W5 and 6. 5/6E5) and site 1. JA at a high value of the error sum of squares; sites 3. 2/3W5 and 4. 2/3W8 comprise the third cluster.

This difference in the separation of the study sites stems from the fact that, when compared with sites 3. 2/3W5 and 4. 2/3W8 , concentrations of phosphorus, chloride, iron, manganese and (NO_2+NO_3)-N were relatively lower in site 2. 2/3W1 in January than in July. This may partly reflect dilution in site 2/3W1; the water table was below the peat surface in all three sites (2, 3 and 4) in July, whereas in January it was above the peat surface in site 2. 2/3W1, though not in the others. The samples collected from 2. 2/3W1 in January, therefore, probably contained a lower proportion of interstitial water from the peat matrix.

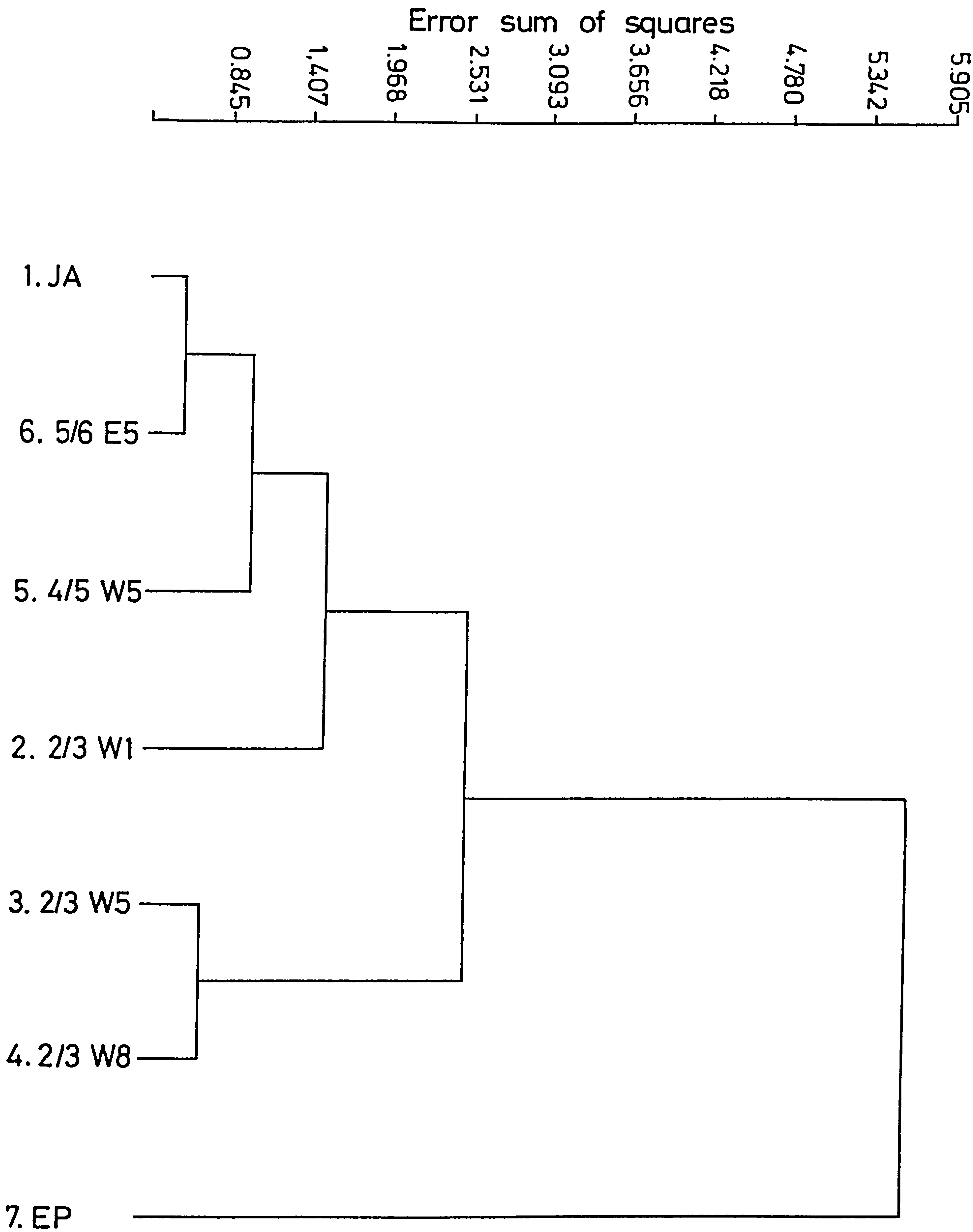


Fig. 6.11 Classification of peat waters of the study sites sampled on 26 January 1981 using Ward's method, based on measured chemical attributes.

Table 6.6 Mean values of chemical variables (mg/1) in clusters shown in Fig. 6.11.

cluster no.	pH	Ca	Mg	Na	K	Fe	Mn	P	$(NH_4+NO_2+NO_3)$-N	NH_4-N	(NO_2+NO_3)-N	SO_4	CL	K_{corr}	no. of sites	study sites
1	4.32	8.63	2.24	6.85	0.92	3.00	0.14	0.006	0.08	0.06	0.05	25.25	18.98	99	4	1, 5, 2
2	4.02	8.28	2.28	6.55	1.98	10.87	0.27	0.076	0.28	0.06	0.22	14.88	25.14	103	2	3, 4
3	3.81	7.62	3.38	8.20	2.87	1.94	0.33	0.001	2.62	1.64	0.98	54.43	22.03	149	1	7

6.4.11 Conclusions

1. Uptake and losses by the vegetation may be reflected in the variation in concentrations of calcium and phosphorus dissolved in the peat waters.

2. Variation in input of sodium and chloride by precipitation may be responsible for fluctuation of concentrations of these ions in the peat waters.

3. Fluctuations in pH and concentrations of sulphate in the peat waters may be related to the height of the water table in relation to the peat surface.

4. Variation in conductivity and magnesium concentrations probably relate to the degree of dilution of the peat waters.

6.5 WATER CHEMISTRY OF THE DRAINS

6.5.1 Methods

To examine the chemistry of the drain waters in relation to the peat cutting study sites, 47 water samples were collected on 3 June 1980 (Fig. 6.12) and analysed for chemical composition (Appendix 4). Some water samples were also collected from the canals on this occasion to allow a comparison with the chemical concentrations in the drains.

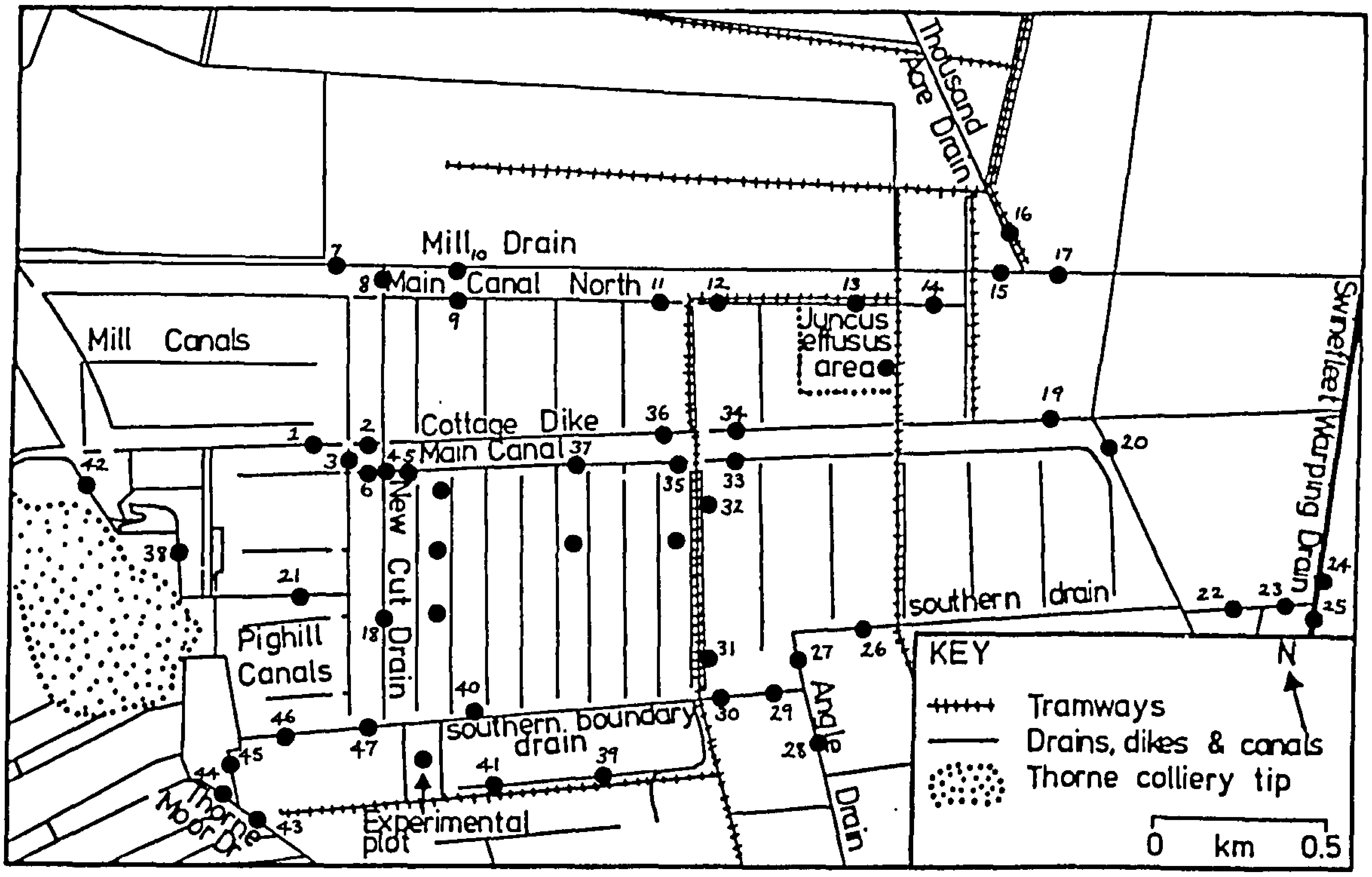


Fig. 6.12 Location of sample sites in drains.

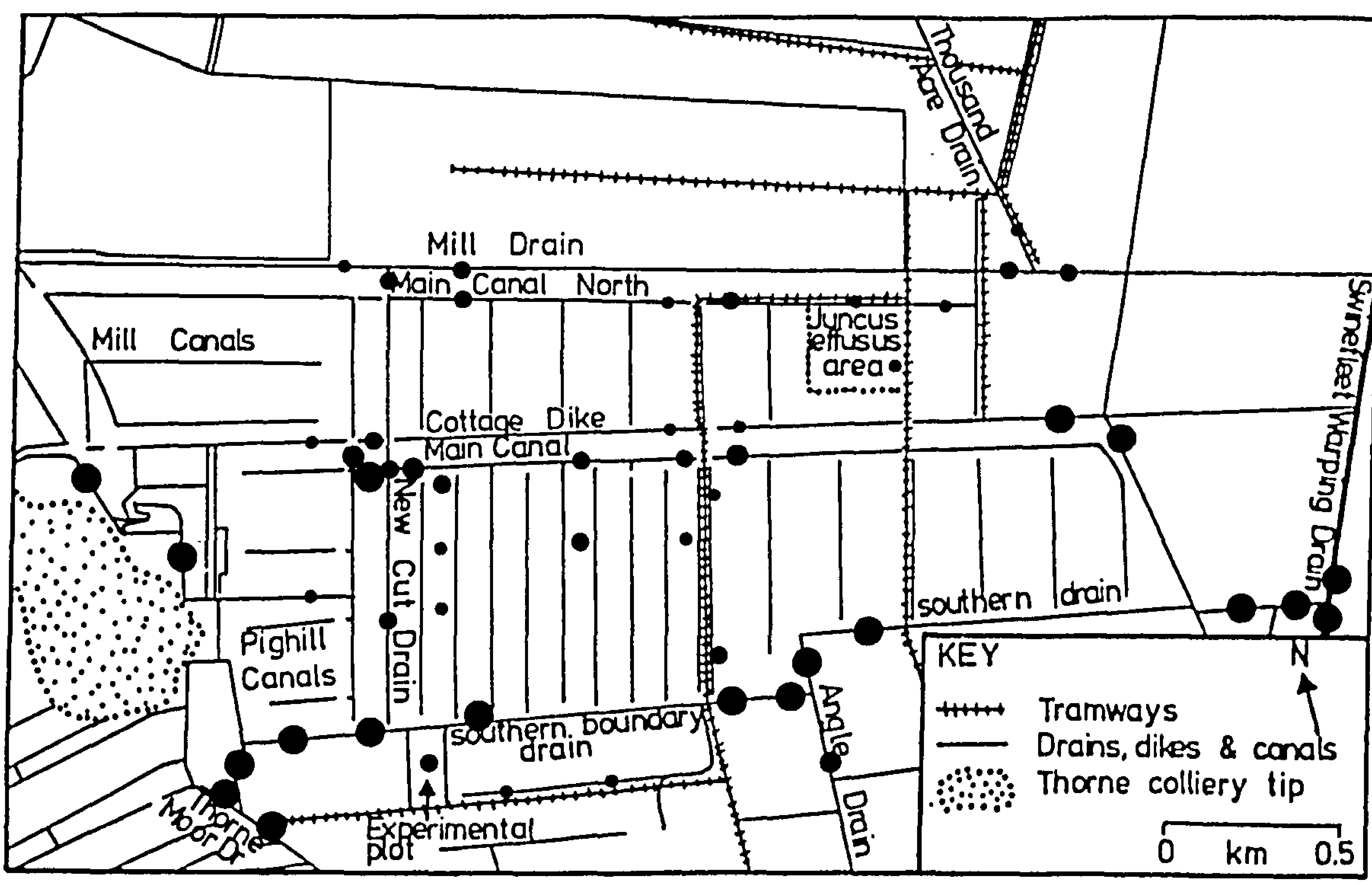


Fig. 6.13 pH of the drain waters: (•) ⩽ 4; (●) 4–5; (●) 5–6; (⬤) ⩾ 6.

6.5.2 Results

The results are shown in Figs. 6.13-6.20. Concentrations of ions at the sample sites are depicted by different sized filled circles. The results of the chemical analysis of the water samples from the peat cutting study sites (6.3) collected on 10 July 1980 are also shown on the maps.

6.5.2.1 pH

The pH (Fig. 6.13) of the drain water was generally higher than that of the pNNR and other study sites. It was particularly high (⩾ 6) in the drain at the base of the colliery tip (subsequently referred to as the 'Mine Drain' because it runs out of the mine workings), the Southern Boundary Drain, the Main Canal and in the vicinity of the Swinefleet Warping Drain. The pH in water from the New Cut was similar to or somewhat higher than that observed in the peat cuttings.

6.5.2.2 Major cations

In most of the drains, concentrations of dissolved calcium, magnesium and sodium (Figs. 6.14a, b and c) were much greater than in the pNNR or at JA and EP. In waters from the New Cut, however, concentrations of calcium and magnesium were similar to those recorded at the peat cutting study sites. The proportion of calcium, magnesium and to a lesser extent sodium in the drain waters at each sample site was constant.

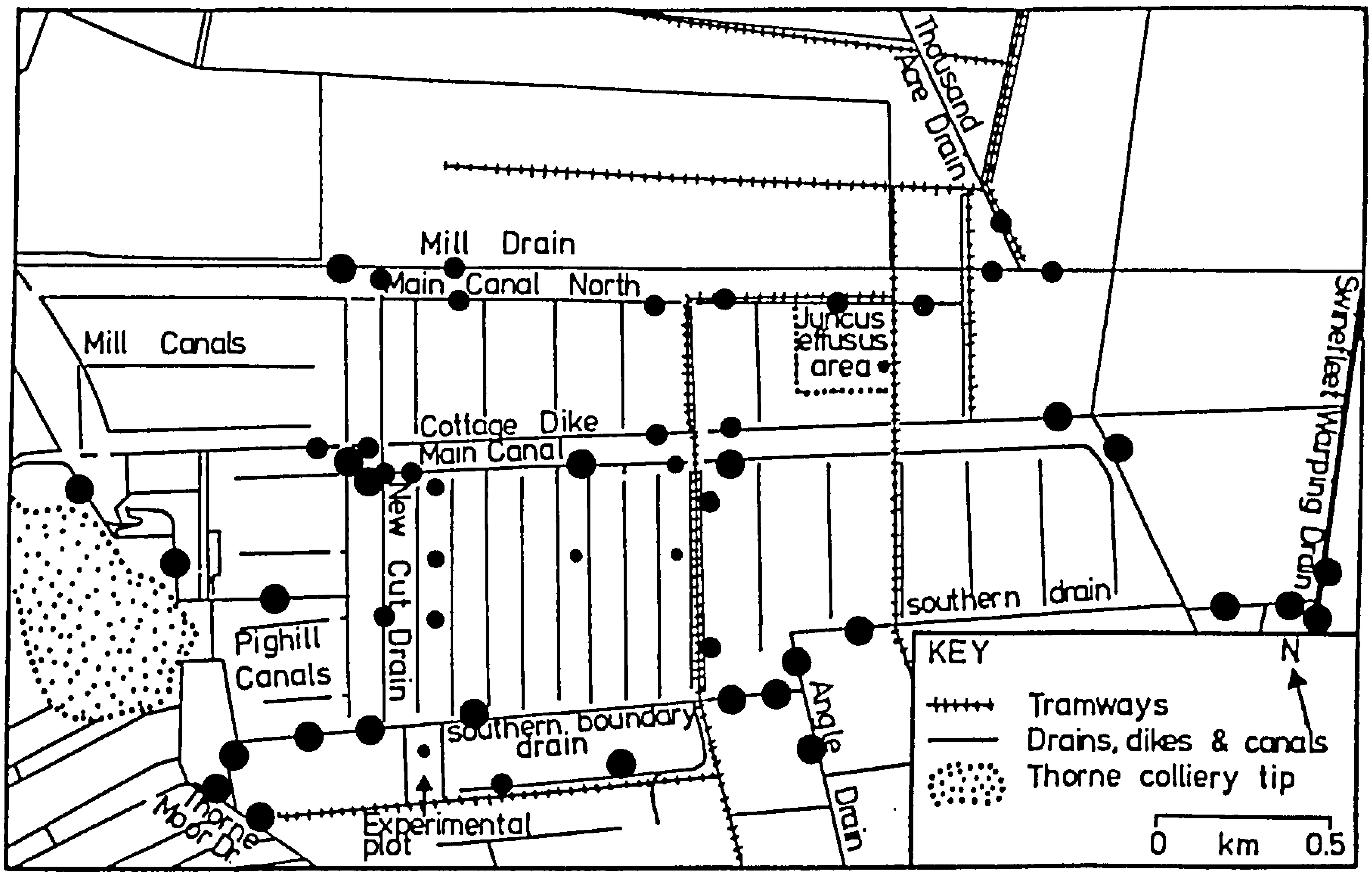


Fig. 6.14a Calcium concentrations in drain waters:
(•) ≤ 8; (●) 8-16; (●) 16-24; (●) ≥ 24 mg/l.

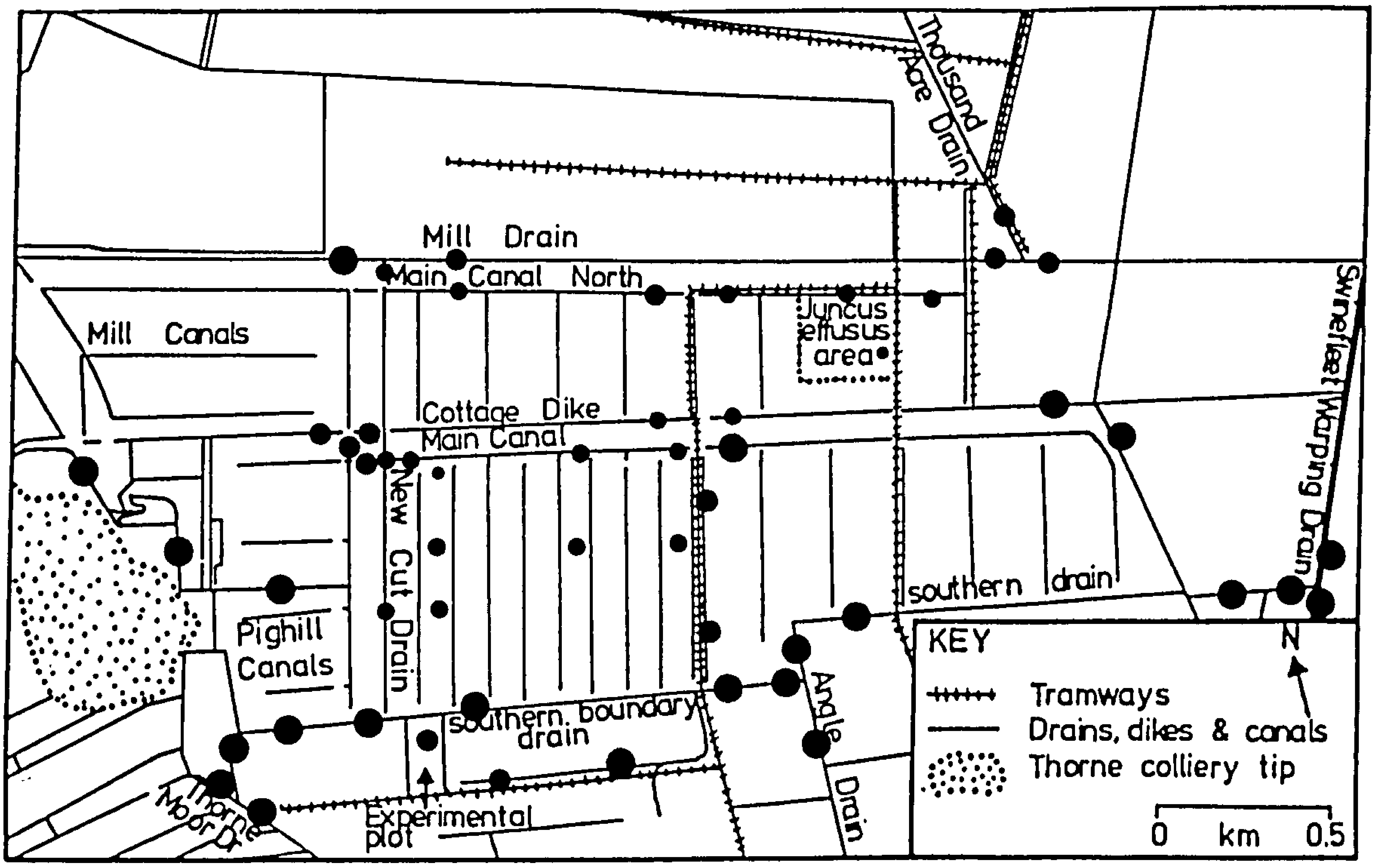


Fig. 6.14b Magnesium concentrations in drain waters:
(•) ≤ 2; (●) 2-4; (●) 4-6; (●) ≥ 6 mg/l.

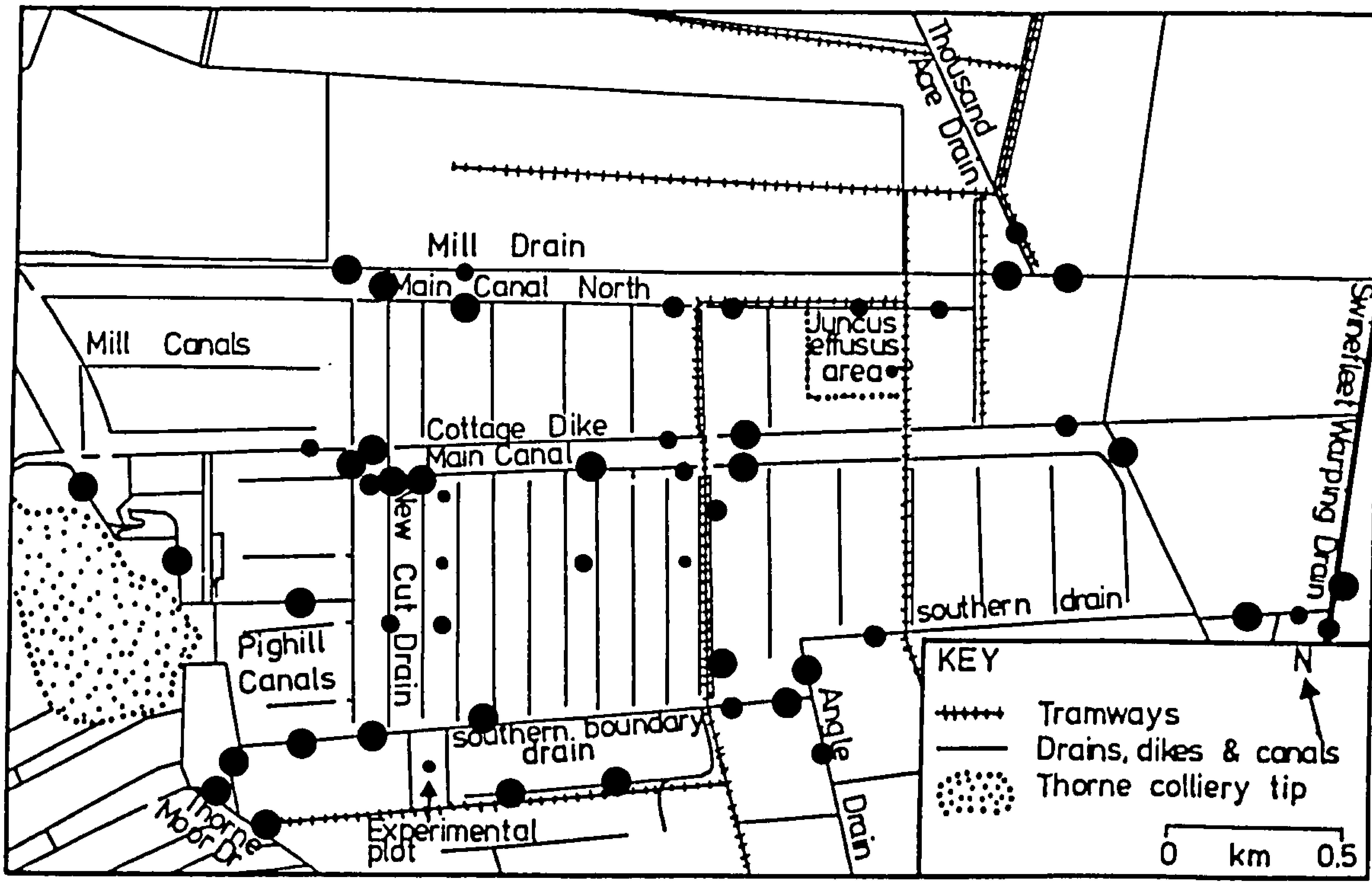


Fig. 6.14c Sodium concentrations in drain waters:
(•) ⩽ 10; (●) 10-20; (●) 20-30; (⬤) ⩾ 30 mg/l.

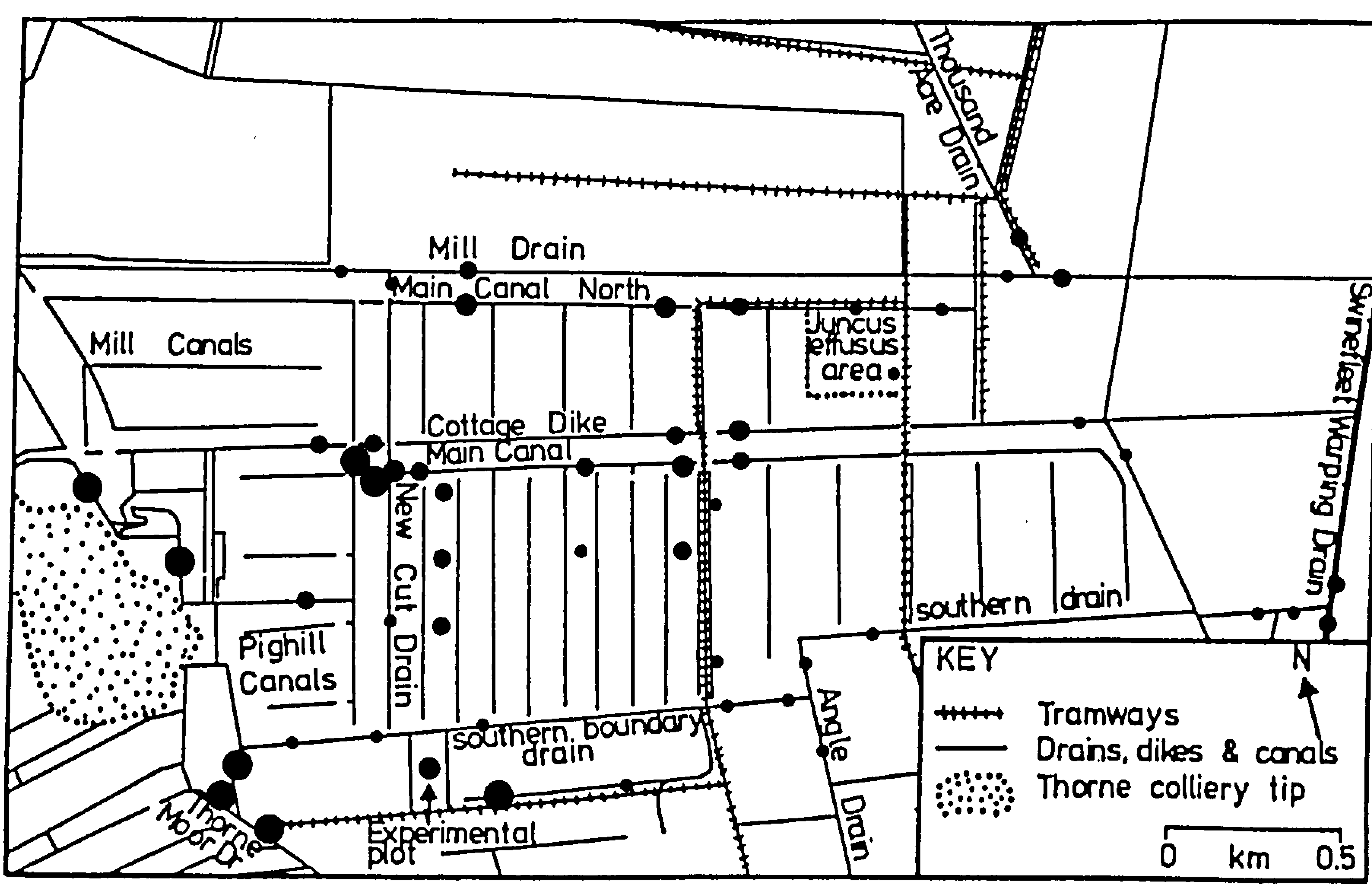


Fig. 6.14d Potassium concentrations in drain waters:
(•) ⩽ 1.5; (●) 1.5-3.0; (●) 3.0-4.5; (⬤) ⩾ 4.5 mg/l.

Potassium concentrations (Fig. 6.14d) in the drain waters were similar to, or a little greater than, those observed in the peat cutting study sites, except in the Mine Drain, Thorne Moor Drain, the Main Canal and canal 1 where levels were much higher. A particularly high concentration of potassium was also recorded at site 41, to the east of EP.

6.5.2.3 Iron

Concentrations of iron in the drain waters (Fig. 6.15) were mostly similar to those recorded in the peat cutting study sites (with the exception of site 3. 2/3W5 where relatively high levels of iron were recorded - see 6.3.4). Relatively high concentrations of iron were measured, however, in waters from sites 22 and 23 where the Southern Drain runs into the Swinefleet Warping Drain.

6.5.2.4 Manganese

Concentrations of manganese in the drain waters (Fig. 6.16) were no greater than those measured in the peat cutting study sites except at sites in, or connected to, the Mine Drain (21, 38, 42, 45) where levels were similar to the high concentrations recorded at 2. 2/3W1.

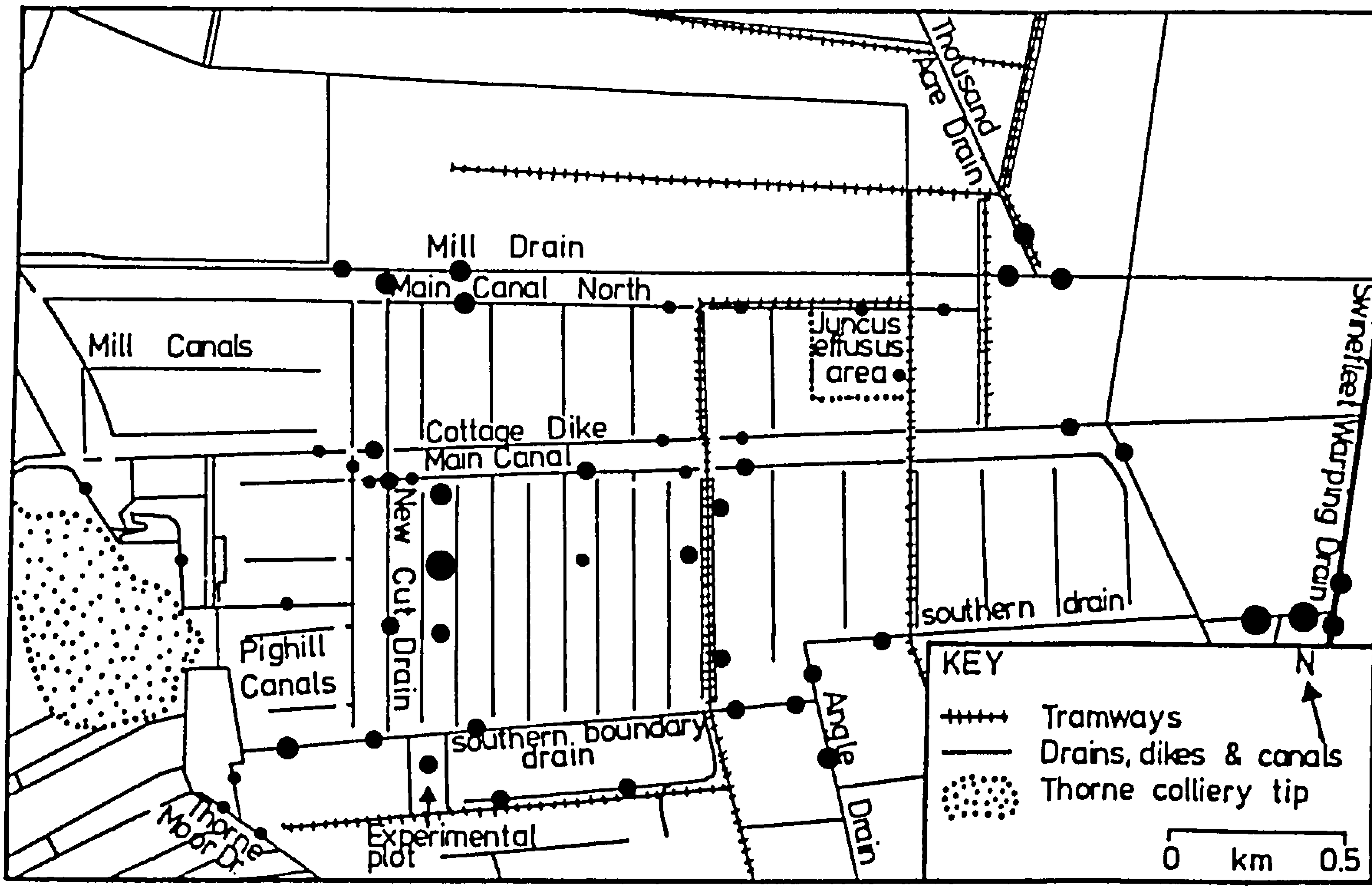


Fig. 6.15 Iron concentrations in drain waters:
(•) ⩽ 5; (●) 5-10; (●) 10-15; (⬤) ⩾ 15 mg/l.

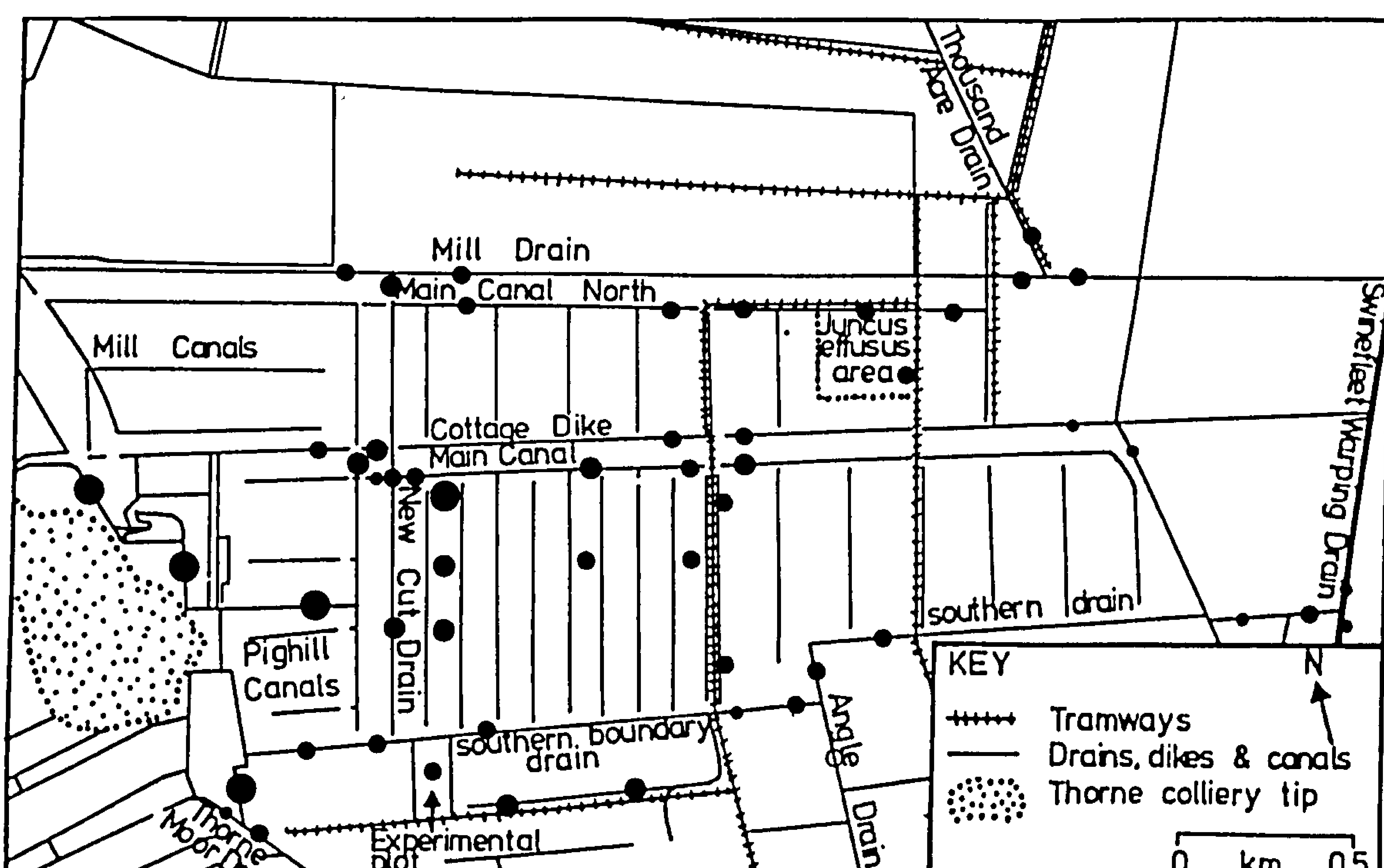


Fig. 6.16 Manganese concentrations in drain waters:
(•) ⩽ 0.1; (●) 0.1-0.2; (●) 0.2-0.3; (⬤) ⩾ 0.3 mg/l.

6.5.2.5 Phosphorus

Concentrations of phosphorus in the drain waters (Fig. 6.17) were generally similar to the low levels recorded at the peat cutting study sites. Higher concentrations of phosphorus, however, were measured in the Southern Boundary Drain and towards the east of the site in Angle Drain, Thousand Acre Drain, Mill Drain, Cottage Dike and in the vicinity of the Swinefleet Warping Drain.

6.5.2.6 Nitrogen

Nitrogen concentrations were low in most of the drain waters (Fig. 6.18) and similar to those recorded in the peat cutting study sites. Thousand Acre Drain and the Mine Drain, however, contained relatively high concentrations of ammonium-nitrogen and (nitrite + nitrate)-nitrogen; Thorne Moor Drain contained relatively high concentrations of (nitrite + nitrate)-nitrogen.

6.5.2.7 Major anions

With the exception of the Southern Boundary and Southern drains, all the drain waters contained greater concentrations of sulphate than those recorded at the peat cutting study sites (Fig. 6.19).

The results of the chloride concentrations in the drain waters are not presented because they were very similar to the sodium levels at the sample sites (Fig. 6.14c).

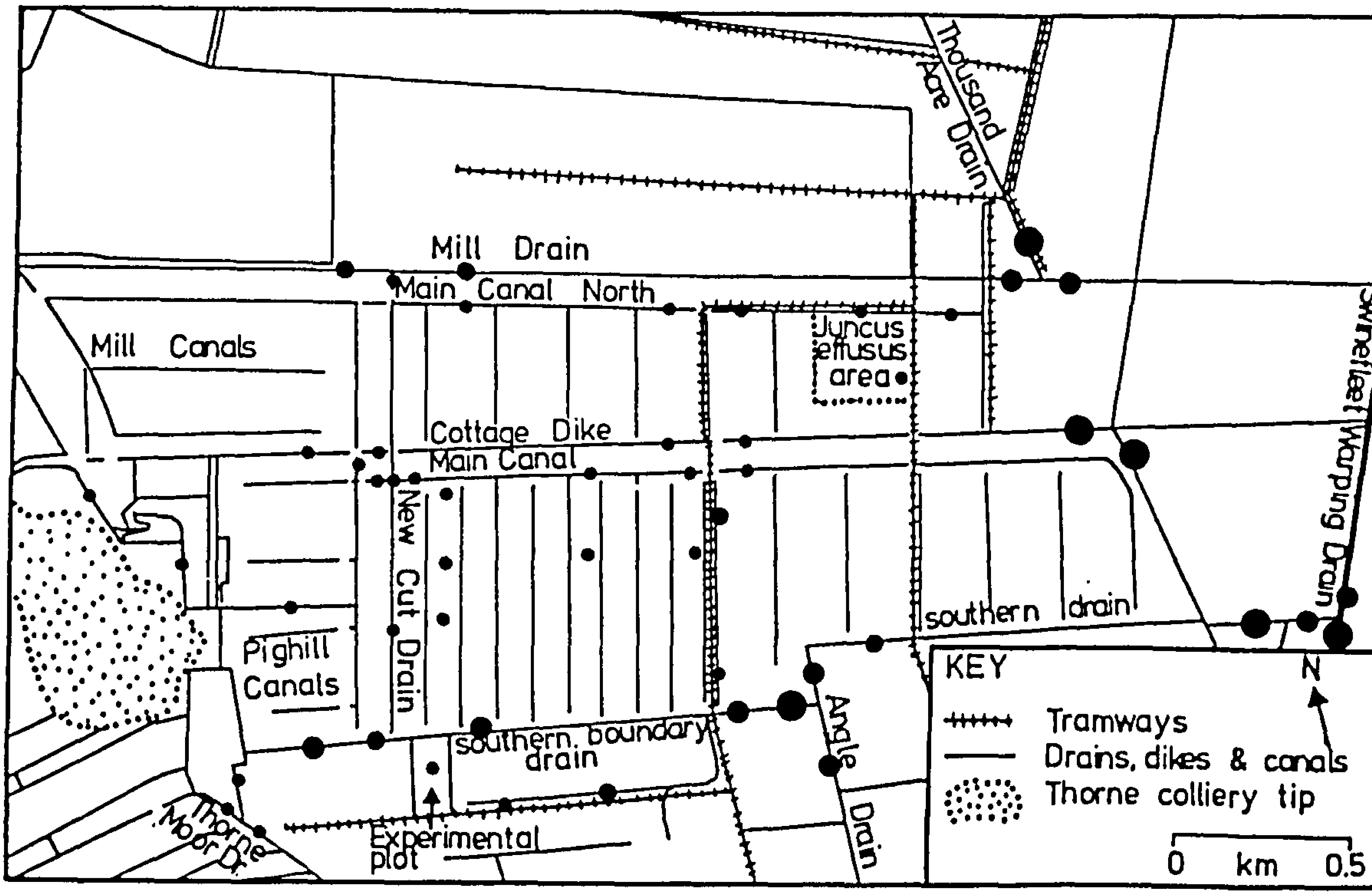


Fig. 6.17 Phosphorus concentrations in drain waters: (•) ⩽ 0.05; (●) 0.05-0.10; (●) 0.10-0.15; (●) ⩾ 0.15 mg/l.

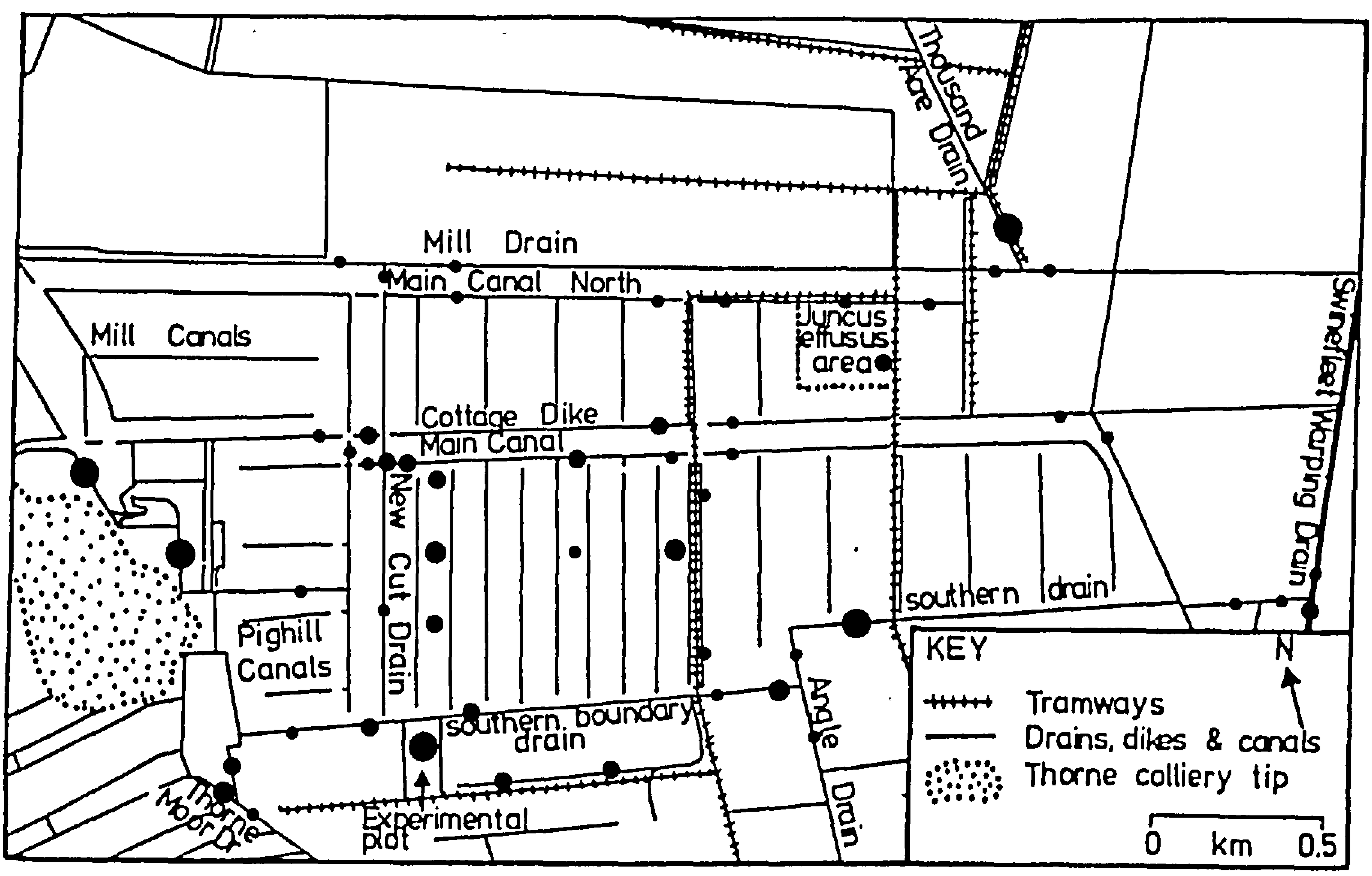


Fig. 6.18a (Ammonium + nitrite + nitrate)-nitrogen concentrations in drain waters: (•) ⩽ 0.5; (●) 0.5-1.0; (●) 1.0-1.5; (●) ⩾ 1.5 mg/l.

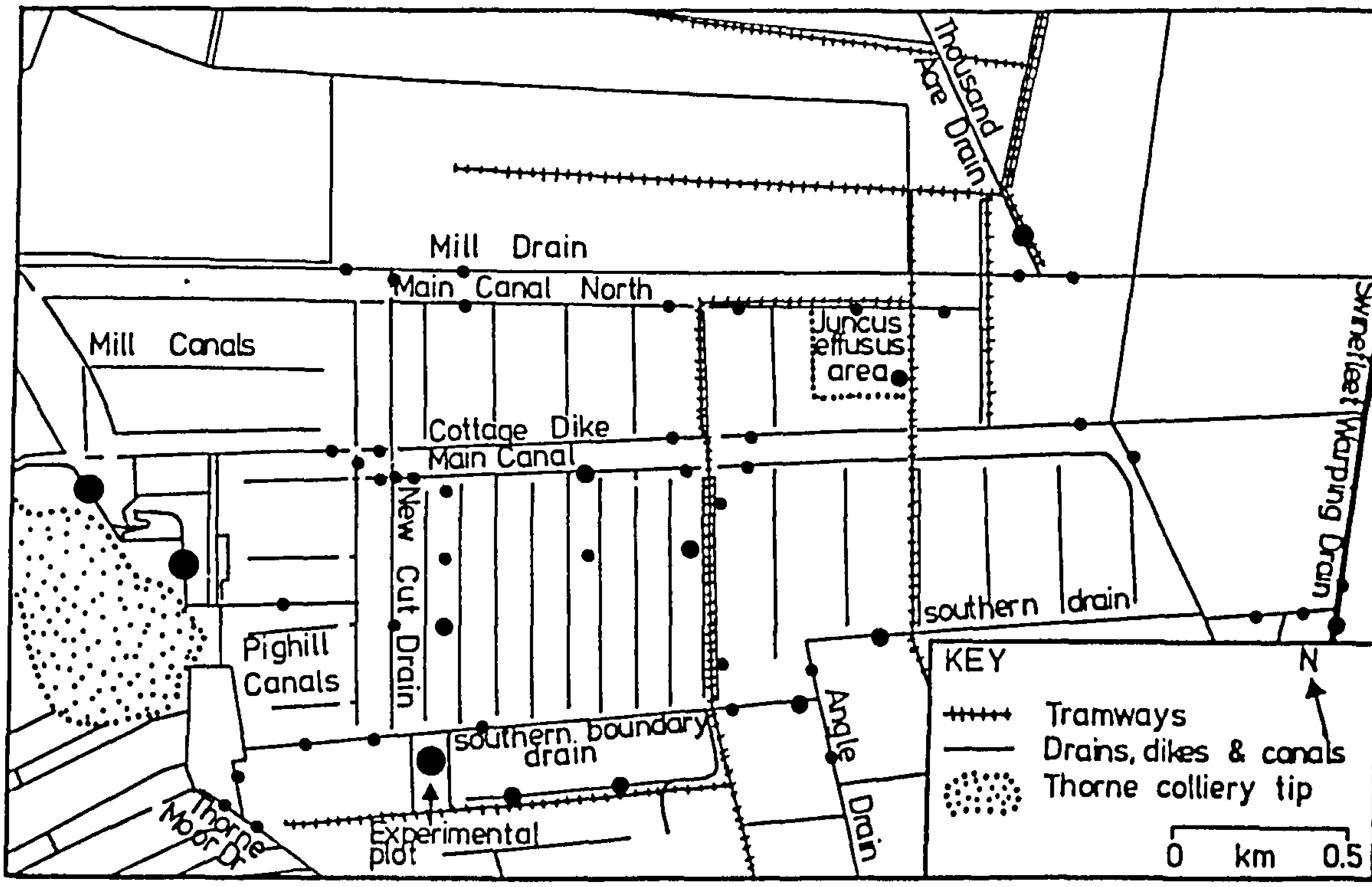


Fig. 6.18b Ammonium-nitrogen concentrations in drain waters: (•) ⩽ 0.5; (●) 0.5-1.0; (●) 1.0-1.5; (⬤) ⩾ 1.5 mg/l.

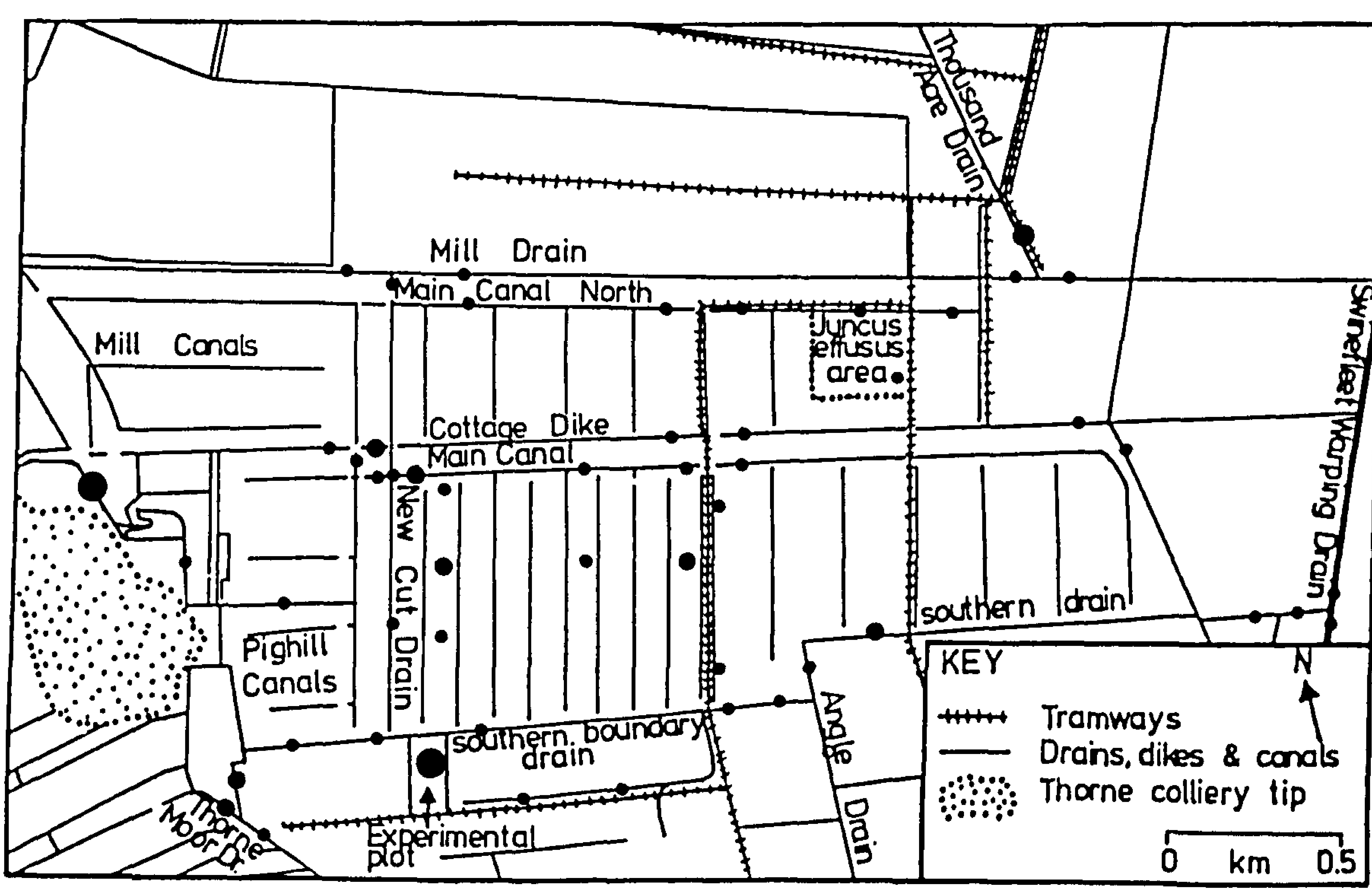


Fig. 6.18c (Nitrite + nitrate)-nitrogen concentrations in drain waters: (•) ⩽ 0.5; (●) 0.5-1.0; (●) 1.0-1.5; (⬤) ⩾ 1.5 mg/l.

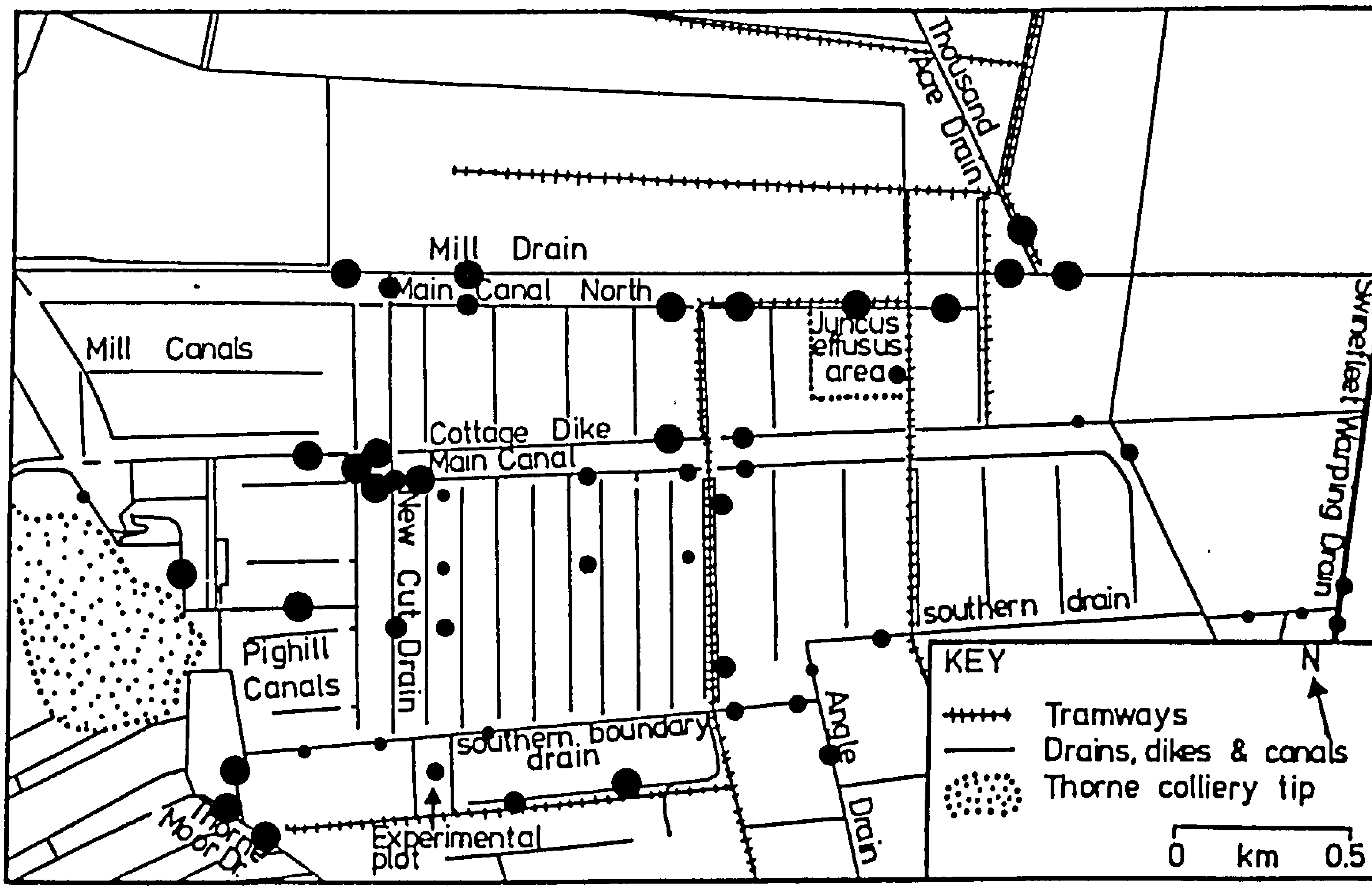


Fig. 6.19 Sulphate concentrations in drain waters:
(•) ⩽ 15; (●) 15-30; (●) 30-45; (⬤) ⩾ 45 mg/l.

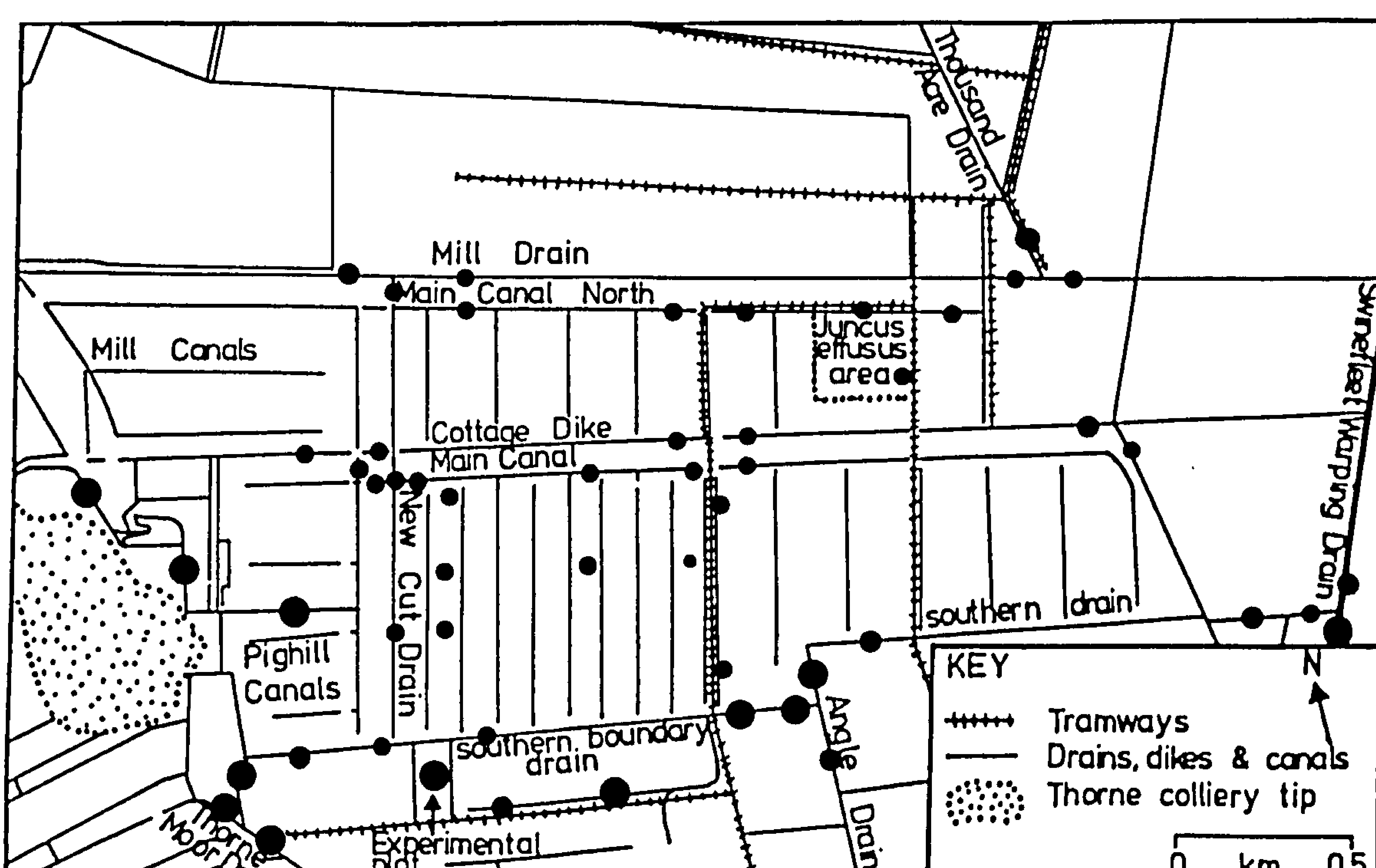


Fig. 6.20 Electrical conductivity (K_{corr}) of drain waters:
(•) ⩽ 100; (●) 100-200;
(●) 200-300; (⬤) ⩾ 300 μS.

6.5.2.8 Electrical conductivity (K_{corr})

The conductivity of the drain waters (Fig. 6.20) was greatest in the Mine Drain, Thorne Moor Drain, the Southern Boundary Drain, Angle Drain and the Swinefleet Warping Drain. It was otherwise similar to or a little greater than that recorded in the peat cutting study sites.

6.5.3 Factors influencing the chemical composition of the drain waters

The relatively high pH and concentrations of calcium, magnesium, sodium and sulphate in the main drains may partly reflect the influence of the underlying clay which these drains penetrate to a greater or lesser extent. Run-off from the clay-covered warp land to the west of the Swinefleet Warping Drain (Fig. 1.2) may also contribute to the high pH and concentrations of calcium, magnesium and sodium at sites 19-25. In addition, the high concentrations of the major cations, particularly sodium, in the Swinefleet Warping Drain, may reflect that this drain runs into the tidal River Ouse at Goole, 7 km from The Moors.

Thorne Moor Drain and the Swinefleet Warping Drain receive drainage water from the surrounding agricultural land; the influence of fertilizers may explain the relatively high concentrations of nitrogen and phosphorus in the Warping Drain and nitrogen and potassium in Thorne Moor Drain.

The chemical composition of the Mine Drain, which contained high concentrations of all ions measured except iron and phosphorus, was probably influenced by water from the mine workings and run-off from the colliery tip. The water in the Mine Drain presumably also had an influence on the water chemistry of Thorne Moor Drain into which it runs.

In addition to the effect of the underlying clay, the high concentrations of sulphate in the drain waters may be due to the release of this ion as a result of drainage of peat areas surrounding the drains (see 6.3.14.3).

The water chemistry of the canals is considered in 6.6.

6.5.4 The influence of the drain waters on the study sites

The main drains flow away from, rather than on to, The Moors (Chapter 1). They are situated up to 2 m below the level of the pNNR and are almost certainly never full enough to back up onto the area. It was considered, therefore, that waters from the main drains were unlikely to have influenced the chemistry of the peat waters in the pNNR directly.

The exceptions to this may be the small drain to the west of canal 1 (sample site 21; Fig. 6.12) and the New Cut, which is dammed. Waters from the Mine Drain may influence the water chemistry of peat cuttings surrounding the drain to the west of canal 1 but this is unlikely to have had a direct influence on the water chemistry of the pNNR study sites owing to the presence of peat baulks, c. 5 m wide, which run along the length of both sides of canal 1. The water level in the New Cut is generally high and sometimes floods the surrounding peat cuttings, because it is dammed at both ends. It is likely, therefore, that water from this drain has had an effect on the chemical composition of the peat waters in the pNNR particularly in the area between canals 1 and 2. The study sites in the pNNR, however, were probably isolated from the water of this drain by the peat baulks, c. 5 m wide, which run along the length of both sides of canal 2.

The chemistry of the peat waters in the *Juncus effusus* area (site 1. JA) is unlikely to have been influenced by water from the main drains, for example Mill Drain, because they flow away from this cutting. The influence of water from the eastern extension of Main Canal North which comprises the northern boundary of this cutting will be considered in 6.6.

It is unlikely that the chemistry of the peat waters in EP was influenced by water from drains (e.g. the Southern Boundary Drain) because this cutting is situated well above the level of the surrounding drains.

6.5.5 Conclusions

1. The concentration of ions and the pH in the drain waters were similar to, and in many instances higher than at the peat cutting study sites.

2. Although some areas of the pNNR may receive water from the drains, it is unlikely that the water chemistry of the peat cutting study sites was influenced by drain waters because of their isolation owing to the presence of peat baulks.

3. The chemistry of the peat waters at study sites 1. JA and 7. EP was unlikely to have been influenced by drain waters because these sites are isolated from the main drains.

6.6 WATER CHEMISTRY OF THE CANALS

6.6.1 Methods

To examine the chemistry of the canal waters in relation to the peat cutting study sites, 34 water samples (Fig. 6.21) were collected on 28 May 1981 and analysed for pH, major cations, iron, manganese, phosphorus, nitrogen and conductivity (Appendix 4). Some water samples were also collected from drains to allow a comparison with chemical concentrations in the canals.

In order to examine the possibility that water from canal 4 has influenced the chemistry of an adjacent cutting (3/4E6), by way of a connecting ditch, surface water samples were collected along a transect in the pNNR on 13 May 1982; this transect crossed canal 3, cuttings 3/4W6 and 3/4E6, canal 4 and cutting 4/5W6 (Fig. 6.28). The water samples were analysed for pH, the major cations, iron, manganese and conductivity.

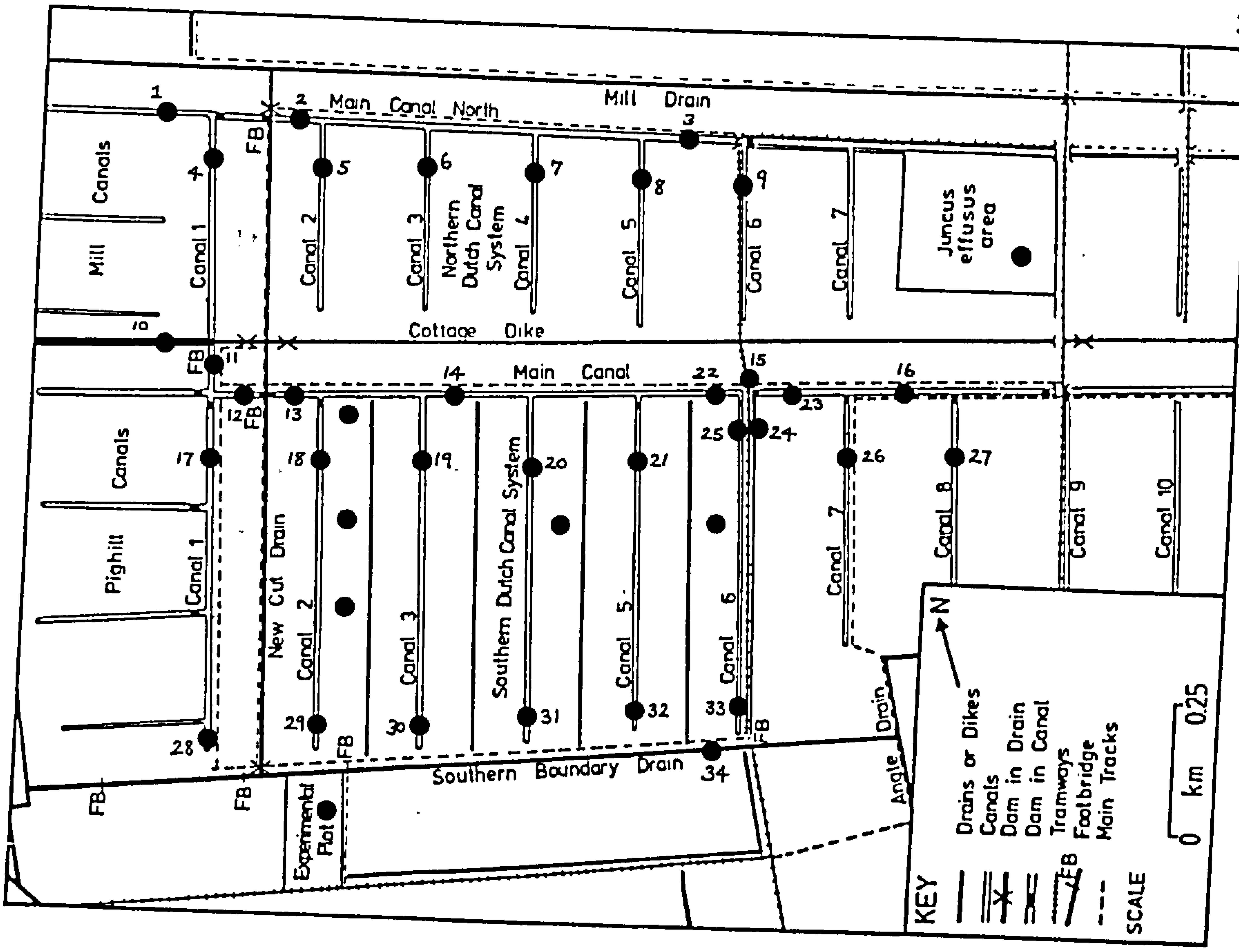


Fig. 6.21 Location of sample sites in canals.

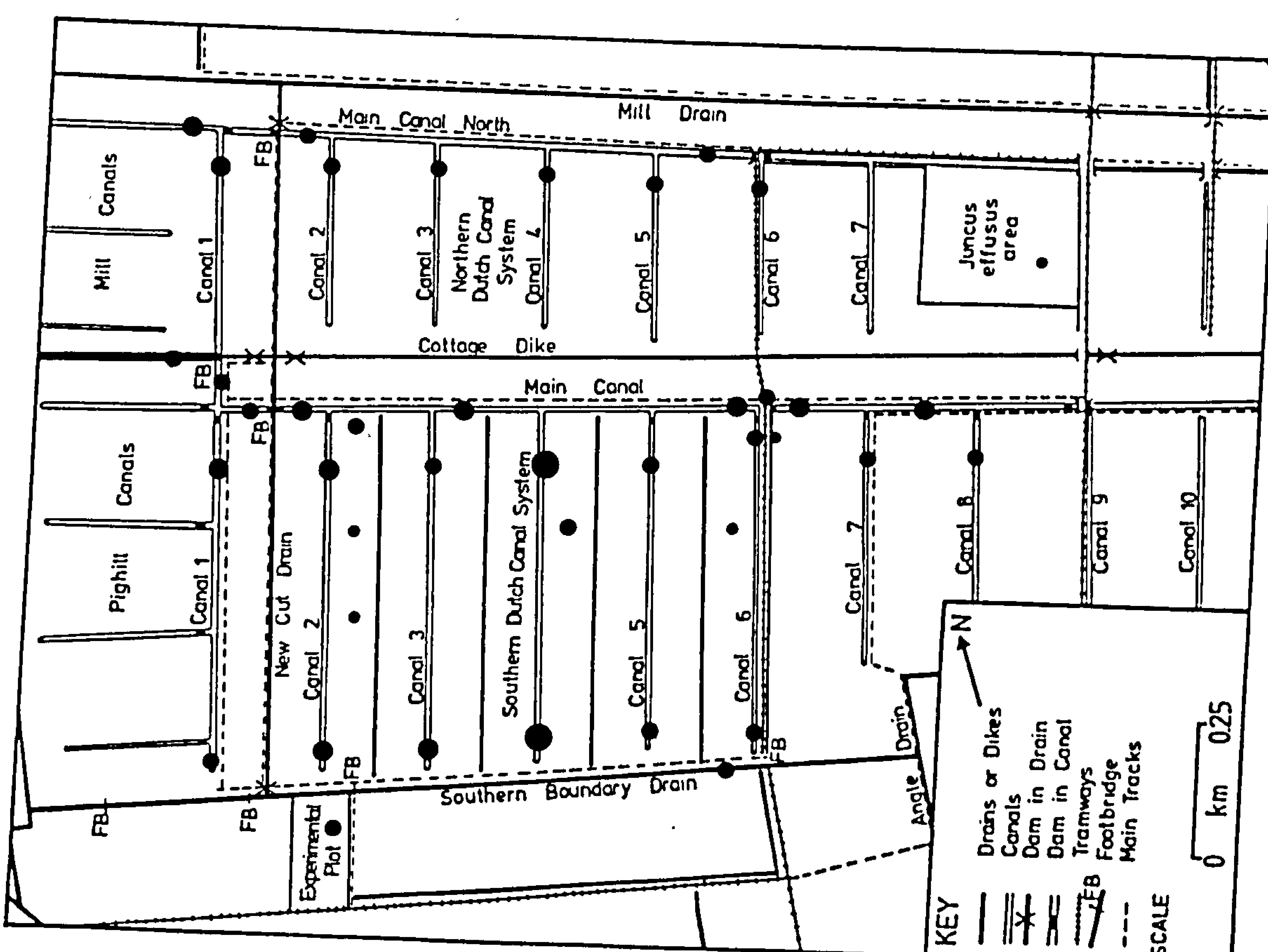


Fig. 6.22 pH of the canal waters:
(•) ⩽ 4; (●) 4–5; (●) 5–6; (⬤) ⩾ 6.

6.6.2 Results

The results of the analysis of the canal waters are shown in Figs. 6.22-6.27. The concentrations of ions are shown by different sized filled circles; these are the same size and represent the same ionic concentrations as those used to depict the chemical composition of the drain waters (Fig. 6.13-6.20). Phosphorus was not detected at most sample sites; nitrogen concentrations were so low that only total nitrogen concentrations are presented. The results of the chemical analysis of the water samples from the peat cutting study sites (6.3) collected on 10 July 1980 are also shown on the maps.

The results of the chemical analysis of water samples from the transect, (subsequently referred to as 'the transect'), are shown in Fig. 6.28.

The canals referred to by number are those of the Southern Dutch Canal System unless otherwise specified.

6.6.2.1 pH

The pH of the Dutch canals (Fig. 6.22 and Fig. 6.28a) was mostly higher than that of the main study sites and the peat cuttings along the transect. The pH was particularly high (≥ 6) in canal 4.

6.6.2.2 Major cations

Comparison of concentrations of cations measured in the analysis of drain waters (Fig. 6.14) and canal waters (Fig. 6.23) shows how ionic concentrations varied on the two sampling occasions. At the same site in the Main Canal (site 6, Fig. 6.12; site 12, Fig. 6.21), for example, $\geqslant$ 24 mg/l of calcium were measured in water collected on 3 June 1980 (Fig. 6.14a) whereas the concentration of calcium measured in water collected on 28 May 1981 was only 8-16 mg/l (Fig. 6.23a). This difference may partly reflect the degree of uptake of ions by the vegetation in the canals on these two occasions.

It is clear, however, that concentrations of calcium were generally greater in the canals than in the peat cutting study sites (Fig. 6.14a and Fig. 6.23a) or in the peat cuttings of the transect (Fig. 6.28b). The highest concentrations of calcium were measured in canal 4.

Magnesium, sodium and potassium concentrations in the canals were similar to (Fig. 6.23 and Fig. 6.28) or somewhat greater than (Fig. 6.14) than those measured in the peat cuttings at the study sites or along the transect.

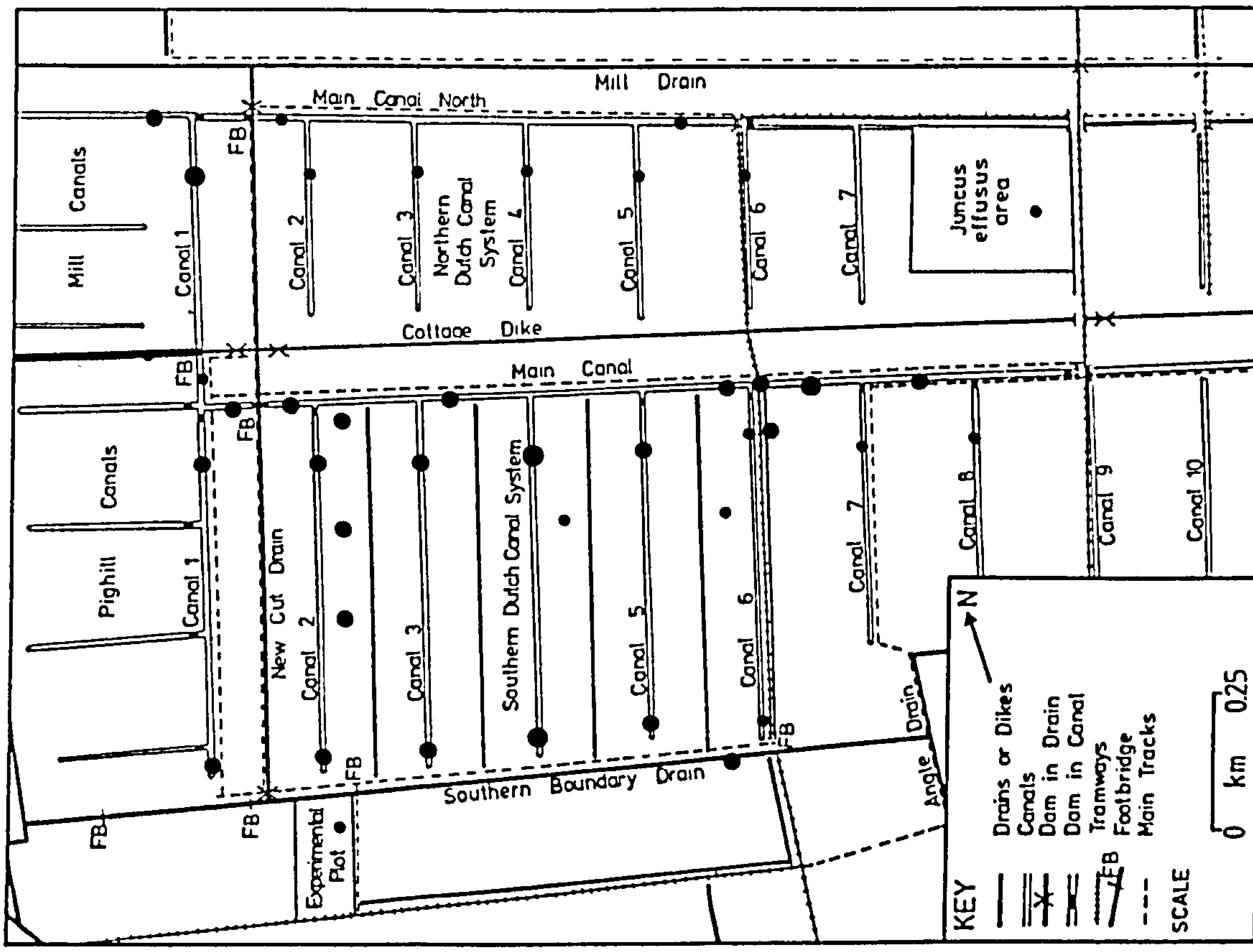


Fig. 6.23a Calcium concentrations in canal waters:
(•) ⩽ 8; (●) 8-16; (●) 16-24; (⬤) ⩾ 24 mg/l.

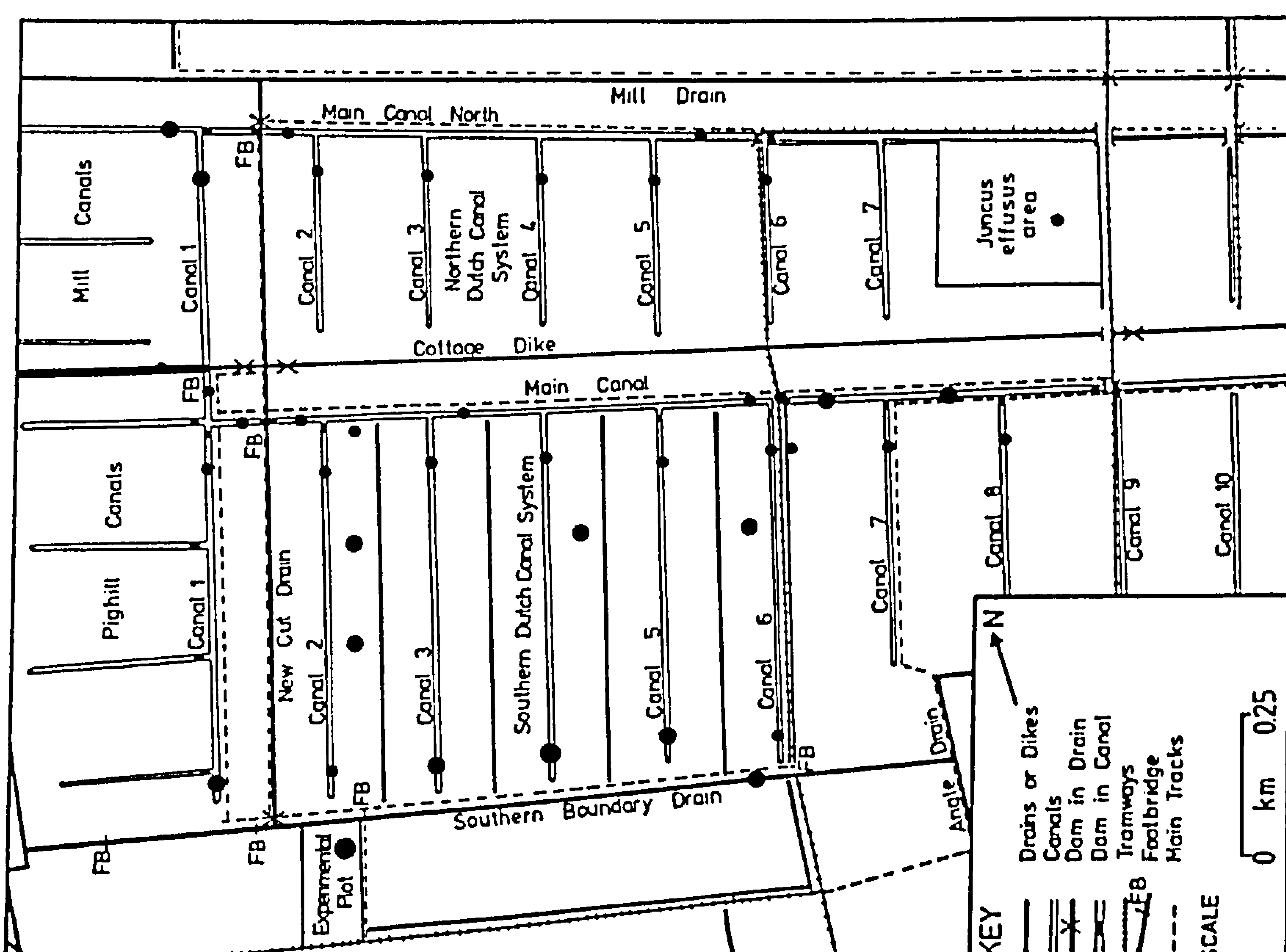


Fig. 6.23b Magnesium concentrations in canal waters:
(•) ⩽ 2; (●) 2-4; (●) 4-6; (⬤ ⩾ 6 mg/l.

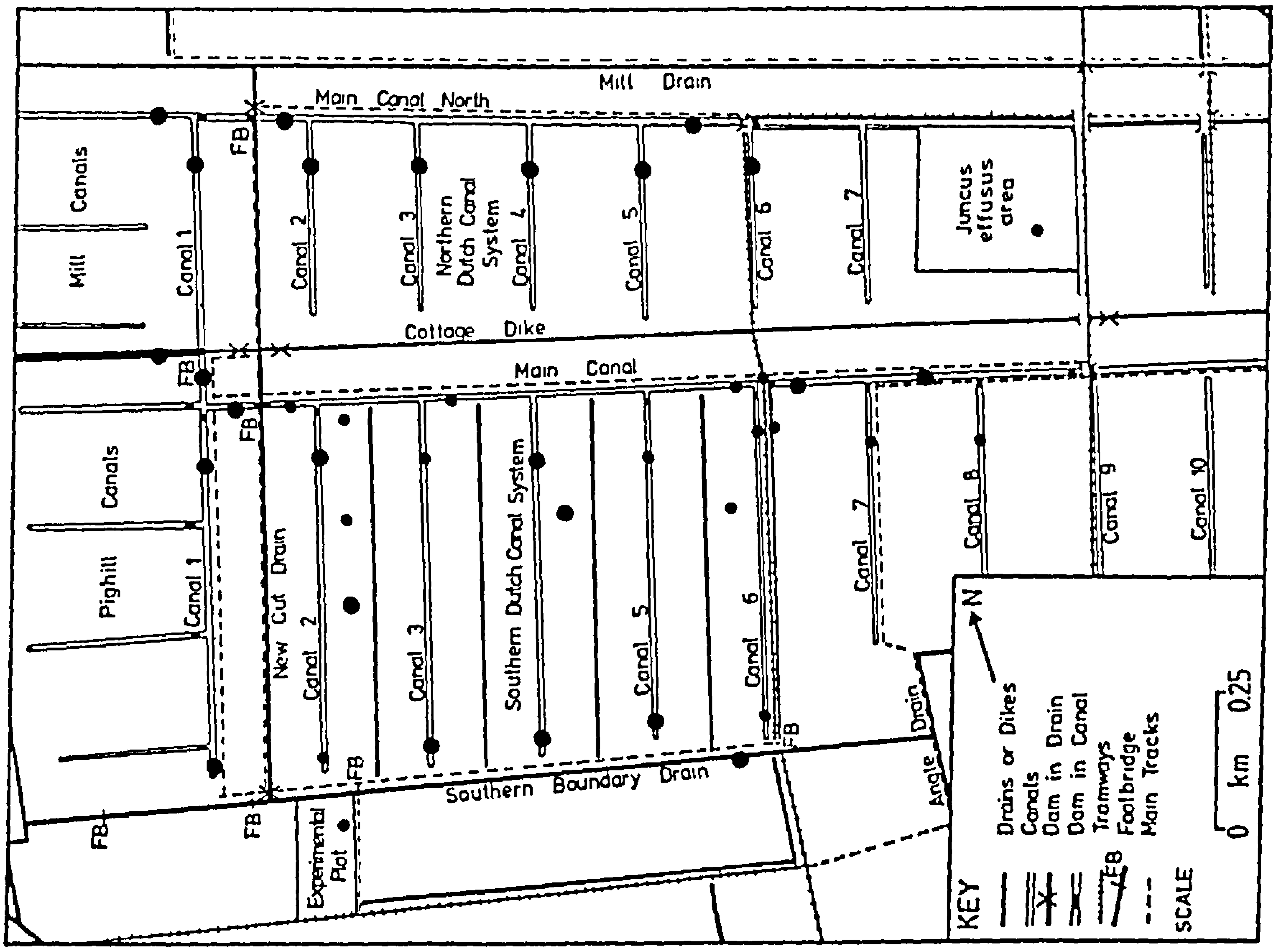


Fig. 6.23c Sodium concentrations in canal waters: (•) ⩽ 10; (●) 10-20; (●) 20-30; (⬤) ⩾ 30 mg/1.

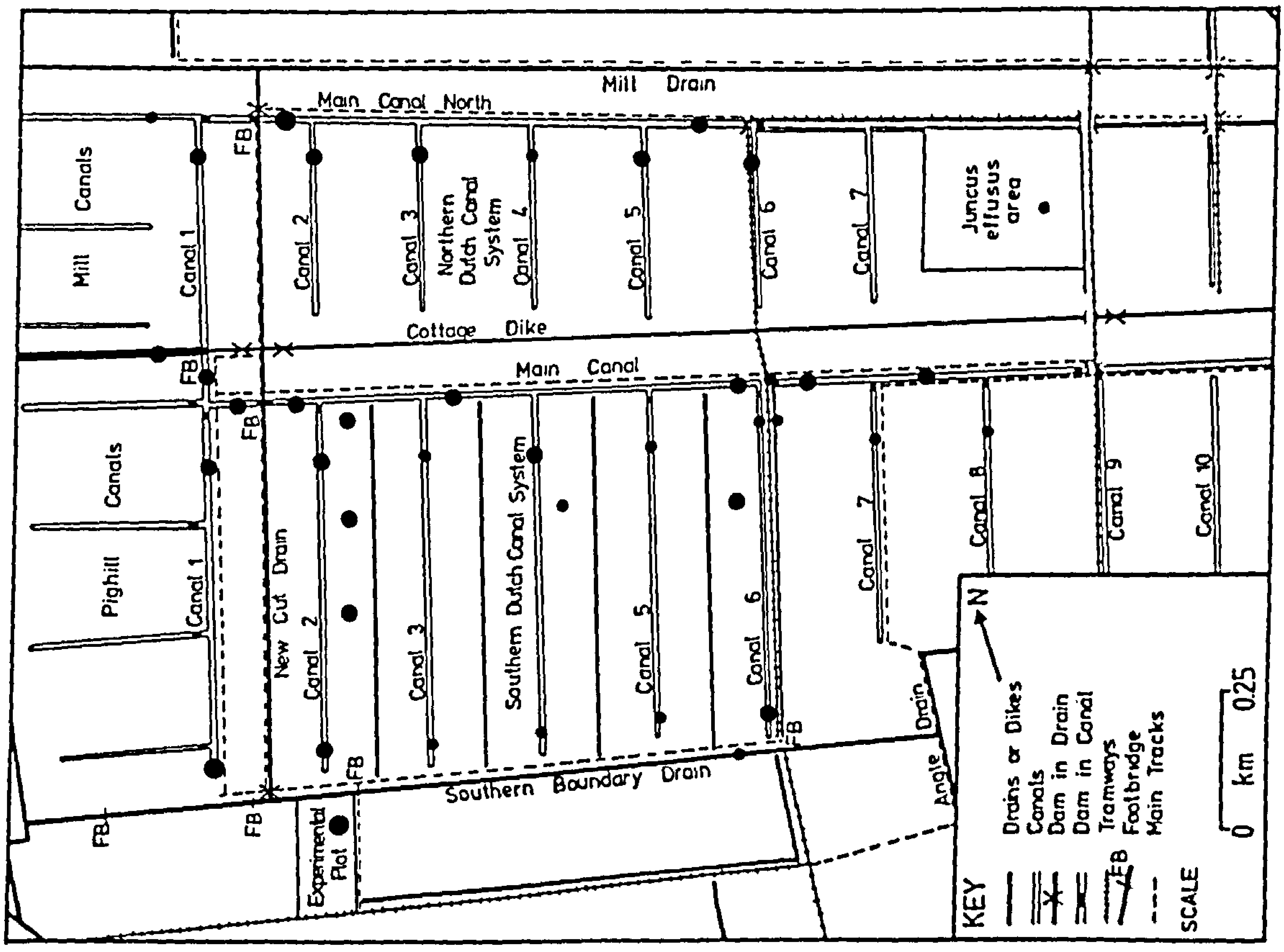


Fig. 6.23d Potassium concentrations in canal waters: (•) ⩽ 1.5; (●) 1.5-3.0; (●) 3.0-4.5; (⬤) ⩾ 4.5 mg/1.

6.6.2.3 Iron

Iron concentrations in the canals (Fig. 6.24) were similar or less than those recorded in peat cutting study sites 2. 2/3W1 and 3. 2/3W5; in the other study sites iron concentrations were similar to those in the canals. Concentrations of iron varied little along the transect (Fig. 6.28b) although levels in canal 3 were somewhat higher than elsewhere.

6.6.2.4 Manganese

Concentrations of manganese varied a great deal at the canal sample sites (Fig. 6.25); levels in canal 4 (site 20) and in Main Canal North (site 1) were as high as those recorded at site 2. 2/3W1 ($\geq$ 0.3 mg/l) whilst elsewhere levels were similar or less than those in the other peat cutting study sites. Manganese concentrations along the transect (Fig. 6.28a) in canal 4 were lower than in the peat cuttings.

6.6.2.5 Nitrogen

Nitrogen concentrations in the canals (Fig. 6.26) were lower than those recorded at the peat cutting study sites.

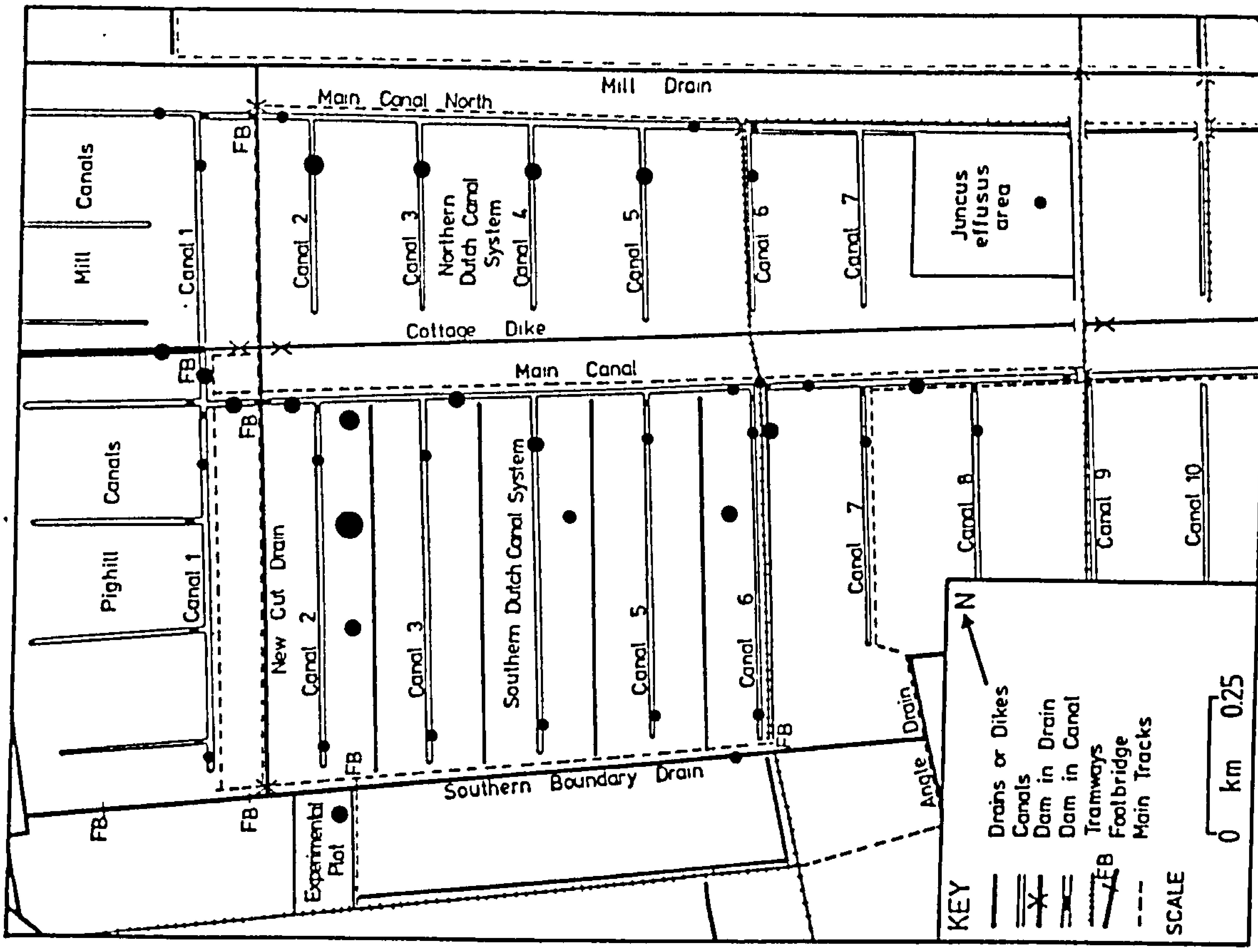


Fig. 6.24 Iron concentrations in canal waters:
(•) ⩽ 5; (●) 5-10; (●) 10-15; (●) ⩾ 15 mg/l.

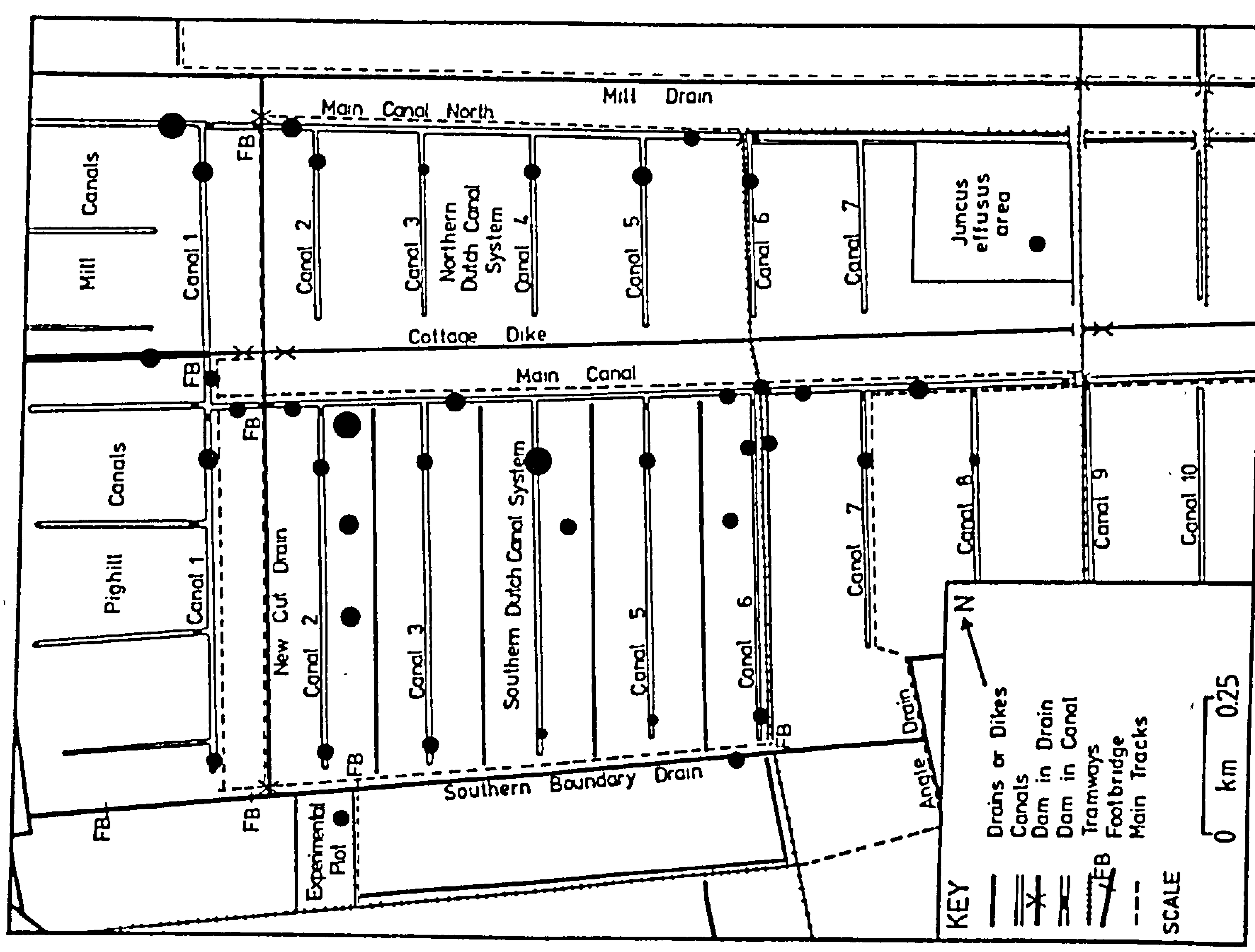


Fig. 6.25 Manganese concentrations in canal waters:
(•) ⩽ 0.1; (●) 0.1-0.2; (●) 0.2-0.3; (●) ⩾ 0.3 mg/l.

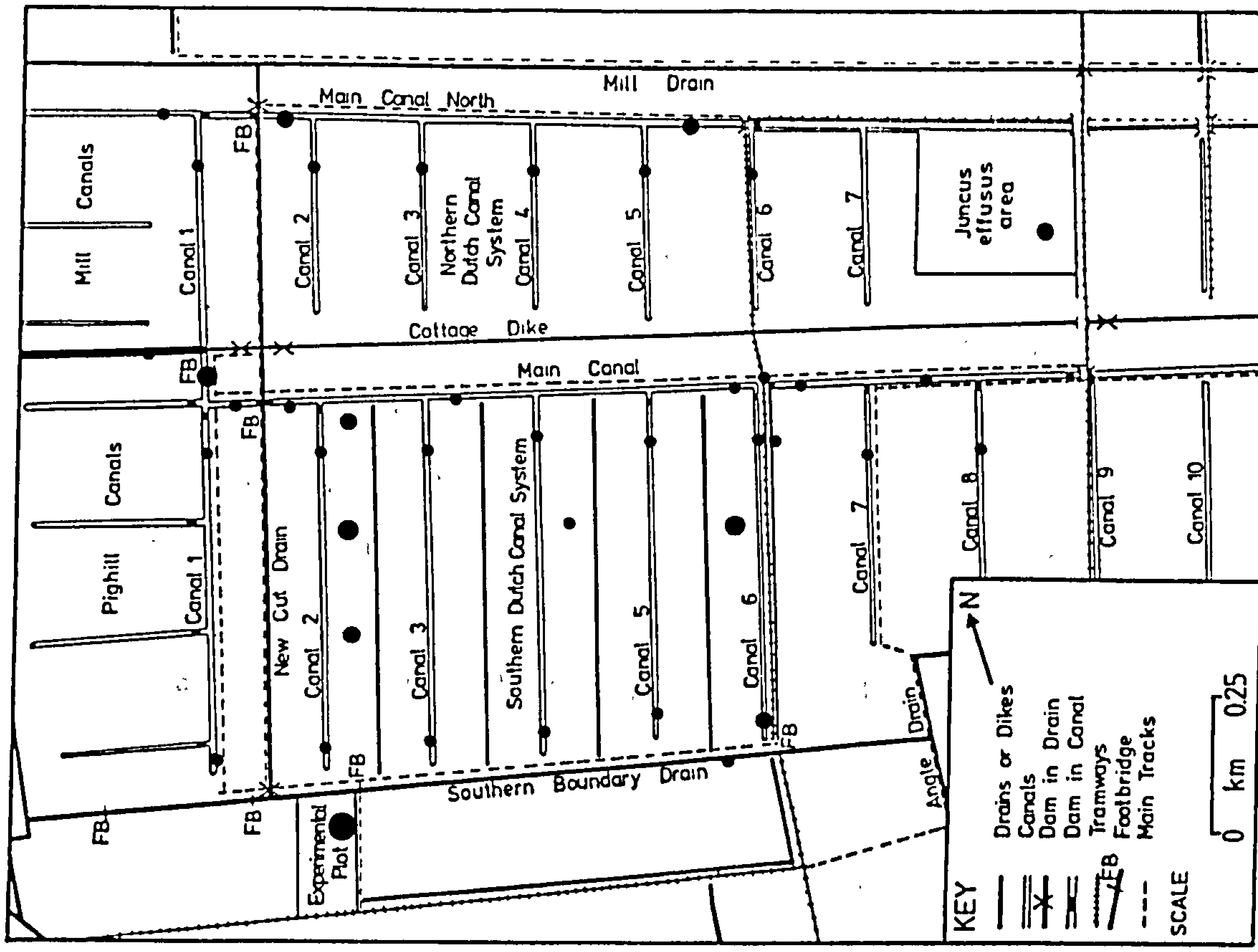


Fig. 6.26 (Ammonium + nitrite + nitrate)-nitrogen concentrations in canal waters:
(•) ⩽ 0.5; (●) 0.5-1.0; (●) 1.0-1.5; (⬤) ⩾ 1.5 mg/l.

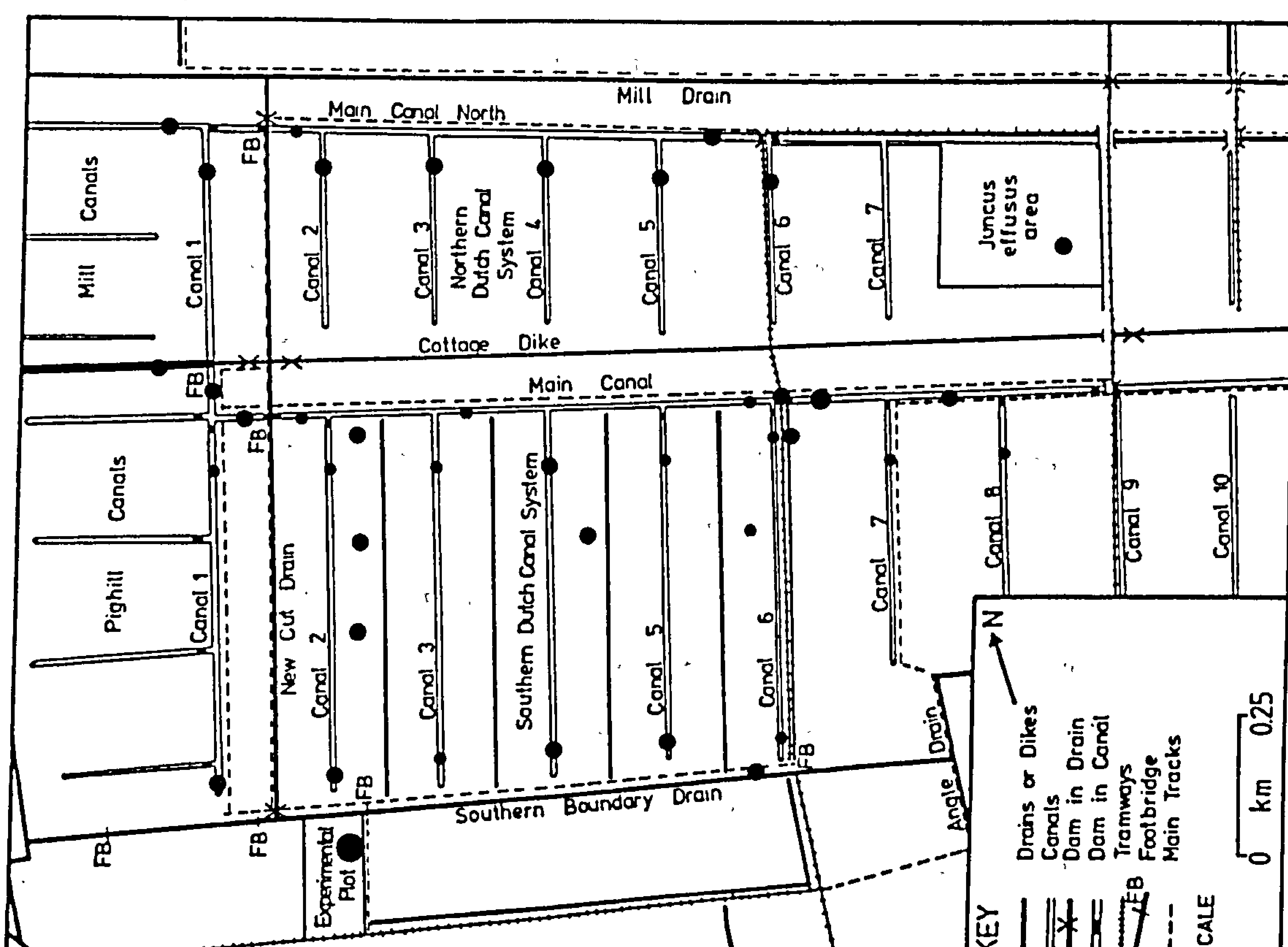


Fig. 6.27 Electrical conductivity (K_{corr}) of canal waters:
(•) ⩽ 100; (●) 100-200;
(●) 200-300; (⬤) ⩾ 300 μS.

6.6.2.6 Electrical conductivity (K_{corr})

The conductivity of the canal waters was similar to, or somewhat greater than, that at the peat cutting study sites (Fig. 6.27). Along the transect the conductivity in canals 3 and 4 was greater than that of the peat cuttings (Fig. 6.28b).

6.6.2.7 Water chemistry of the peat cuttings along the transect (Fig. 6.28)

Concentrations of ions in 3/4E5, connected to canal 4 by a ditch, were no greater than in the other two peat cuttings which were isolated from the adjacent canals. In the ditch linking canal 4 to 3/4E6, in the ditch adjacent and parallel to canal 3 and in the drains running parallel to the canals ionic concentrations were similar to those of the cuttings.

6.6.3 Factors influencing the chemical composition of the canal waters

The high pH and concentrations of the major cations, particularly calcium, in the Main Canal may reflect run-off from the chalk rubble towpath which runs along the northern side of this canal (Chapter 2). Water from this source may also have influenced the water chemistry of the side canals of the Southern System; it is unlikely to continue to do so in canals 1, 2, 5 and 6 which have been recently dammed and are, therefore, isolated from the Main Canal.

Fig. 6.28a pH and concentrations of sodium, potassium and manganese ions along a transect across three peat cuttings and two canals in the pNNR.

Fig. 6.28b Electrical conductivity (K_{corr}) and concentrations of calcium, magnesium and iron ions along a transect across three peat cuttings and two canals in the pNNR.

Before 1920, when the Dutch were cutting peat, water was pumped into the Main Canal from the Durham Warping Drain over which it crossed by an aqueduct (Goode 1973; Chapter 2); this may also explain the relatively high concentrations of cations in the canal waters.

The presence of clay below the vegetation in the canals (probably originally used by the Dutch to line the canals; Chapter 4) is another factor which may have contributed to the high recorded cation concentrations. Although clay was found only at some places in canal 1 and canal 3 (Chapter 4), the relatively high cation concentrations recorded from the whole Dutch Canal System suggest that it may have been dumped in all the canals.

The Dutch horse-drawn barges (Chapter 2) probably caused mixing of the canal waters, to a certain extent, resulting in a more even distribution of cations.

Water running off from the hard core of the tramway which runs parallel to canal 6 in both the Northern and Southern Dutch Canal Systems may have influenced the water chemistry in these canals.

6.6.4 The influence of the canal waters on the water chemistry of the peat cuttings

6.6.4.1 Peat cuttings in the pNNR

At present the peat cuttings in the pNNR and the canals are hydrologically isolated by peat baulks c. 5 m wide which run along both sides of all canals. Some water may flow from the canals into the cuttings (e.g. 3/4E6; Fig. 6.28) by way of deep ditches in the baulks but the water level in the canal has to be very high for this to occur. There are no deep ditches in the baulks near the main study sites; this, together with the fact that concentrations of ions in 3/4E6 were no greater than in 3/4W6 and 4/5W6 (Fig. 6.28), suggest that the current influence of canal water on the water chemistry of the study sites is likely to be minimal.

In the past, however, a great quantity of water from the canals may have entered the cuttings of the pNNR. Before 1920, when barges were used, the water level in the canals was much higher than in adjacent peat cuttings (Chapter 2). The shallow ditches, perpendicular to the canals, which regularly cross the baulks (which are parallel to the canals) were probably cut sometime after 1920 when the Dutch abandoned peat cutting in the area. The cutting of these ditches, the bases of which are now well above the water level in the peat cuttings, will probably have caused much water to flow into the cuttings.

The nutrients in this water may since have dispersed within each compartment of peat cuttings between the canals.

An influx of canal water, therefore, sometime after 1920 may explain the fact that the concentrations of ions recorded in peat waters from the cuttings were greater than those characteristic of ombrotrophic mires. The differences between the water chemistry of the study sites (6.3.10) may be explained by variation in the quality and quantity of nutrient-rich water which flowed into the cuttings. The generally higher concentrations of ions in the sites of the 2/3W transect (2, 3 and 4) may be explained by a second influx of canal water owing to further breaching of the canals, when the western section of the pNNR was cut for the second time.

6.6.4.2 Study sites 1. JA and 7. EP

The *Juncus effusus* area (JA) may receive water from the eastern extension of Main Canal North, which is incompletely dammed, flows eastwards into Mill Drain and comprises the northern boundary of this cutting. Flooding of JA by water from Main Canal North probably explains the relatively high concentrations of ions recorded in this cutting.

The Experimental Plot (EP), isolated from the canals by the Southern Boundary Drain, has probably never been inundated by water from the canals.

6.6.5 Conclusions

1. Differences in the chemical composition of the canal waters may be related to variation in:

a) the influence of the chalk rubble towpath along the Main Canal and the tramway which runs parallel to canal 6;

b) the dispersion of water from the Durham Warping Drain;

c) the distribution of clay used to line the canals.

2. The pH, conductivity and concentrations of the major cations in the canal waters were similar to, or somewhat greater than those recorded at the peat cutting study sites.

3. The concentrations of iron, manganese and nitrogen were similar to or lower than those recorded at the peat cutting study sites.

4. At present, little water is thought to flow from the canals into the peat cuttings of the pNNR.

5. A former influx of canal water may explain the relatively high concentrations of ions measured at the peat cutting study sites in the pNNR.

6. The water chemistry at site 1. JA may be accounted for by the flooding of this cutting by water from Main Canal North.

7. The chemistry of the peat waters in EP (site 7) cannot be accounted for by inundation by canal waters.

6.6.6 The relationship between water chemistry and vegetation in the canals

6.6.6.1 Vegetation of the sample sites

Table 6.7 shows the vegetation of the sample sites; the water chemistry of the sample sites is shown in Figs. 6.22-6.27. The sample sites are listed and discussed in order of decreasing pH and concentrations of calcium.

Table 6.7 Vegetation of canal sample sites (Fig. 6.21). Full descriptions of the canal vegetation noda are given in 3.5. The distribution of the noda is described in Fig. 3.9.

sample site number	sample site location	canal (C) nodum number
20	N. of canal 4	1
31	S. of canal 4	4
30	S. of canal 3	4
29	S. of canal 2	3
28	S. of canal 1	3
18	N. of canal 2	2
13	Main Canal, E. of New Cut	2
22	Main Canal, between canals 5 and 6	2
12	Main Canal, W. of New Cut	2
21	N. of canal 5	2
17	N. of canal 1	6
14	Main Canal, between canals 3 and 4	6
19	N. of canal 3	6
32	S. of canal 5	5
25	N. of canal 6	5
33	S. of canal 6	5

Nodum C1:

Many of the plant species which characterize nodum C1 and occur in the north of canal 4 are consistent with the relatively high pH (≥6) and concentrations of the major cations (e.g. 16-24 mg/l calcium) recorded at site 20. Plants such as *Juncus articulatus, Phragmites australis, Carex acutiformis* and *Equisetum fluviatile*, for example, dominant in this nodum, are characteristic of base-rich mires in Britain (cf. Wheeler 1980b).

Nodum C4:

At the south of canals 3 and 4, where vegetation of nodum C4 occurs, the pH (5-≥6), conductivity and concentrations of the major cations were generally somewhat lower than those associated with vegetation of nodum C1 (e.g. 8-24 mg/l calcium). The presence of *Carex elata, Lycopus europaeus, Hydrocotyle vulgaris* and *Sphagnum subnitens* which characterize nodum C4, may indicate these more mesotrophic conditions (cf. Wheeler 1980b).

Schoenoplectus tabernaemontani, also characteristic of nodum C4, may reflect the relatively high concentrations of sodium (10-20 mg/l) measured at the sample sites.

Nodum C3:

Vegetation of nodum C3, occurring at the south of canals 1 and 2, is also characterized by plants found in base-rich mires, for example, *Cirsium palustre*, *Carex elata* and *Salix repens* (cf. Wheeler 1980b). A high proportion of *Vaccinium oxycoccus*, *Sphagnum cuspidatum* and *Potamogeton polygonifolius*, however, may reflect the fact that the pH (4-6) and concentrations of cations (e.g. 8-16 mg/l calcium) were generally lower in sample sites 28 and 29 than in noda C1 and C4 type vegetation (cf. Proctor 1974).

Nodum C2:

The chemical composition of waters from canals 2 and 5 and the Main Canal where nodum C2 vegetation occurs was similar to that of waters associated with vegetation of nodum C3. Nodum C2, however, is characterized by *Cardamine pratensis*, *Hydrocotyle vulgaris*, *Galium palustre* and *Potentilla palustris* (plants of mesotrophic mires) as well as *Sphagnum recurvum* and *Sphagnum squarrosum*.

Nodum C6:

The reedswamp vegetation which characterizes and dominates nodum C6 and occurs in sample sites in the north of canals 1 and 3 and the Main Canal is associated with some of the lowest pH values (4-6) and cation concentrations (e.g. 8-16 mg/1 calcium) recorded from the canals. This vegetation consists of dominant *Glyceria maxima, Phalaris arundinacea* and *Typha latifolia* with *Phragmites australis* and *Cladium mariscus*. Some of these species are known to occur in a wide range of chemical conditions. *Phragmites australis*, for example, grows in waters at Parys Mountain, Anglesey, where pH values of 1.8 have been recorded and *Typha latifolia* frequently occurs in poor fens e.g. in the Cheshire 'schwingmoors' (see Table 6.3). However, the usual restriction of *G. maxima* and *P. arundinacea* to rich fens (cf. Wheeler 1980a) makes the occurrence of this group of species in an oligotrophic canal of particular interest.

Nodum C5:

In canal 6 and the south of canal 5 the presence of plants such as *Calamagrostis canescens, Lythrum salicaria* and *Potentilla palustris* which characterize nodum C5 is consistent with the pH (4-6) and cation concentrations (e.g. $\leqslant$ 16 mg/1 calcium) recorded at sample sites 25, 32 and 33. The increased dominance of *Calluna, Drosera rotundifolia* and *Eriophorum vaginatum* in nodum C5 may reflect the fact that in general the lowest pH values and concentrations of the major cations were recorded at sample sites containing this vegetation type.

In all vegetation noda of the canals plants such as *Calluna vulgaris*, *Erica tetralix* and *Aulacomnium palustre*, normally found in poor fens or bogs, co-exist with plants characteristic of base-rich mires; this suggests that small scale variation in chemical conditions may occur in the canals.

6.6.6.2 Conclusions

1. Differences in the vegetation noda of the canals are, to a certain extent, reflected in the chemical conditions recorded at the sample sites.

2. The distribution of the vegetation noda in the canals cannot entirely be explained by differences in water chemistry.

3. The co-existence of plants which occur in both rich fens and bogs, in all vegetation noda, may reflect small scale variation in chemical conditions.

6.7 CHEMICAL STRATIFICATION OF INTERSTITIAL PEAT WATER IN PEAT CUTTINGS AND A CANAL

6.7.1 Methods

In order to examine the chemical stratification of the peat waters in canal 3 and peat cuttings JA, 4/5W4 and EP, water samples were taken at 10 cm intervals to a depth of 150 cm below the peat surface. Small samples of water (c. 50 ml) were taken at increasing depths with a sampling device shown in Appendix 4. The sampler was rinsed with surface water between the collection of successive samples because it was considered that these would be more dilute than those within the peat (cf. Sjörs 1950). The water samples, collected on 26 May 1982, were analysed for pH, the major cations, iron and conductivity (Appendix 4).

6.7.2 Results and discussion

The chemical stratification of the peat waters is shown in Fig. 6.29. In canal 3 there was a peak in pH, conductivity and concentrations of the major cations between 20-35 cm; this probably reflects the chemical composition of the clay used to line the canals (6.6.3). Below this depth, concentrations of calcium and magnesium were consistently higher than those recorded in the other profiles; this is also reflected in the high pH and conductivity values. Below 100 cm the high ionic concentrations may reflect the proximity of the underlying clay (Chapter 4).

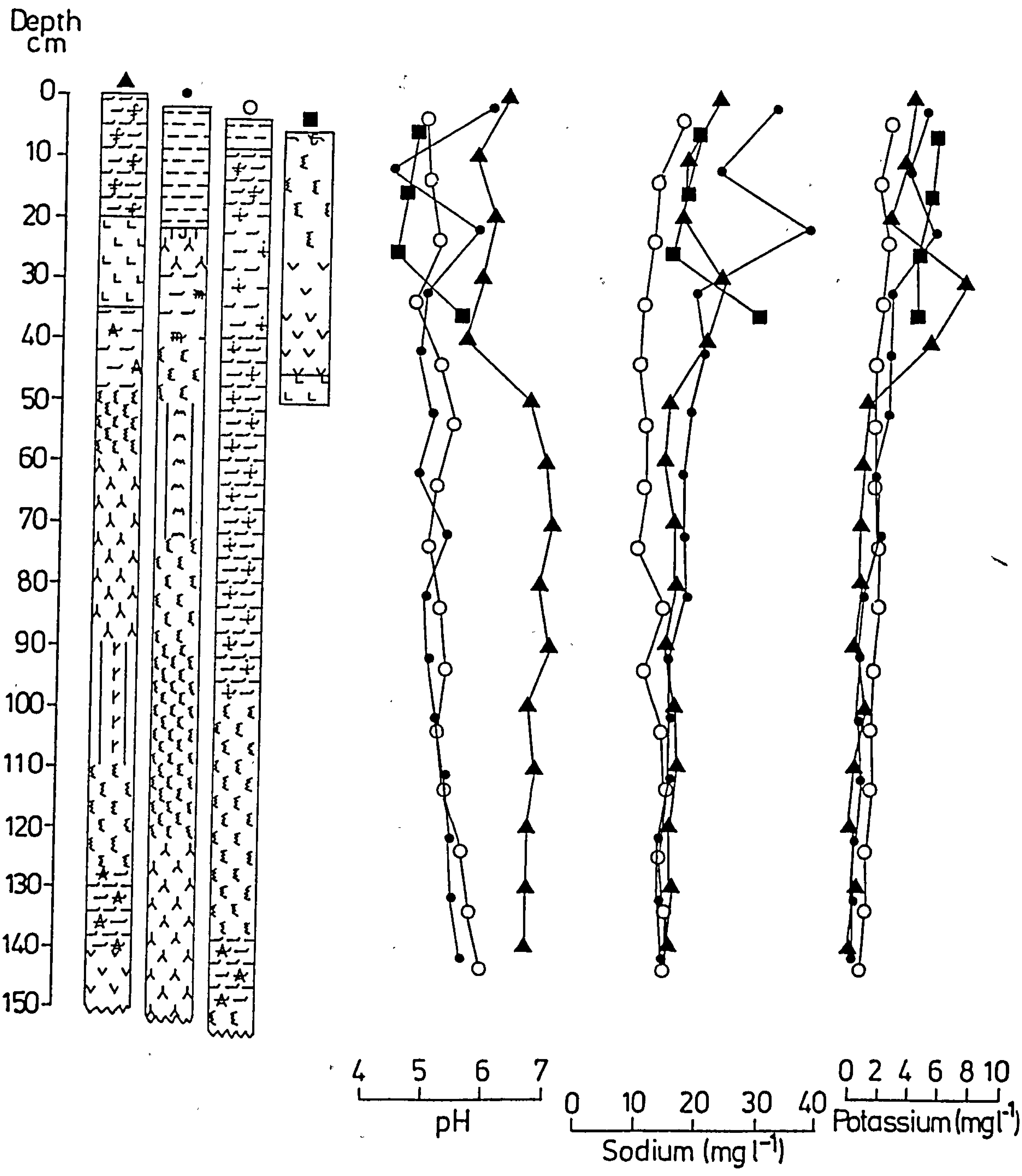


Fig. 6.29a Chemical analyses of peat waters from the upper 150 cm of peat in canal 3 (▲), JA (●), 4/5W4 (O) and EP (■). A key to the stratigraphy symbols is given in Fig. 4.2. The graphs are staggered for clarity.

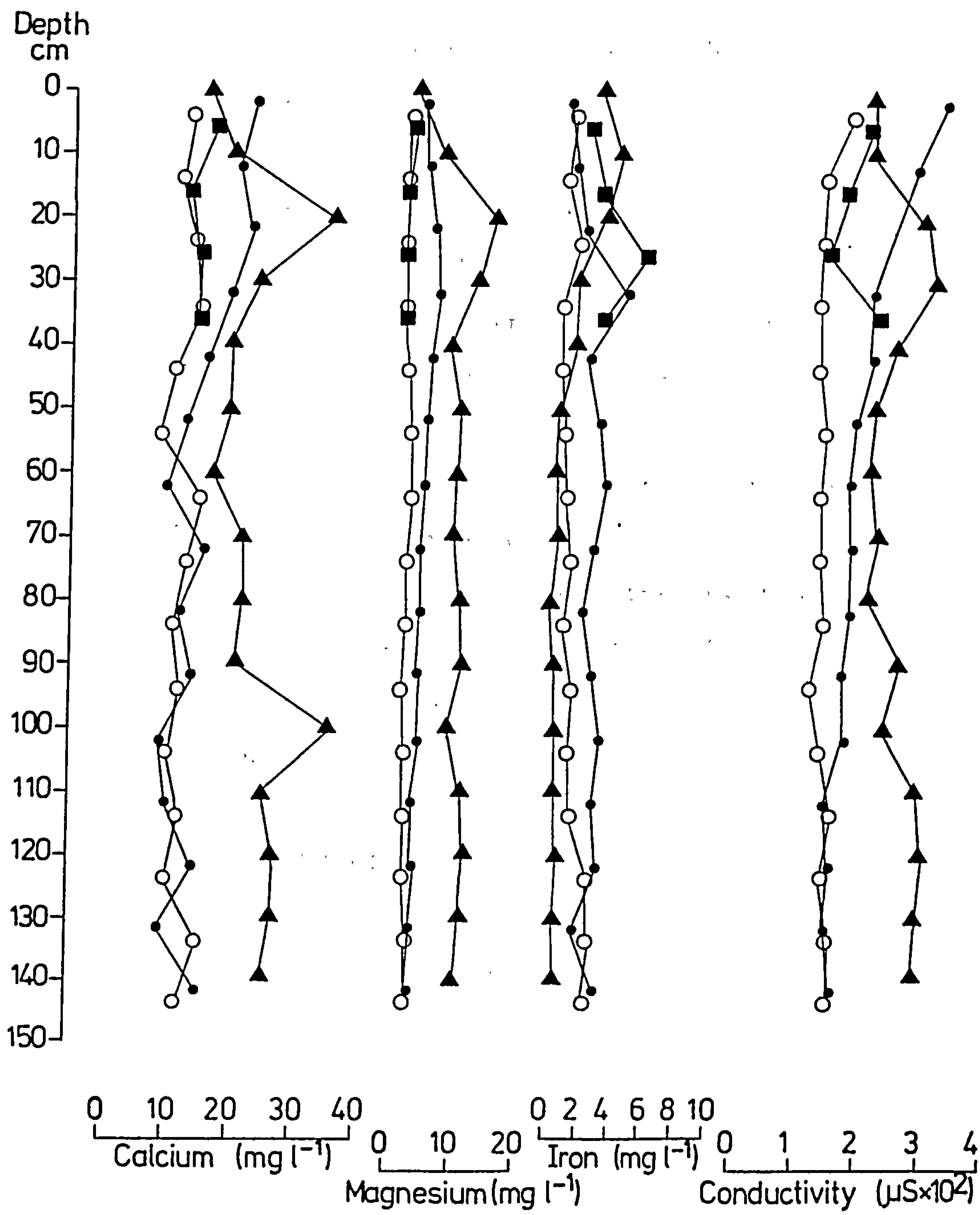


Fig. 6.29b Chemical analyses of peat waters from the upper 150 cm of peat in canal 3 (▲), JA (●), 4/5W4 (○) and EP (■). The graphs are staggered for clarity.

Subsequent to the invasion of *Phragmites*, associated with a peak in calcium concentration at 100 cm, the high ionic concentrations may represent recycling from below by the vegetation (cf. Chapman 1964).

In JA concentrations of ions were generally greater towards the surface of the profiles. This suggests that the relatively high concentrations of ions recorded from surface peat waters (6.3) may represent comparatively recent changes in water chemistry. The relatively low pH and sodium concentration in JA at 10 cm may indicate stratification of the water above the peat surface in this cutting (Fig. 6.29a).

In 4/5W4 the conductivity and concentrations of cations were somewhat higher towards the surface of the profiles. The significance of this small surface peak in cation concentrations is uncertain because only one set of samples was collected from each profile.

In EP, the high pH, conductivity and concentrations of sodium and iron at the base of this cutting probably reflect the proximity of the underlying clay.

6.7.3 Conclusions

1. Relatively high cation concentrations in canal 3 are associated with the clay used to line the canals.

2. The relatively high cation concentrations recorded at site 1. JA (6.3) may represent comparatively recent changes in water chemistry.

3. In EP (site 7; 6.3) the relatively high concentrations of ions in the waters of the surface peats probably reflect the proximity of the underlying clay.

CHAPTER 7

THE EFFECT OF BISULPHITE POLLUTION ON *SPHAGNUM* SPECIES

7.1 INTRODUCTION

7.1.1 The *Sphagnum* flora of Thorne Moors

At present, the only *Sphagnum* species widespread on Thorne Moors are *S. recurvum*, *S. cuspidatum* and *S. fimbriatum*; other species, including *S. papillosum*, *S. subnitens* and *S. capillifolium*, are scarce (Chapter 3). Stratigraphical studies (Chapter 4), however, suggest that *Sphagnum* species such as *S. imbricatum*, *S. papillosum*, *S. magellanicum* and members of *Sphagnum* sect. *Acutifolia* were once widespread in the area.

A decline in the frequency of *Sphagnum* spp. has been observed in various areas of Britain, notably the Southern Pennines (Tallis 1964). Reasons put forward in the literature to account for the disappearance of species from contemporary peatland surfaces include a decrease in oceanicity of climate (Godwin & Conway 1939), a decrease in the height of the water table (King & Morrison 1956), biotic activities, particularly burning and grazing (Pearsall 1956) and atmospheric pollution (Tallis 1964).

In Chapter 4 it was suggested that *Sphagnum* species currently absent from the site, *S. imbricatum* and *S. magellanicum*, recolonized cut-over surfaces abandoned around 1920. As these species apparently survived the partial drainage of the site, through peat cutting activities, it was decided to determine whether atmospheric pollution could account for their disappearance.

7.1.2 Sulphur pollution

Ferguson, Lee & Bell (1978) and Ferguson & Lee (1979, 1980) have demonstrated that the growth of a number of *Sphagnum* species is sensitive to sulphur pollutants within the range of concentrations found in Great Britain today.

Sulphur pollutants include, and are derived from, sulphur dioxide produced as a result of the combustion of fossil fuels (Spedding 1974).

The distribution of ionic species in SO_2 solutions is markedly pH-dependent (Puckett *et al.* 1973). Although the pH of rain varies according to the other substances dissolved in it, it is generally between pH 4 and 6 (Clymo 1963; Spedding 1974); within this range SO_2 solution products are primarily in the form of bisulphite (Puckett *et al.* 1973). In a mire, therefore, where low pH values prevail, SO_2 solution products will meet the vegetation in the form of HSO_3^-, SO_4^{2-} and as dry SO_2 and SO_4 (Ferguson, Lee & Bell 1978).

Ferguson & Lee (1979, 1980) have shown that the growth and rates of photosynthetic oxygen evolution and carbon fixation in *Sphagnum* species can be reduced by additions of bisulphite. By contrast, additions of sulphate had no effect on the rate of photosynthesis in *Sphagnum* species and caused a reduction in growth rate only when in concentrations of 480 mg/l. The effect of the deposition of dry SO_2 and SO_4 is not well understood but it is likely to contribute substantially to the total concentration of sulphur compounds dissolving on plant surfaces (Ferguson, Lee & Bell 1978).

Thorne Moors are placed such that they will receive an appreciable level of sulphur pollution. The Drax power station is situated c. 10 km from the site. Thorne Moors are also situated down wind of Sheffield, Rotherham and Doncaster.

7.1.3 Specific objectives

To determine whether bisulphite pollution could account for the current low diversity of *Sphagnum* species it was decided to measure the concentration of this ion in the rainwater at Thorne Moors. In addition, several species of *Sphagnum* were re-introduced onto Thorne Moors from a site in the north of England and their growth was monitored.

7.2 THE CONCENTRATION OF BISULPHITE IN RAINWATER AT THORNE MOORS

7.2.1 Methods for the determination of the concentration of bisulphite in rainwater

Eight samples of rainwater collected at Thorne Moors between March and December 1981 were analysed for bisulphite concentration. Full details of the methods used are given in Appendix 5.

7.2.2 Results

Mean and range of concentrations of bisulphite (HSO_3^-) in rainwater (mg/1) collected at Thorne Moors between March and December 1981:

mean	range
5.78	4.80 - 6.36

7.2.3 Comparison with concentrations of bisulphite recorded from other areas.

The concentrations of bisulphite recorded from Thorne Moors were somewhat lower than those recorded from other areas. Davies (1976), for example, recorded at least nine individual 'rain events' in Sheffield between October 1969 and March 1970 with mean bisulphite concentrations of more than 40 mg/1, one in excess of 162 mg/1 and, over a slightly longer period, 32 of more than 17 mg/1. In Brussels, 20 mg/1 of bisulphite was recorded by Meurrens (1974). The difference between these bisulphite concentrations and those recorded at Thorne Moors may reflect the fact that Thorne Moors are situated somewhat further from major sources of sulphur dioxide pollution than these cities. However, the concentrations of bisulphite recorded from Thorne Moors were of a similar magnitude to those measured from samples of Manchester rain although they fluctuated less: during 1975-1976 a range of bisulphite concentrations were recorded from 0-12 mg/1, with a mean of c. 2 mg/1 (Ferguson & Lee 1980).

7.3 THE INTRODUCTION OF SPECIES OF *SPHAGNUM* ONTO THORNE MOORS

7.3.1 Materials and methods

Various *Sphagnum* species were collected from Butterburn Flowe, Northumberland on 30 March 1981. Large polythene sacks were used to transport the specimens. The Sphagna were 'replanted' on Thorne Moors within 48 hours of collection, having been stored meanwhile under refrigeration at 4^{o}C (cf. Clymo 1963).

Pre-cut lengths of *Sphagnum* were packed into cylinders of 'netlon' (mesh size 12 mm) 22.5 cm in length, 12 cm in diameter and open at each end so as to offer the minimum resistance to lateral or vertical water movements. For each species, an attempt was made to make the number of shoots in each cylinder correspond to the natural density of the plants. A constant length of netlon was left protruding above the level of the *Sphagnum* in each cylinder. Dead *Sphagnum* stems were inserted into the base of the cylinders both to support the plants and create a wick between the material in and below the cylinders.

The cylinders were incorporated into *Sphagnum* hummocks and lawns (mostly of *Sphagnum fimbriatum* and *S. recurvum*) in one peat cutting (4/5W4). An attempt was made to position each species at a height in relation to the water table corresponding to that at which the species in the cylinder is normally found. To test the effect of transplanting, controls consisting of cylinders containing pre-cut lengths of *Sphagnum fimbriatum* from Thorne Moors were also incorporated into the peat cutting.

In the case of *Sphagnum cuspidatum*, plants were placed in areas of open water enclosed by netlon cylinders c. 30 cm in diameter. Control plants from Thorne Moors consisting of *S. cuspidatum* and *S. recurvum* (which had a more aquatic habit than the material from Butterburn Flowe) were placed in similar cylinders.

The growth of the *Sphagnum* plants was assessed by measuring the mean increase in length of the plants in each cylinder (cf. Chapman 1965; Clymo 1970; Ferguson & Lee 1980). This value was obtained by calculating the mean decrease in the amount of netlon protruding at the top of each cylinder. Measurements were taken 8, 14 and 23 months after the *Sphagnum* was transplanted. In the cylinders containing *S. cuspidatum* and the *S. recurvum* from Thorne Moors, the survival or otherwise of the plants only was recorded.

Notes were taken on the general condition of all transplanted material throughout the investigation.

7.3.2 Results

Table 7.2 Mean increase in length per month as a percentage of the previously measured increase in length (see Table 7.1).
* Damaged by fire.

Sphagnum species	between 8 and 14 months	between 14 and 23 months
S. capillifolium	7.2	7.8
S. fimbriatum (from Thorne)	4.2	-*
S. magellanicum	1.0	1.0
S. papillosum	1.0	2.9
S. subnitens	4.3	0.3
S. recurvum	0	0

Table 7.1 shows that all the transplanted material survived except the *Sphagnum cuspidatum* from Butterburn Flowe which was not re-found and presumed to have died. Most species increased in length over the period of investigation, the highest growth rates occurring during the first 8 months after transplanting. Thereafter, all species exhibited a reduced rate of increase in length (Table 7.2). Between 8 and 23 months the mean increase in length per month of *S. capillifolium* was maintained at a relatively high rate when compared with the other species. *S. magellanicum* also maintained its growth rate between 8 and 23 months, although at a relatively low rate (Table 7.2). There were some indications that *S. capillifolium* and some of the *S. magellanicum* may

Sphagnum species	original length (cm)	number of cylinders	increase in length (cm): 2 December 1981 mean	2 December 1981 range	25 May 1982 mean	25 May 1982 range	8 March 1983 mean	8 March 1983 range
S. capillifolium+	15	3	3.0	2.5-3.5	4.3	3.5-5.0	7.3	6.0-10.0
*S. fimbriatum** (from Thorne)	18	2	2.0	1.0-3.0	2.5	1.0-4.0	2.0	0.0- 4.0
S. magellanicum	15	8	3.1	2.2-4.0	3.3	2.2-5.0	3.6	2.3- 6.0
S. papillosum+	15	5	3.2	2.4-4.0	3.4	2.5-4.0	4.3	2.5- 6.0
S. subnitens+	8	4	2.7	1.7-4.0	3.4	2.0-4.0	3.5	2.0- 4.0
*S. recurvum**	15	1	7.0	-	7.0	-	7.0	-
			condition of transplanted material					
*S. recurvum** (from Thorne)	-	1	thriving		thriving		thriving	
*S. cuspidatum**	-	2	not survived		not survived		not survived	
*S. cuspidatum** (from Thorne)	-	2	thriving		thriving		thriving	

Table 7.1 The increase in length of *Sphagnum* plants introduced onto Thorne Moors on 1 April 1981 after approximately 8, 14 and 23 months.

* common at Thorne Moors

\+ occasional at Thorne Moors

eventually be shaded out by faster growing *S. fimbriatum* surrounding the cylinders. Some cylinders containing these species were also being invaded by *Polytrichum commune*.

The mean increase in length per month of *S. papillosum* was higher between 14 and 23 months than between 8 and 14 months. This species and *S. subnitens* which, by contrast, exhibited a marked reduction in growth rate after 14 months, were colonizing areas outside the cylinders.

S. recurvum increased by 7.0 cm over the first 8 months but showed no further increase in length. The mean length of the *S. fimbriatum* controls from Thorne appear to have decreased between 14 and 23 months after transplanting (Table 7.1). This is because one of the cylinders was badly burnt by the fire on 2 June 1982. The burnt material in the cylinder, however, has since been recolonized by *S. fimbriatum*.

7.4 BISULPHITE POLLUTION AND THE GROWTH OF *SPHAGNUM* SPECIES

Ferguson, Lee & Bell (1978) and Ferguson & Lee (1980) have demonstrated that concentrations of bisulphite between c. 4 and 8 mg/l reduce the growth (measured as mean increase in length) of *Sphagnum tenellum, S. imbricatum, S. papillosum, S. capillaceum* (which was taken to include *S. capillifolium*), *S. cuspidatum* and *S. magellanicum.* By contrast, *S. recurvum* was found to be more resistant to bisulphite; this moss withstood bisulphite concentrations of up to c. 40 mg/l before a significant reduction in growth occurred. It is possible, therefore, that the concentrations of bisulphite in the rain at Thorne Moors (4.80-6.36 mg/l) may explain the disappearance of *S. imbricatum* (a species found by Ferguson & Lee (1980) to be particularly sensitive to bisulphite pollution) and *S. magellanicum* from the site and the current scarcity of *S. capillifolium, S. papillosum* and *S. subnitens.* The observations of Ferguson & Lee (1980) are also consistent with the current dominance of *S. recurvum* at Thorne Moors. They do not, however, explain the current status of *S. cuspidatum*, another species widespread on The Moors. It may be that this species survives by growing in aquatic conditions. Bisulphite in solution oxidizes fairly rapidly to sulphate, having a half-life of about 5.5 hours (Ferguson, Lee & Bell 1978), so that *S. cuspidatum* may be exposed to lower concentrations of HSO_3^- than the more terrestrial *Sphagnum* species.

Although the *Sphagnum* plants introduced onto Thorne Moors on 1 April 1981 were still alive (with the exception of the *S. cuspidatum* from Butterburn Flowe) 23 months later, all species exhibited a marked reduction in growth after 8 months. The fact that the growth rates of *S. fimbriatum* and *S. recurvum* (currently widespread on The Moors) were amongst the lowest recorded, suggests that the results may be accounted for by an effect of transplanting the material. There is no evidence, therefore, as to whether the concentrations of bisulphite recorded in the rain had any affect on the growth of the introduced *Sphagnum* plants. However, it is possible that the shading out of *S. magellanicum* and *S. capillifolium* (species particularly sensitive to bisulphite pollution; Ferguson & Lee 1980) by *S. fimbriatum* and the invasion of *S. capillifolium* by *Polytrichum commune* may reflect the effect of bisulphite pollution.

These findings are in contrast to those of Ferguson & Lee (unpublished) who observed the growth of *Sphagnum* species introduced onto Holme Moss, near Manchester from the Berwyn Mountains, N. Wales. After 6 months they found that the rate of growth of *S. imbricatum, S. capillifolium* and *S. magellanicum* had decreased substantially (compared to control material in the Berwyn Mountains); after 18 months no further growth had occurred. However, the rate of growth of *S. recurvum* was comparable to that observed in control material of this species in the Berwyn Mountains.

It is not known why the *S. cuspidatum* from Butterburn Flowe died. It may be that this was an ecad of the species which was unable to tolerate the chemical composition of the peat waters at Thorne (cf. Green 1968; Chapter 6).

Concentrations of bisulphite in the rain at Thorne Moors were probably much higher during and at times since the Industrial Revolution than those recorded in the present investigation (cf. Tallis 1964; Spedding 1974). This may explain the current low diversity of *Sphagnum* species on the site and may partly account for the survival, to date, of the *Sphagnum* plants introduced to the site.

Stages in the sexual reproduction of *Sphagnum* may be particularly susceptible to sulphur pollution. In the Sheffield area, fruiting *Sphagnum* could not be found until 6 years ago; fruiting may have resumed as a result of decreased pollution resultant on the Clean Air Acts (Dr D J Read, personal communication). Additional studies need to be carried out, however, before further comment can be made on these suggestions.

7.5 CONCLUSIONS

1. The concentration of bisulphite in the rainwater may explain the disappearance of *Sphagnum imbricatum* and *S. magellanicum* from Thorne Moors, the current low diversity of *Sphagnum* species and the dominance of *S. recurvum* at the site.

2. There is no evidence that the growth of *Sphagnum* species introduced onto Thorne Moors was substantially affected by the concentrations of bisulphite recorded in the rain.

3. Higher concentrations of bisulphite in the rain during, and at times since the Industrial Revolution, and the possibility that stages in the sexual reproduction of *Sphagnum* species are particularly susceptible to sulphur pollution may explain the survival of the transplanted material and the current low number of species of this genus.

CHAPTER 8

THE MAIN FLORISTIC FEATURES OF THE RE-VEGETATED PEAT CUTTINGS

Factors affecting the main floristic features of the re-vegetated peat cuttings are assessed here, with some emphasis on the dominant species (*Sphagnum recurvum, Eriophorum vaginatum, Juncus effusus* and *Betula pubescens*); the age of the peat cuttings is also discussed. In addition, attention is paid to the recolonization and present distribution of the vegetation in the canals.

8.1 THE AGE OF PEAT CUTTINGS

In addition to the effects of hydrological and chemical factors, the composition of the present vegetation of the peat cuttings at Thorne, and hence the distribution of vegetation noda in the pNNR, may be determined by the time which has elapsed since the peat cuttings were abandoned.

The Southern Dutch Canal System was probably worked from west to east between 1870-c. 1920; subsequent to abandonment, the peat baulks were removed from the western section of the pNNR (2.7; Fig. 8.1). The oldest part of the cutting complex, therefore, probably occupies the centre of the pNNR. This is also where the most species-rich cuttings are now found. For example, AC nodum 10 (*Vaccinium-Andromeda*) is confined to the centre of the pNNR (Fig. 3.8). It is characterized by dominant *Andromeda polifolia* and *Vaccinium oxycoccus* and also contains *Eriophorum* spp., and four species of *Sphagnum: S. recurvum, S. cuspidatum, S. fimbriatum* and *S. papillosum* (3.4). In some other noda *Andromeda polifolia, Vaccinium oxycoccus* and *Sphagnum papillosum* are extremely infrequent;

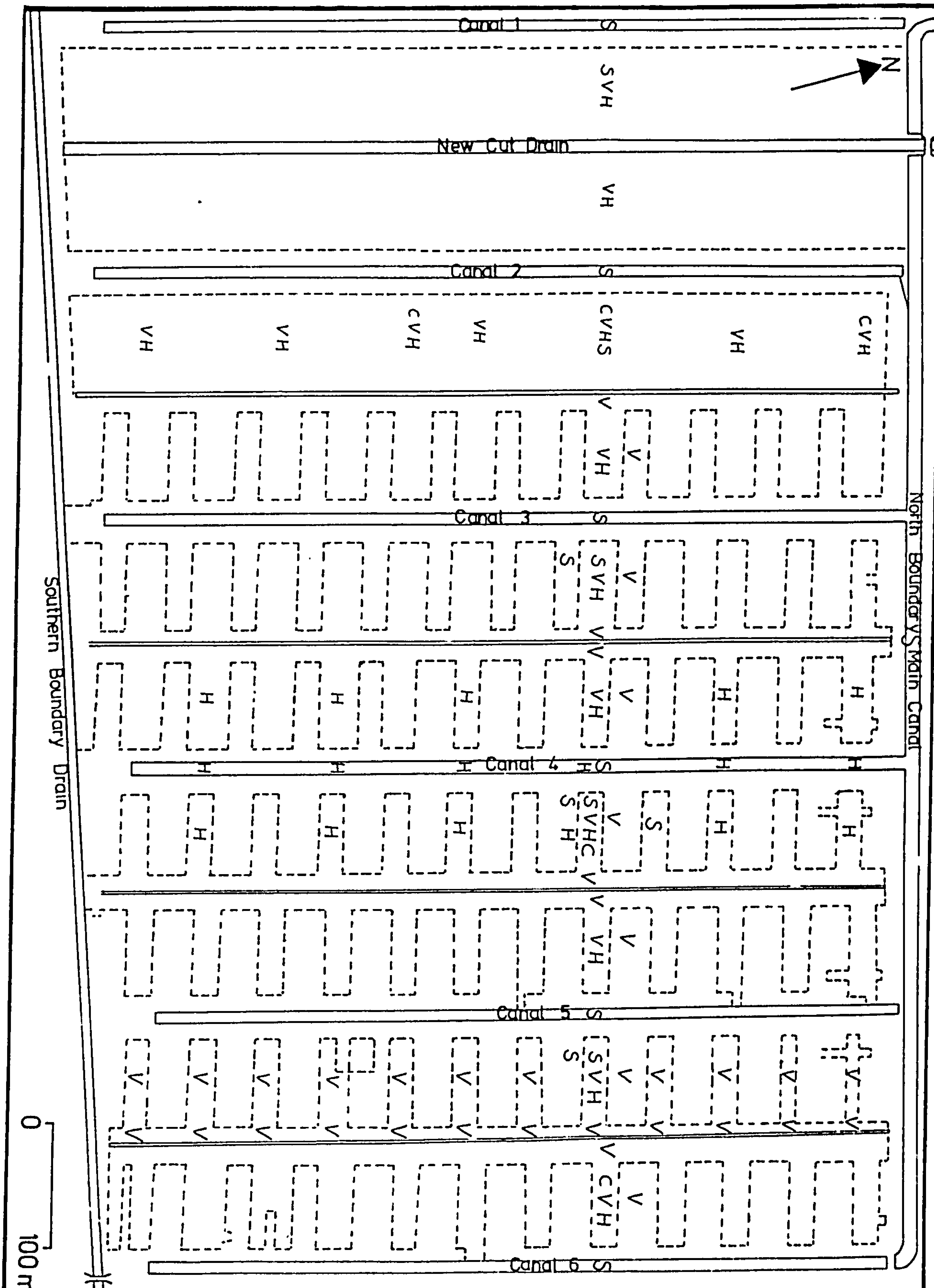


Fig. 8.1 Location of major sample sites selected for investigations into the vegetation (V; Figs. 3.3 and 3.4), stratigraphy (S; Fig. 4.1), hydrology (H; Figs. 5.1 and 5.3) and water chemistry (C; Fig. 6.1) of the pNNR.

for example, in AC noda 4 (*Eriophorum angustifolium-Sphagnum*) and 7 (*Sphagnum fimbriatum-S. cuspidatum*) which occur only east of canal 5 and west of the drain between canals 2 and 3 (Fig. 3.8). The presence of these species in the centre of the pNNR may well reflect the greater age of the cuttings.

The fact that the peat baulks were cut from the western portion of the pNNR some years after the area was worked initially means that the age of re-vegetated areas in this section varies. As it is not easy to determine with certainty the exact areas which comprise the original cuttings, it is difficult to comment on the relationship between the vegetation noda and the time of abandonment of this area. In any case it is likely that the re-cutting involved some disturbance to the established vegetation. Nevertheless areas occupied by vegetation of AC nodum 3 (*Eriophorum vaginatum-Sphagnum recurvum-Vaccinium*) and AC nodum 5 (*Andromeda-S. recurvum*) probably comprise the original cuttings (Fig. 3.8).

The low diversity of the vegetation currently established in the Experimental Plot (EP ; 3.3), abandoned 11 years ago, again mainly reflects the age of this cutting. This suggests that the recolonization of 'modern' peat cuttings, which comprise large areas of Thorne Moors (Fig. 1.2), is an extremely slow process. Additional support for this idea comes from observations on small, rectangular (3 m x 2 m) peat cuttings dug in EP to a variety of depths between 5 and 25 cm from the peat surface during the summer of 1981. Eighteen months later, no plants had recolonized these areas. The underlying clay may conceivably exert an adverse influence on recolonization in this shallow cutting (Chapters 4 and 6). However, similar peat cuttings dug on undisturbed parts of Glasson Moss, Cumbria (Chapter 9) which were surrounded by vegetation characteristic of undisturbed raised bogs were similarly devoid of vegetation eighteen months after excavation.

8.2 THE ABUNDANCE OF *SPHAGNUM RECURVUM*

Sphagnum recurvum is the most abundant species of the genus at Thorne Moors, occurring in all vegetation noda except AC nodum 1 (*Pteridium-Campylopus*; 3.4). This moss has been noted to be a colonizer of wet peat cuttings in many mires e.g. Llyn Mire, Wales (Moore & Beckett 1971), the Duddon Mosses, Cumbria (Lindsay 1978) and the Cheshire 'schwingmoors' (Green & Pearson 1968; Tallis 1973b); see also Chapter 9.

As indicated previously (6.3.13), *S. recurvum* is a species of wide tolerance as regards its mineral status. At Thorne Moors its occurrence has been shown to be consistent with the chemical composition of the peat water; this was found to have greater chemical affinities with a weakly minerotrophic mire than with an ombrotrophic mire, in consequence of various sources of enrichment (Chapter 6). It seems likely that the dominance of *S. recurvum* in peat cuttings on other cut-over sites is also associated with their water chemistry; the drainage of peatland areas associated with peat cutting activities is likely to increase the electrical conductivity of the peat water (6.3.12) even in mires otherwise completely isolated from sources of enrichment.

Sphagnum recurvum also exhibits a wide tolerance as regards the height of the water table (5.8). However, it has poor desiccation tolerance compared with other species of *Sphagnum* (Green 1968). An inability to withstand low summer water tables in competition with more resistant members of *Sphagnum* sect. *Acutifolia* and *S.* sect. *Sphagnum* may account for its absence from undisturbed raised mires (Green & Pearson 1968). An increase in the height of the water table relative to the peat surface produced by the removal of peat may therefore be a further factor which accounts for the abundance of this species in flooded peat cuttings.

Other factors which also help explain the dominance of *S. recurvum* at Thorne Moors include its relatively rapid growth rate (Green 1968) and its tolerance to sulphur pollutants (Chapter 7).

8.3 THE DOMINANCE OF *ERIOPHORUM VAGINATUM*

Eriophorum vaginatum is present in all vegetation noda of the Dutch Canal System and dominant in AC noda 3 (*Eriophorum vaginatum-Sphagnum recurvum-Vaccinium*), 7 (*Sphagnum fimbriatum-S. cuspidatum*), 8 (*Erica-Eriophorum vaginatum-Sphagnum fimbriatum*) and 9 (*S. fimbriatum-S. recurvum*); 3.4. It is also abundant in other re-vegetated peat cuttings on Thorne Moors (Chapter 3; Fig. 1.2).

There is little information available on the precise conditions necessary for the establishment of *Eriophorum vaginatum* in the field. However, Wein (1973) notes that although this species can grow over a wide range of moisture conditions, the mature plant is a dominant component of peat communities that have a surface water table in the spring but which become drier in the summer (Tansley 1939). Gimingham (1964) also mentions that the water table in *E. vaginatum*-dominated communities can be high enough to flood the hollows between *E. vaginatum* tussocks in winter but that the upper horizons may dry out considerably in summer. It is likely, therefore, that *E. vaginatum* became established when the water table was somewhat lower than at present (Chapter 5).

Support for this observation comes from the suggestion of Tallis (1964) that *E. vaginatum* increases greatly during periods of dryness and in situations where the drainage has been improved; also Kuusipalo & Vuorinen (1981) observed that *E. vaginatum* became widespread owing to the influence of incomplete drainage on a drained peatland in Finland. Green & Pearson (1968) further consider that cotton grass 'stillstand' communities are characteristic of drained peat.

An overall increase in the height of the water table since the abandonment of peat cutting and the establishment of *Eriophorum vaginatum* in the pNNR may have been brought about by the effects of mining subsidence (2.9 and 5.5) and the recent hydrological 'sealing off' of the area (2.7 and Chapter 5). The partial drainage of the pNNR effected by Fisons Ltd. in the early 1970's (2.7) and the drought of 1976 are likely to have caused temporary reductions in the water table; this may have allowed further establishment of *Eriophorum vaginatum*.

Tallis (1964) observed that the growth habit of *Eriophorum vaginatum* appears to provide a very unfavourable habitat for the healthy growth of *Sphagnum*. Indeed, during the current investigation, it was noticed that *S. cuspidatum* and *S. recurvum* were often found on paths trampled in some stands of *Eriophorum vaginatum*. In view of this, it was decided to trample down the whole of the central section of an *E. vaginatum*-dominated cutting. This was effected by marching (twice) along the long axis of the peat cutting. To date, the *E. vaginatum* appears to be dying, probably because the integrity of the tussocks has been destroyed; *S. cuspidatum* and *S. recurvum* are colonizing open water areas between the tussocks. In this connection it is of interest that the loose, fan-like, senescent tussocks of *E. vaginatum* often have *Sphagnum* spp. and *Vaccinium oxycoccus* associated with them (Mr R A Lindsay, personal communication).

If the water table in the pNNR is maintained at its present level, *E. vaginatum* is unlikely to re-establish from seed and may eventually lose its current dominance. However, this plant is known to be extremely long lived, tussocks remaining active for over 100 years (Wein 1973). In addition *E. vaginatum* is relatively tolerant to burning, exhibiting renewed growth in response to released nutrients (NERC Unit of Comparative Plant Ecology, Survey III data).

8.4 THE DOMINANCE OF *JUNCUS EFFUSUS*

It was shown in 4.5 that *Juncus effusus* colonized the '*Juncus effusus* area' (JA on Fig. 1.2) relatively recently and it was suggested in 5.8 that the water table was relatively low at the time of establishment. The dry summer of 1976 may have allowed *Juncus effusus* to achieve its present dominance (5.8); it is likely that the drain which forms the northern boundary of this cutting (the eastern extension of Main Canal North; Fig. 2.2) caused the water table to fall somewhat below the peat surface.

Why *Juncus effusus* should have become dominant in JA (and another cut north of Mill Drain; 3.3) whilst *Eriophorum vaginatum* came to dominate much of the pNNR is not clear. Both plants may germinate and become established when the water table is at, or very close to the surface (Lazenby 1955; 8.3; cf. Rogers & Bellamy 1972), conditions which are thought to have occurred in both areas. The answer may lie in the fact that water probably flows through the *Juncus effusus* area from surrounding peat cuttings into the eastern extension of Main Canal North (5.5). The increased oxygen and nutrient supply associated with flowing water may have provided conditions more suited to the establishment of *J. effusus* than *Eriophorum vaginatum* (cf. Richards & Clapham 1941; Ingram 1967). The latter plant tends to occur in areas of stagnant rather than moving water (Gore & Urquhart 1966). Another possibility is that nutrients supplied by Black-headed gulls may have favoured the establishment of *J. effusus* (6.4). This is unlikely, however, because the use of this area as a nesting site by these birds was probably the result, rather than the cause of, the establishment of *J. effusus* (6.3).

As in the pNNR, an overall increase in the height of the water table may have occurred through mining subsidence (2.9 and 5.5). The dominance of the mature *Juncus effusus* plants may be maintained by oxygen and nutrients provided by water flowing through the area and, when the water table is high, by the flooding of this cutting with nutrient-rich water from the eastern extension of Main Canal North (6.4 and 6.6). The nutrients provided by Black-headed gulls probably also help to sustain these plants (6.4).

8.5 THE ABUNDANCE OF *BETULA PUBESCENS*

Betula pubescens is abundant in re-vegetated peat cuttings on Thorne Moors; it is present in all vegetation noda of the Dutch Canal System (Chapter 3). However, in the late 1960's it was not widespread in the pNNR (Dr D A Goode, personal communication).

For germination and establishment, *B. pubescens* requires a relatively low summer water table (Dr J G Hodgson, personal communication). It is likely, therefore, that the partial drainage of the pNNR by Fisons Ltd., during the early 1970's (2.7), caused the spread of this plant. Today *B. pubescens* can apparently withstand the wide range of water table conditions observed in the pNNR (5.8). However, in the deepest water areas there are signs that it is becoming moribund and dying.

8.6 THE RECOLONIZATION OF THE DUTCH CANALS

8.6.1 The flora of the Dutch Canals

The Dutch Canals have been recolonized by a diverse flora including species characteristic of both ombrotrophic and mesotrophic mires and maritime habitats (3.5). It was shown in 6.6.6 that the distribution of six vegetation noda in the Southern Dutch Canal System (Fig. 3.9) reflected, to a certain extent, the chemistry of the peat waters; the pH, conductivity and concentrations of the major cations were found to be similar to, or greater than those recorded at sites in peat cuttings in the pNNR owing to various sources of enrichment (6.6.3). The distribution of vegetation in canal 4 also reflected the height of the water table (5.8).

8.6.2 The introduction of the plants which recolonized the Dutch Canals

The Dutch Canals were probably recolonized by ombrotrophic species from the surrounding mire and by species introduced naturally (wind and animal dispersed seeds) and 'artificially', as a result of the peat cutting industry. The water pumped from the Durham Warping Drain into the Main Canal (2.7 and 6.6), for example, is likely to have contained seeds and fragments of wetland species, including maritime species (2.5 and 3.5), not originally present on the mire. Many wetland species (e.g. *Cladium mariscus*) have large seeds which float (Moore 1982); the movements of the Dutch peat barges (2.7) may have helped to transport seeds and plant fragments along the Main Canal and into the side canals. Seeds may also have been introduced into the canals in the warp clay (2.5) used to line the canals (2.7, Chapter 4, and 6.6) and by the horses which pulled the barges (2.7).

8.6.3 The distribution of vegetation in the Southern Dutch Canal System

The distribution of vegetation in the Southern Dutch Canal System (Fig. 3.9) may be explained by a variety of factors. The species introduced into different parts of the Dutch Canal System by the mechanisms mentioned above are likely to have varied; for example, there is likely to have been variation in the amount of water from the Durham Warping Drain reaching the side canals, and the barges are likely to have travelled along different canals at different times (2.7).

The pH, conductivity and concentrations of the major cations in the canal waters were probably greater when peat was being cut and transported along the canals than at present (6.6); when, for example, clay was dumped into the canals, water was still being pumped from the Durham Warping Drain into the Main Canal and before nutrients were taken up by the recolonizing vegetation. Variation in the influence of the sources of enrichment (6.6) may have affected the course of recolonization.

The water table in the Dutch Canals may also have affected their recolonization. The reduction in water table effected by the cutting of ditches perpendicular to the canals, after they were abandoned (2.7), probably varied in different areas though the possible significance of this is not known.

The fact that the canals were, in all probability, abandoned in different years, may also have caused environmental conditions to vary at the time of establishment of the recolonizing vegetation.

8.6.4 Recolonization of the canals in relation to stratigraphy and geology

Rogers & Bellamy (1972) consider that the flora which recolonized the canals did so as a result of nutrient enrichment from underlying fen peat and alluvial clay. By contrast, the stratigraphy of other sites on Thorne Moors was found to consist of *Sphagnum* peat developed over birch/sedge peat which lay directly over Triassic sand. It was shown in 6.7 that the pH, conductivity and concentrations of the major cations in a profile from one canal were somewhat higher than those from other profiles, probably reflecting the proximity of the underlying clay. However, in Chapter 4 it was also shown that the basal stratigraphy of sites in the canals was broadly similar to that of other sites on Thorne Moors and that all deposits were underlain by similar mineral material (clay). Rogers & Bellamy (1972) make no mention of the sources of enrichment described in 6.6.

8.6.5 Changes in the flora of the Dutch Canals

The flora of those canals which have not been filled in or completely cut away (2.7) is likely to have undergone some changes since it became established. For example, the collapse of culverts (by which drains ran under the canals), the drainage activities of Fisons Ltd. in 1972 and recent damming of the canals by the NCC warden are all likely to have altered physical conditions in the canals. In addition, as suggested in Chapter 7, the *Sphagnum* flora of the canals may have been modified by the effects of sulphur pollution.

8.6.6 The rate of recolonization of the canals

Since their abandonment in 1920 the canals have become filled with vegetation. There are some indications that the recolonization of the canals may have proceeded more rapidly than in the adjacent peat cuttings. For example, the 53 cm of peat which has developed over the clay in canal 1 (Fig. 4.8a) may be contrasted with the 25 cm of peat thought to have recolonized the cutting surface in peat cutting 4/5W4 (core C, Fig. 4.3; 4.5). In addition, there are few areas of open water in the canals today whereas in the peat cuttings large areas of open water are present.

The reason for this difference is probably partly the 'artificial' introduction of some of the species which recolonized the canals and partly the higher nutrient status of the canals. It may also relate to the size of the canals. White (1930) observed that the area of a peat cutting in an ombrotrophic mire influences the rate at which recolonization takes place; a small peat cutting was noted to recolonize more rapidly than an area the same size which was part of a larger peat cutting. He considered that this was probably because any one part of the smaller peat cutting was nearer the source of potentially recolonizing vegetation than much of the area of the larger peat cutting. This may, therefore, have influenced the recolonization of the canals. In addition, the fact that in the canals the ratio of the distance of the edges to the surface area is relatively high may have led to the creation of a relatively large area in which conditions varied enough to allow the germination and establishment of a wide variety of species.

CHAPTER 9

OBSERVATIONS ON OTHER CUT-OVER PEATLANDS

Reports of site visits to some other cut-over peatlands are included in Appendices 6-9. These comprise site descriptions, assessments of the potential for reclamation (with any constraints) and management prescriptions. Copies of these reports have been sent to the appropriate Nature Conservancy Council regions. The main factors relevant to a consideration of the management of peatlands are itemized below, for each site.

9.1 DANES MOSS (SEE APPENDIX 6)

1. The dry parts of this cut-over peatland (the area outside the Cheshire Conservation Trust Reserve) were dominated by *Betula pubescens* and *Molinia caerulea*. The dominance of the latter may be partly because of the westerly (and, therefore, oceanic) location of Danes Moss; nowhere on Thorne Moors is *Molinia caerulea* as abundant.

2. The raising of the water table (to 100-300 mm above the peat surface) in a relatively dry peatland area initially resulted in 'blooms' of algae and fungi (which presumably exploited nutrients released by dying *Molinia caerulea*). However, four years later *Sphagnum cuspidatum* was dominant in the flooded area forming substantial inundated lawns in places. *Eriophorum vaginatum* was apparently surviving inundation through the formation of huge tussocks which raised the plant above the level of the water table. *Betula pubescens* was dying as a result of the flooding.

Variation in the height of the water table in the flooded parts (produced by the partial covering of old peat stacks) increased the diversity of the area by allowing colonization by *Calluna vulgaris*, *Erica tetralix*, *Molinia caerulea* and a number of bryophytes.

3. Parts of Danes Moss were enriched by:

a. Run-off from agricultural land. Ditches containing nutrient-rich water were diverted away from the flooded area of the reserve. Advantage was taken of the fact that cation concentrations in water in a ditch which drained agricultural land were higher than those elsewhere on the moss: some poor fen species were successfully introduced into a pool excavated adjacent to the ditch.

b. Run-off from railway ballast. *Typha latifolia* was present in the ditch receiving this water. The flooded area of the reserve was probably not affected by enrichment from this source.

c. Run-off from a rubbish dump. Drains were polluted at least 200 m from the edge of the tip; this had encouraged colonization by opportunist species. In addition, a colony of Black-headed gulls associated with the tip were probably a further source of enrichment at the site.

9.2 CUMBRIAN PEATLANDS (SEE APPENDIX 7)

9.2.1 Glasson Moss

1. The small, rectangular peat cuttings were probably recolonized by spores and seeds from the nearby intact raised bog.

2. The small size of the peat cuttings may have aided their recolonization. The edge length: surface area ratio is high in such sites, thus providing a high proportion of sites suitable for plant establishment (as in the canals at Thorne Moors; see 8.6).

3. Differences in the height of the water table in the cuttings may account for the variation in the species of *Sphagnum* dominant in each cutting.

4. The species of *Sphagnum* dominant in each cutting may also reflect the age of the cutting. For example, *S. magellanicum* may have colonized a cutting originally dominated by *S. cuspidatum; S. cuspidatum*-dominated cuttings, therefore, may have been abandoned later than those dominated by 'hummock' species.

5. The presence of *Carex nigra, Dryopteris carthusiana,* and *Molinia caerulea* in the cuttings (species scarce on the surface of the intact mire) may reflect the fact that the pH and concentrations of anions and cations were somewhat higher than elsewhere on the mire. This enrichment may have occurred as a result of the drainage of the surrounding peat (see 6.3).

9.2.2 Wedholme Flow

1. On a burnt, cut-over peatland area the highest proportion of regenerating *Erica tetralix, Calluna vulgaris, Rhynchospora alba* and *Drosera rotundifolia* occurred nearest a region of intact raised bog.

2. *Sphagnum recurvum* was widespread on cut-over parts of Wedholme Flow, as on other cut-over peatlands (8.2).

3. Over a period of 15 years, a series of peat cuttings previously almost dismissed by Ratcliffe (1969) became recolonized by *Sphagnum magellanicum, Drosera anglica, D. rotundifolia, Narthecium ossifragum, Andromeda polifolia* and *Vaccinium oxycoccus*. There were some signs that a hollow/hummock microtopography was developing.

9.2.3 Tarn Moss, Troutbeck

1. The situation at Tarn Moss (where acidophilous nuclei have developed on a poor fen vegetation) illustrates how difficult it may be to determine the cutting history of peatlands. The vegetation may be 'natural' or may constitute a recolonized cut-over area developing back into an ombrotrophic mire.

9.2.4 Salta Moss

1. Cut-over communities were dominated by *Sphagnum recurvum* as on many other cut-over peatlands (8.2).

2. Peat cutting may have increased the supply of nutrients to the site through the exposure of 'fen' or 'sedge' peats.

3. The removal of peat may also have increased the amount of water (and, therefore, the supply of nutrients) flowing through the centre of this valley mire.

4. The re-vegetation of some water-filled peat cuttings has occurred through the development of a 'carpet' of vegetation over open water, forming a 'schwingmoor'.

9.3 FENN'S AND WHIXALL MOSS (SEE APPENDIX 8)

1. The small rectangular peat cuttings in areas 1 and 2 ('cases') are highly conducive to the rehabilitation of ombrotrophic peatland communities:

a. The water table has been reached through the removal of c. 1 m of peat.

b. At least 2 m of peat remains so that there is unlikely to be chemical interference from the underlying mineral substratum.

c. As at Glasson Moss (9.2.1), differences in the height of the water table appear to have given rise to variation in the vegetation in each cutting.

d. The height of the water table also varies within each cutting because of the existence of 'steps' or 'shelves' in the cases. It is possible that these could eventually be made to support communities which form equivalents to the micro-topographic levels represented on an intact raised bog.

e. The water table in these cuttings is potentially easily manipulated. In cuttings which have 'openings' in their walls, the 'openings' could either be deepened (to allow excess water to flow away) or dammed (to impound water). In 'closed' cuttings further removal of peat from the floor would increase the height of the water table; small drains could be excavated to decrease the height of the water table.

2. The replacing of surface sods onto the cut-over peat surface appears to promote the colonization of cuttings. This practice, known as 'shoeing', introduces the plants, allows them to grow on a firmer substrate and prevents oxidation of the exposed peat surface.

3. The diversity of peat cuttings appeared to increase with the age of the cuttings. However, some species including *Sphagnum magellanicum* and *Rhynchospora alba*, present on the uncut area of the mire (4a), were absent from re-vegetated peat workings in areas 1 and 2.

4. Parts of Fenn's and Whixall Moss were colonized by invasive species:

a. A Dutch variety of *Molinia caerulea* has been deliberately seeded onto trackways to help bind the surface peat. This plant has spread into the drier levels of the workings, thereby preventing colonization by other bog species.

b. *Betula pubescens* has invaded many dry areas. Its spread is probably encouraged by fire (used to remove surface vegetation and control the adder population).

c. Burning may also have encouraged the invasion of *Pinus sylvestris* in the drier areas. Seedlings of this plant appear to have spread from a plantation adjacent to the site.

d. Plants uncharacteristic of peatlands have colonized areas where rubbish has been dumped.

5. Apart from its intrinsic interest, the presence of an area of undisturbed bog (4a) on the site demonstrates the state of the original mire surface in terms of species composition and microtopography; it also helps to indicate the type of communities which ideally would be created in the cut-over areas. In addition, the area serves as a seed and spore source to surrounding cut-over regions.

6. Parts of Fenn's and Whixall Moss were enriched by:

a. Run-off from refuse (area 2).

b. Water percolating from the boulder clay embankment of the Shropshire Union Canal onto the moss (area 4). This has produced a species-rich alder-dominated carr.

7. One large, flooded peat cutting (area 5) was dominated by *Eriophorum vaginatum* with *Sphagnum cuspidatum* and *S. recurvum*. Communities dominated by these species are widespread on Thorne Moors (Chapter 3) and other cut-over areas (e.g. parts of Danes Moss; see also Chapter 8). They apparently occur where the water table is relatively high; *Eriophorum vaginatum*, however, may become established when the water table is relatively low (8.3).

8. The dominance of *Sphagnum recurvum* in a seemingly undisturbed community on the mire suggested that the area had, at one time, been cut (cf. 8.2). The stratigraphy of the area confirmed this view; loose *Sphagnum* peat had developed over a firmer layer of *Eriophorum angustifolium* peat about 1 m down.

9. Live *Sphagnum* is collected by florists from Fenn's and Whixall Moss.

10. This peatland complex consists of a number of contrasting areas, each of which has a different cutting history. This has given rise to wide variation in the plant communities which have recolonized the cut-over areas.

9.4 SHAPWICK HEATH NNR (SEE APPENDIX 9)

1. Many difficulties are encountered in the management of an upstanding block of peat at Shapwick (area 1). These include:

a. Maintenance of the water table. In the adjacent commercial peat workings the water table is lowered to the excavation level (c. 2 m below the level of the peatland block). To maintain the water table within the block (which would otherwise dry out completely) water is pumped from the commerical workings into the block. However, in spite of the presence of a clay 'wall' around the vegetation of the block and an arterial network of ditches designed to distribute water within the area the water backs up in the direction of the pump. This means that only part of the block receives water and occurs because the water is pumped into a relatively low-lying part of the block.

b. Formation of a fissure in the 'wall' of peat above the commercial workings. The wall currently threatens to collapse into the workings.

c. Possible nutrient enrichment. As the underlying clay is approached in the commerical workings, the concentration of certain ions in water pumped into the peat block may rise.

2. It is proposed to seal the peat block with a clay bund and pump water into the highest part of the block.

3. The diverse Shapwick fen meadows (re-vegetated peat cuttings which have developed under the influence of base-rich waters) are maintained by, and depend on traditional farming methods. Deviations from these methods threaten the vegetation of the meadows.

4. Rehabilitation of peatland communities in commercially worked-out areas is likely to be difficult because the intention is to remove all the peat, down to the underlying clay. At Thorne Moors, by contrast, abandoned commercially worked areas are covered by c. 50 cm of wood peat (which the machinery is apparently unable to tackle). Given the situation at Shapwick it would be desirable to attempt to establish reed bed communities.

5. It is proposed to construct a series of artificial lakes in the commercially worked-out areas. It would be informative to attempt to establish wetland communities on peat and clay substrates.

6. The clearing and enlargement of ditches in a re-vegetated, cut-over area (3) four years before the site visit resulted in the spread of *Sphagnum* lawns.

7. The nutrient status of water in the vicinity may be too high to allow the rehabilitation of ombrotrophic peatland communities. In this case, it was felt that a management policy of maintaining and creating poor fen communities should be pursued.

CHAPTER 10

GUIDELINES FOR THE MANAGEMENT OF CUT-OVER PEATLANDS

10.1 INTRODUCTION

This chapter suggests guidelines for the management of cut-over peatlands, the aim of which is to recreate communities characteristic of ombrotrophic mires.

These guidelines form the basis of 'Nature Conservancy Council Chief Scientist's Team Notes' on the management of cut-over peatlands. They will be prefaced by a resumé of the issues dictating the adoption of the various management policies, discussed more fully in other parts of this thesis.

10.2 THE WATER TABLE

10.2.1 Height and fluctuation of the water table

The importance of the height and fluctuation of the water table in determining the composition of bog vegetation is emphasized by the fact that, on an intact peatland, water level modes for plants characteristic of hummocks and hollows may differ by only 5 cm (Goode 1970). In a recently abandoned cut-over peatland the water table should be raised as soon as possible such that in the *majority* of the area the summer level never falls below 10 cm above the peat surface; the total annual fluctuation of the water table should ideally be no greater than c. 15 cm (cf. Chapman 1965; Goode 1970).

It is recognized that a water depth of > 10 cm may allow colonization by only the more aquatic *Sphagnum* species such as *S. cuspidatum* and *S. recurvum*. However, the aim at this stage is to prevent the establishment of invasive species such as *Eriophorum vaginatum* (8.3) and *Betula pubescens* (8.5), as well as to encourage the development of lawns of *Sphagnum cuspidatum* and *S. recurvum* (which may subsequently be colonized by species characteristic of the higher levels of the bog). In any case, most cut-over peatlands exhibit much local variation in the height of the water table relative to the peat surface owing to the presence of baulks, drains and stacks. Peat surfaces somewhat above the level of the flooded area offer the opportunity for the establishment of communities equivalent to the higher microtopographic components of a raised bog (as at Glasson Moss (9.2) and Fenn's and Whixall Moss (9.3)).

To eradicate established swards of invasive species (e.g. *Betula pubescens* and *Molinia caerulea*), and to prevent development into carr or woodland, the water table should be similarly raised, as at Danes Moss (9.1). Raising the water table in dry peatland areas is also likely to halt the development of structural changes in the peat such as the formation of cracks or fissures.

The water table can be raised and its fluctuations somewhat controlled by means of dams in ditches and drains, peat baulks, pumping and clay bunds.

10.2.2 Dams in ditches and drains

In a flooded cut-over peatland the upper limit of the water table and the amplitude of fluctuation are largely determined by the heights and permeabilities of dams in ditches and drains (5.5). The drainage of peatland areas can be reduced (and the water table raised) by damming all drains and ditches which allow water to flow from the site both on and around the margins of the peatland.

To maintain some control over the height and fluctuation of the water table, an overflow pipe or simple sluice may be installed at an appropriate level within a dam (10.2.1). Water should not 'over-top' or 'leak through' dams; this is eventually likely to erode them and increase water loss from the site. The repeated breaching and building-up of a dam as a means of water table control will also eventually weaken it.

10.2.3 Peat baulks

Peat baulks (banks of dry peat) can be used to retain and impound water in flooded cut-over areas. Where possible, therefore, attempts should be made to negotiate with peat cutting companies for peat baulks to be left on completion of cutting activities.

The baulks should be as wide as possible (at least 5 m). Their effectiveness depends on the tendency of water to flow through them. This is determined by the hydraulic conductivity of the peat and the hydraulic gradient (difference in height of the water table) between the inside and outside of the baulk (itself related to the baulk dimensions; cf. Boelter 1972).

There are some indications that the peat of dry baulks has an extremely low hydraulic conductivity, making them particularly conducive to the retention of water in flooded areas (5.6). This is thought to be a result of the drainage and subsequent drying of the baulks causing an increase in humification, compaction and subsidence. However, the long term effects (> 60 years) of further humification, compaction and subsidence as well as continuous re-wetting on the hydrophysical properties of dry peats are uncertain (5.6).

Dry peat baulks are particularly susceptible to burning. It is therefore recommended that, if necessary, they are cut down to a height of no more than 50 cm above the highest water table. Repeated burning of baulks will eventually result in their loss (see also 10.6).

10.2.4 Pumping

If the water table is raised by pumping (particularly applicable to the management of upstanding blocks of peat), it is essential that the water is fed to the highest part of the peatland. Otherwise, water may not reach parts of the peatland area and back up in the direction of the pump. At Shapwick Heath NNR (9.4), the pressure of water backing up has caused the formation of a fissure in the 'wall' of the upstanding peatland block. An arterial network of ditches may be utilized to help distribute the water within the peatland; this may involve excavation of new ditches and/or use of ditches already present on the site.

It is also important to ensure that water pumped into the peatland is of the correct quality (cf. 10.3.11).

10.2.5 Clay bunds

In peatlands situated somewhat above the level of their surroundings, the water table can be raised by means of clay bunds; these reduce water loss by marginal seepage (cf. 9.4).

10.2.6 Buffer-zones

The buffer-zone of a peatland may be regarded as the width necessary to accommodate any water drawdown at the periphery of the site. The width required is a function of the hydraulic conductivity of the peat and the difference between the height of the water table in a fully saturated (central) part of the peatland and in the lowest lying part of the adjacent area (van der Molen 1981).

The concept of the buffer-zone is extremely important as it is related to the proportion of the peatland area in which the water table is near enough the surface to support bog communities and the proportion of the peatland area where it is not. If two similar peatland areas are compared, one large and one small, clearly the proportion of the area occupied by the buffer-zone in the small peatland is much greater than that in the large peatland. However, small peatlands can support viable mire communities where the water table is held at a level which is high enough to render the width of the buffer-zone extremely narrow. An example of such a peatland is the basin mire Cranberry Bog, Staffordshire, where the hydraulic gradient at the edge of the mire is virtually negligible owing to its situation (Ratcliffe 1977). On cut-over peatlands the area of the 'new' bog community which can be supported will partly be determined by the effectiveness of the methods used to raise the water table. The buffer-zone should clearly be protected from drainage operations as these will increase the width of this zone.

Formulae for the calculation of the width of buffer-zones:

1. $E = 200\,H\,k$ (an empirical formula; Eggelsmann 1977) where E = width of buffer-zone (m); H = difference between the height of the

water table in a fully saturated (central) part of the peatland and in the lowest lying part of the adjacent area (m); k = hydraulic conductivity of the peat (m/day).

2. $E = \frac{2.2 \sqrt{k\ H\ t}}{\sqrt{\mu}}$ (a theoretical formula; van der Molen 1981)

where E, H and k are the same as for formula 1; t = time of year (in number of days); μ = storage coefficient.

The second formula allows calculation of the width of the buffer-zone at various times of the year by substitution of different values of H, t and μ. Formula 2 generates higher values for the width of the buffer-zone.

10.2.7 Excavation of pools

After the flooding of the majority of the cut-over peatland some areas may remain well above the level of the water table (as at Thorne Moors); in this case, or if there has been only limited success with attempts to raise the water table, the peat surface can be brought closer to the water table in places by the excavation of pools.

10.2.7.1 Constraints upon location

Pools should not be located in or near peat baulks used for the retention of water in cut-over areas, or on buffer-zones. Areas of shallow peat (< 1 m) should be avoided owing to possible chemical interference from the underlying substratum (10.3) and excavation should not involve the destruction of established mire communities or rare species. They should be located as near as possible to a seed/spore source (cf. 9.2.1; see 10.4).

10.2.7.2 Pool dimensions

Lindsay (1977) gives details for the construction of pools. The pools should be excavated such that the summer water level never falls below 10 cm above the peat surface at the base of the pool. This depth can be determined by digging small pits (c. 20 cm in diameter, left for 48 hours to equilibrate) in the areas where pools are to be excavated, to establish the height of the water table in the peat. Pools should be given sloping sides (the angle of which should range from shallow to fairly steep) to allow colonization by a range of Sphagna and other species. A suitable diameter for a circular pool is 4 m.

In some cases it may be desirable to deepen existing peat cuttings by removing peat from their bases. The (usually vertical) sides of such cuttings could be shaped to give sloping edges or excavated into a series of 'steps' or 'shelves', as at Fenn's and Whixall Moss (9.3); the latter may be a simpler operation and also provides variation in the height of the water table relative to the peat surface.

Excavated peat can be used to construct or reinforce dams in ditches and drains.

Factors affecting the recolonization of pools and cuttings are considered in 10.4.

10.2.8 Other factors influencing the height of the water table

1. Trees

The presence of trees including *Betula pubescens*, *Pinus sylvestris* and *Salix* spp. in wet cuttings and on dry baulks may substantially increase the amount of water lost from the site by evapotranspiration and interception (5.4; 10.5).

2. Mining subsidence

The undermining of sites is likely to increase the height of the water table relative to the peat surface (2.9; 5.5). This should be borne in mind if mining operations are proposed in the locality of the mire.

3. Interference with the underlying substratum

The hydrology of mires may be affected by interference with the underlying substratum. For example, the extraction of sand and gravel from beneath a basin mire may destroy the hydrological security of the basin and result in a lowering of the water table as well as some nutrient enrichment (cf. 10.3). In this case back-filling with outwash material may provide a suitable 'plug', but the success of this will depend on many factors which cannot be predicted (Mr R A Lindsay, personal communication).

4. Regional lowering of the water table

Attempts to lower the water table in whole regions (e.g. in the Somerset Levels to 'improve' agricultural land; Appendix 9) are likely to result in a significant reduction of the height of the water table, and consequently considerable change in the vegetation.

5. Peat wastage

The continued progression of subsidence, compaction and decomposition in peat above the water table will result in peat wastage (as at Holme Fen, Hutchinson 1980; see also 4.6 and 5.6). This may cause some alteration in the height of the water table relative to the peat surface.

10.2.9 Monitoring of the water table

The height and fluctuation of the water table may be monitored by means of sampling tubes (pipes) embedded into the underlying substrate. These should be of metal (to resist fire), c. 10 cm in diameter and have numerous holes drilled in the sides. The water table relative to the peat surface should be measured at least once a month in a series of sampling tubes located across the length and breadth of the peatland, including the buffer-zone. The first readings should be taken one month after installation (to allow equilibration).

An overall similarity in the magnitude and pattern of water table fluctuation in the sample tubes inside the buffer-zone suggests that the whole site is responding similarly to changes in water relations; this in turn indicates that the methods used to raise and control the water table are effective.

10.3 WATER CHEMISTRY

10.3.1 The water chemistry of ombrotrophic mires

A consideration of the water chemistry in cut-over ombrotrophic peatlands is important because this, more than any other single factor, will determine the plant communities which develop. In intact ombrotrophic mires (fed solely by rainwater) the concentration of ions in the peat waters is extremely low (Gorham 1956a, b; Tallis 1973b; 6.3). These concentrations generally increase as a result of peat cutting activities. Possible sources of enrichment and other factors that may affect water quality on cut-over peatlands are described below.

10.3.2 Run-off from adjacent areas

The removal of peat may result in an increase in the amount of water running onto a site from adjacent areas. Run-off from the following sources is likely to lead to enrichment of the peat waters at a cut-over site:

mineral soil/rock (cf. 9.2)
agricultural land (6.5; 9.1)
clay-covered warpland (2.5; 6.5)
embankments of canals (9.3)
hardcore tracks or canal towpaths (6.6)
railway (9.1) and tramway ballast (6.6)
refuse tips (9.1; 9.3)
coal mines and colliery tips (6.5)
clay or other mineral material dumped on or near the peat surface (6.3).

Mining subsidence and peat wastage (10.2.8) may increase the amount of water running from these sources onto the mire.

Run-off from these sources is likely to preclude the development of ombrotrophic vegetation. However, it should be noted that some of these sources of enrichment may give rise to species-rich vegetation types of interest in their own right; e.g. as at Crymlyn Bog where pulverized fuel ash has been dumped onto the mire surface (Meade 1983; cf. 6.6 and 10.3.11).

10.3.3 Black-headed gulls

Colonies of Black-headed gulls associated with refuse tips (9.1) or, on Thorne Moors, with a stand of *Juncus effusus* (6.3), are likely to enrich cut-over sites through 'guanotrophication'.

10.3.4 Exposure of underlying fen peats

The removal of peat may expose underlying fen peats resulting in some enrichment to water flooding peat cuttings (6.7; 9.2; Chapman 1964; Tallis 1973b).

10.3.5 The influence of the underlying mineral material

In areas where peat has been removed completely or where a shallow layer of peat remains, the underlying mineral substrate will influence water chemistry (6.7; 9.4).

A 'critical residual peat depth' for the rehabilitation of ombrotrophic communities will depend on the chemical influence of both the underlying fen peat (10.3.4) and the underlying substratum. It would be desirable, however, to negotiate with peat cutting companies for at least 50 cm of peat (above the fen peat) to be left on completion of cutting activities (6.7; cf. 9.3 and 9.4).

10.3.6 Water movement

The removal of peat may result in an increase in the amount of water (and, therefore, the supply of nutrients) flowing through a mire (cf. 9.2; Ingram 1967).

10.3.7 The effect of drainage

There is evidence that the drainage of a bog results in a decrease in the pH and an increase in the conductivity of peat waters (6.3; 8.2; cf. 9.2 and 9.3; 10.8).

10.3.8 The effects of flooding

10.3.8.1 Flooding of a dry peat area

Oxidation of a dry, cut-over surface may result in an increase in the proportion of inorganic material per unit volume in the upper horizons of peat. This may give rise to a corresponding increase in the concentration of ions in water flooding such an area.

10.3.8.2 Flooding of a re-vegetated peat cutting

The flooding of a re-vegetated peat cutting (dominated, for example, by *Molinia caerulea*), may result in eutrophication caused by the breakdown of much organic material. Temporary algal and fungal blooms may develop (9.1).

10.3.8.3 Flooding of drains

The flooding or overflowing of peatland drains (which may have been 'sealed off' hydrologically) could result in the introduction of nutrient-rich water into peat cuttings, particularly if the drains penetrate the underlying mineral substrate (6.5). At Thorne Moors the water chemistry has also been affected by an influx of nutrient-rich water from canals (6.6).

10.3.9 Bisulphite pollution

The concentration of sulphur pollutants, particularly bisulphite, in rainwater may be important in determining the survival of *Sphagnum* species (Chapter 7).

10.3.10 Fire

The burning of a cut-over peatland will result in some temporary nutrient enrichment at the site (10.6).

10.3.11 Measures to isolate cut-over peatlands from sources of enrichment

Where the cut-over mire lies at a similar or somewhat lower level than its surroundings, drains containing nutrient-rich water should be diverted away from the site (9.1). This may involve the damming and embanking of existing drains and the construction of new drains. Peat baulks may also be utilized to isolate the site.

Water pumped into an upstanding peatland from the surrounding area is likely to be particularly nutrient-rich (9.4; cf. Duffey 1971). One solution might be to pump the water into a securely embanked ditch located at the perimeter of the peatland. As long as the water level in the ditch was maintained at a slightly higher level than that in the peatland adjacent to it, 'filtered' water would flow from the ditch into the mire (cf. 10.2.4). *Typha latifolia* could be introduced into the ditch to lower the nutrient status of the water; this may also help to stabilize the ditch and embankment. The pressure of water in the ditch, however, may cause fissures to form in the 'wall' of the peatland (cf. 9.4). In addition, pumping would be inefficient in that much of the water in the ditch would flow towards the outside of the peatland.

In some cases it may be impossible to isolate cut-over sites effectively from sources of enrichment - for example, where the water chemistry is influenced by the underlying mineral material or the exposure of underlying fen peats. In other cases constraints of cost may limit the measures that can be taken to isolate sites. In these situations it is considered that a management policy of maintaining and creating poor (or even rich) fen communities should be pursued (cf. 9.4).

10.3.12 Monitoring of water chemistry

The chemistry of the peat waters may be monitored effectively by measurement of pH and electrical conductivity (K_{corr}; Appendix 4). Measurements should be taken at least once a month at sample sites located near suspected sources of enrichment and across the length and breadth of the peatland. Water samples may be collected from sample tubes utilized for measurement of the water table (cf. 6.2; 10.2.9).

10.4 THE RECOLONIZATION OF CUT-OVER PEATLANDS

10.4.1 Source of colonizing species

The establishment of appropriate ombrotrophic species on cut-over peatlands will proceed more quickly if there is a nearby population (Schmatzler & Tüxen 1980; 9.2). For this reason it would be desirable, where possible, to negotiate with peat cutting companies for an area of un-cut bog to be left undrained (cf. 9.3). Such an area would also demonstrate the state of the original mire surface in terms of species composition and microtopography and help to indicate the type of communities which ideally would be created in the cut-over areas.

Un-cut areas on otherwise cut-over peatlands may be left as upstanding blocks (cf. 10.2.4; 10.2.5; 10.3.11). If only limited success is achieved with attempts to raise the water table, it might be appropriate, in the last resort, to cut off the living surface turf and replace it onto lower-lying areas (see 10.4.4). Before undertaking such an operation, however, trials should be conducted to determine whether or not it is likely to be successful.

The collection of live *Sphagnum* by florists should be discouraged (9.3).

10.4.2 Size of peat cuttings

Small cuttings are likely to be recolonized at a faster rate than larger cuttings. This is because the length of the edge of a small cutting is relatively high compared to its surface area, probably providing a relatively high proportion of sites suitable for plant establishment (8.6; 9.2; cf. 10.2.7.2; White 1930). In addition, parts of smaller peat cuttings in relatively intact mires will be nearer the source of colonizing species (9.2).

Large flooded peat cuttings may be subject to wave action; this may cause erosion and is likely to reduce recolonization rates or prevent it altogether. For this reason, the long axis of (rectangular or oval) pools might be profitably aligned across the direction of the prevailing wind (10.2.7; Wheeler 1983).

10.4.3 The recolonization of deep water areas

The flooding of cut-over peatlands may give rise to some relatively deep water areas (i.e. >30 cm; Chapter 5; 10.2.1). Such areas may revegetate via 'schwingmoor' development whereby a floating raft of plants grows out vegetatively from firm land over open water (9.2). This type of recolonization has certain advantages because floating peat rafts have been shown to compensate for water level fluctuation (Green & Pearson 1968; Giller 1982). A raft of polystyrene balls might encourage schwingmoor development (Dr B D Wheeler, personal communication).

10.4.4 The introduction of species into cut-over areas

The recolonization of cut-over areas may proceed more quickly if species are introduced, although this practice is not universally accepted by ecologists. Vegetative spread is probably the main means of propagation for most plant species of ombrotrophic mires. Seeds often do not germinate readily and conditions are frequently unfavourable for seedling establishment. Species are best introduced, therefore, as mature plants.

One means of re-introducing ombrotrophic species is by the replacement of the living surface turf onto the cut-over surface (9.3). This practice, known as 'shoeing', introduces established plants, allows them to grow on a firm substrate and prevents oxidation of the exposed peat surface. It would be desirable, where possible, to negotiate with peat cutters for surface sods to be saved for this purpose. The water table should be maintained at the surface of replaced turves.

The long term feasibility of introducing *Sphagnum* species is not clear. Introduced species at Thorne appeared to grow readily for approximately two years, after which time a marked reduction in the rate of growth was found (Chapter 7). The production of spores has not been observed in introduced *Sphagnum* material at Thorne; this, however, may reflect the fact that sexual reproduction is particularly susceptible to the relatively high SO_2 concentrations prevalent at this site (10.3.9; Chapter 7).

In flooded areas from which the peat has been removed completely it would be appropriate to attempt to establish reed bed communities by the introduction of *Phragmites australis* and *Typha* *latifolia* (9.4). In deep water, *Typha* is often a principal pioneer species and without it terrestrialization of deep water may proceed only slowly, or not at all (Lambert 1951; Wheeler 1983). Other species may eventually be introduced according to the nutrient status of the water.

10.4.5 Monitoring of recolonization

The recolonization of cut-over peatlands may effectively be monitored in permanent quadrats (e.g. 2 x 2 m) by fixed point photography and recording of abundance of species present.

10.5 CONTROL OF DOMINANT SPECIES

10.5.1 *Eriophorum vaginatum*

Once established, *E. vaginatum* can tolerate relatively high water tables (8.3; 9.1; 9.3). Trampling may help to eradicate *E. vaginatum*; this destroys the integrity of the tussocks (8.3).

10.5.2 *Betula pubescens*

The flooding of cut-over peatlands eventually results in the death of *Betula pubescens* (8.5; 9.1). If, however, the water table cannot be raised sufficiently to initiate the eradication of birch, a policy of cutting, and perhaps chemical treatment of the stumps, should be pursued.

10.5.3 *Molinia caerulea*

Molinia caerulea may be eliminated by flooding the area which it dominates (9.1). However, if water flows through the peatland area this control measure will not be effective because the growth of *Molinia* in waterlogged conditions is favoured by moving water (as in fens; Armstrong & Boatman 1967; cf. Ingram 1967). In addition, flooding will not necessarily be effective in western sites where *Molinia caerulea* is a natural component of ombrotrophic vegetation; however, even here this control measure is likely to prevent extreme dominance.

10.5.4 *Juncus effusus*

Juncus effusus can survive the flooding of cut-over areas once established, and may be additionally encouraged by 'fertilization' by the Black-headed gulls which it sometimes attracts (Chapter 5; 8.4). Active removal (e.g. cutting or uprooting) may be the only means of eradicating this species. Such a control measure would be costly in terms of time and energy but may be worthwhile in view of the problems of enrichment associated with Black-headed gulls (10.3.3).

10.5.5 *Salix* spp.

Willows such as *Salix cinerea* can withstand flooding once established (on mires which have been enriched; 10.3) and active removal may be the only solution to their control (cf. 10.5.2).

10.5.6 *Pteridium aquilinum*

Bracken, a serious pest on dry peat areas, can be eradicated by raising the water table.

10.6 FIRE

Fire is a hazard on cut-over peatlands as on all other peatlands. In dry areas it encourages the spread of invasive species including *Betula pubescens* and *Pinus sylvestris* (9.3) and it may help to maintain the dominance of *Eriophorum vaginatum* (8.3). Fire may also destroy the (often limited) sources of recolonizing species.

For these reasons and because burning results in nutrient enrichment (10.3.10), material such as birch or willow cleared from peatland areas should never be burnt on site.

It may be necessary to excavate fire moats, particularly in areas where it is difficult to raise the water table. Details for their construction are given by Lindsay (1977). On cut-over peatlands blocked drains may be utilized for fire moats. Their excavation should not involve the destruction of established mire communities or rare species.

10.7 THE USE OF MACHINERY ON CUT-OVER PEATLANDS

It may be possible to negotiate with peat cutting companies for their machinery to be used for active management operations (e.g. the excavation of pools). However, if machinery is used physical damage to the present vegetation *must* be minimized. Apart from the fact that this vegetation may itself be of conservational importance, it is this vegetation that will be instrumental in recolonization of cut-over areas. In addition, clay, (used, for example, for bunding) and other mineral material should not be dumped onto the site (cf. 10.3.2).

10.8 THE REHABILITATION OF OMBROTROPHIC COMMUNITIES

The indications are that the development of ombrotrophic communities on cut-over peatlands takes a long time. On Thorne Moors, for example, the most species-rich communities characteristic of ombrotrophic mires occur in cuttings which were abandoned up to 50 years before less diverse cuttings (see also 9.2 and 9.3).

The time it takes for the development of ombrotrophic communities is partly related to the effects of peat drainage (6.3; 8.2; 10.3.7); even if all factors relating to the water table and the availability of recolonizing species are optimal for rehabilitation, and a site is isolated from all external sources of enrichment, this factor will have increased the conductivity of the peat water (rendering the development of truly ombrotrophic communities unlikely). A lowering of the conductivity of the peat water is mostly effected by *Sphagnum recurvum* which is capable of colonizing enriched peat cuttings (8.2; cf. Clymo 1967). This moss, therefore, eventually creates conditions which allow colonization by species characteristic of ombrotrophic situations such as *Sphagnum papillosum* and *Sphagnum magellanicum* (6.3.13).

This process can be speeded up by the correct management regime. At Thorne Moors, for example, the management procedures adopted for the last 5 years have, amongst other things, resulted in the spread of *Sphagnum recurvum* and encouraged the initiation, in places, of nuclei of *S. papillosum*.

CHAPTER 11

GUIDELINES FOR THE MANAGEMENT OF THORNE MOORS

11.1 INTRODUCTION

The primary aim of management on Thorne Moors pNNR is to encourage the development of communities characteristic of ombrotrophic mires (Ratcliffe 1977; Bonner 1978). The management guidelines presented here, many of which are being implemented at present, are mainly concerned with achieving this aim; they should be practised in conjunction with those guidelines set out in Chapter 10.

11.2 MANAGEMENT OF THE pNNR

11.2.1 Water table in the pNNR

1. The water table should be maintained at its present level (Chapters 1 and 5; 10.2.1).

2. It is necessary to reinforce the dam at the southern end of the New Cut (Figs. 1.3 and 2.2), and it would be desirable to install an overflow pipe or simple sluice at the level at which water currently over-tops the present dam. This would prevent erosion of the dam and allow a more precise control over the level and fluctuation of the water table than the repeated breaching and building-up of the dam as sometimes practised by Fisons Ltd. (cf. 10.2.2 and 10.2.8). All other dams which leak should also be reinforced both in the pNNR and in the area protected under the Section 15 Agreement (Fig. 1.2). The integrity of the peat baulks which retain and impound water in these areas should be maintained.

3. A consideration of the buffer-zone of the pNNR is complicated by the fact that there is a slight rise in height to the south and west of this area (5.5). However, the indications are that the pNNR is hydrologically viable at present because on its north and west sides the buffer-zone occurs in the Section 15 area and on its east and south sides effective 'sealing' of the area has reduced its width to a minimum (5.5; 10.2.6). Flooded cut-over areas to the east of the pNNR also help maintain the water table within this area.

4. The long term hydrological viability of the pNNR is questionable if the Section 15 area or the peat to the east of the pNNR is cut away. In this case the buffer-zone would occupy a high proportion of the pNNR, so reducing the area capable of supporting bog communities (cf. 10.2.6). If these areas were cut it would be essential to re-flood them as soon as possible afterwards. This would entail the retention of strategically placed peat baulks (10.2.3). It must be reiterated, however, that even if the cut-over areas were re-flooded there would still be an overall reduction of the height of the water table in the pNNR. Such an operation may even render it necessary to pump water into the pNNR (10.2.4 and 10.3.11).

5. The water table should be monitored at monthly intervals (details in 10.2.10). Sampling tubes may be located as in Fig. 5.1 with some additional tubes installed at the four corners of the pNNR and in the Section 15 area.

11.2.2 Fire

1. With the exception of the flooded peat cuttings, the whole of Thorne Moors is susceptible to burning as shown by the fire of 2 June 1982. The spread of this fire was aided by the dry peat and birch scrub in the area, thereby demonstrating the need to control birch effectively (see subsequent sections) and the hazards of a high proportion of peat above the water table (cf. 10.2.3). Much of the birch scrub and the dry peat were destroyed by the fire (11.4).

2. The New Cut would probably act as an effective firebreak against fires spreading from the region of Thorne Colliery (Fig. 2.2). It would not be appropriate to deepen and completely clear canal 1 for this purpose (Fig. 2.2; cf. Bonner 1978); this canal contains vegetation of conservational importance which in addition forms a source of colonizing species (cf. 10.4, 10.6; 11.5).

3. The immediate reflooding of all abandoned cut-over areas, particularly those adjacent to the pNNR (Goode 1973; 11.6), would also help protect the pNNR (and other cuttings) from fire.

4. Material such as birch or willow cut or cleared from cuttings, baulks and canals should not be burnt on site (10.3.10; 10.6).

11.3 MANAGEMENT PRESCRIPTION FOR THE PEAT CUTTINGS OF THE pNNR

1. In parts of cuttings in which the water table remains below the peat surface (mostly central sections of cuttings in the south and west of the pNNR), pools should be excavated to encourage the spread of *Sphagnum* spp. (details in 10.2.7 and 10.4.2; cf. 10.2.1; 10.7; 10.8).

2. The recolonization of deep water areas (the outer or peripheral sections of peat cuttings) by 'schwingmoor' development may be encouraged by a raft of polystyrene balls (10.2.1; 10.4.3). This idea should be tested in some peat cuttings.

3. With the exception of the cuttings between canals 1 and 2 which are flooded by water from the New Cut (6.5), the current input of nutrient-rich water into the peat cuttings is considered to be minimal (Chapter 6). This isolation from external sources of enrichment must be maintained (see 10.3).

4. It is essential to encourage the spread of *Sphagnum recurvum*. This is because this species can act as a primary colonist of the cuttings, and in so doing helps lower the conductivity of the peat water (relatively high in the peat cuttings; Chapter 6), making conditions suitable for colonization by species such as *S. papillosum* and *S. subnitens* (10.8).

5. The chemistry of the peat water should be monitored, desirably at monthly intervals, in samples from sampling tubes located across the length and breadth of the pNNR (details in 10.3.12).

6. The oldest, most diverse cuttings occur in the centre of the pNNR (8.1). Apart from being of high conservational importance, these cuttings are a prime source of colonizing species in the pNNR and should be protected totally from disturbance (10.4; 10.7; 11.4).

7. When a revegetated area (outside the pNNR) is about to be cut by Fisons Ltd., it would be desirable to collect suitable species (e.g. *Andromeda polifolia* and *Vaccinium oxycoccus*) to introduce into the pNNR. It may even be possible to negotiate for surface sods to be saved for 'shoeing' appropriate areas in the pNNR (10.4.4).

8. The vegetation may be effectively monitored by fixed point photography and recording of abundance of species present in permanent quadrats (e.g. 2 x 2 m); these should be placed along transects of peat cuttings across the length and breadth of the pNNR.

9. The dominance of *Eriophorum vaginatum* may be reduced by trampling down the tussocks of this plant (8.3; 10.5.1).

10. Birch is dying in the flooded peat cuttings of the pNNR (8.5; 10.2.9; 10.5.2); much was also burnt out by the fire of 2 June 1982 (11.2.2). It would be desirable to pull out some of the moribund trees. In drier parts of the cuttings a policy of cutting, perhaps followed by chemical treatment of the stumps, should be pursued. *Salix* spp. and *Rhododendron ponticum* should also be removed from the cuttings (see 10.5.5).

11.4 MANAGEMENT PRESCRIPTION FOR THE PEAT BAULKS OF THE pNNR

1. The fire which occurred on 2 June 1982 brought the surface of the peat baulks closer to the water table (10.2.1; 11.2.2; cf. Fig. 5.15). They are now less susceptible to burning (10.2.3) and more capable of supporting bog communities.

2. It would be desirable to excavate pools on the peat baulks (11.3 nos. 1 and 4) and in some cases to shape the vertical sides of the baulks into sloping edges to allow colonization by a range of Sphagna and other species (10.2.7.2).

3. *Betula pubescens* should be removed from the peat baulks within the pNNR (10.2.9; 11.2.2). This may be extremely difficult in future, if the fire, by effectively increasing the height of the water table relative to the peat surface, has created conditions suitable for the establishment of birch (8.5; cf. 10.5). It is suggested that the trees are tackled when young.

11.5 MANAGEMENT PRESCRIPTION FOR THE CANALS OF THE pNNR

1. The canals which surround the peat cuttings are the main source of colonizing species in the pNNR and contain vegetation of high conservational importance (3.5; 10.4; Goode 1973). It is therefore essential that the present vegetation is not damaged during management operations.

2. To maintain this vegetation, the canals should be periodically cleared *selectively* in small sections. This should involve removal of the vegetation in such a way that rare species (e.g. *Osmunda regalis*) are either preserved or transplanted to a canal location where the successional stage and the chemistry of the peat water (cf. 6.6) are appropriate to the survival of the plant. Ombrotrophic species could be introduced into peat cuttings.

3. Moribund birch trees should be cleared from the canals as in the cuttings (11.3, no. 10). In drier parts birch may have to be cut out. In addition to periodic clearance of small sections of canals (above), *Salix* spp. (with the exception of *S. repens*) should also be thinned in areas where it excludes most other species.

11.6 MANAGEMENT PRESCRIPTION FOR ABANDONED 'MODERN' CUTTINGS ON THORNE MOORS

1. It would be desirable to flood worked-out areas of Thorne Moors making use of the tramways and peat baulks protected under the Section 15 Agreement (Fig. 1.2; Goode 1973; 10.2). Suitable areas are described by Goode (1973). In addition to creating new wetland habitats, the flooding of cut-over areas would also help maintain the water table in the pNNR (cf. 11.2). Where necessary, it may be possible to negotiate with Fisons Ltd. for their machinery to be used to 'seal off' areas hydrologically, as with the Experimental Plot (Lindsay 1979).

2. The water flooding abandoned peat cuttings is likely to be somewhat enriched owing to the fact that the peat layer remaining in these areas is shallow (e.g. 40-80 cm in EP; 4.3 and 6.7); 10.3. It might be appropriate, therefore, to attempt to establish reedbed communities in some of the compartments (separated by peat baulks) within cut-over areas (10.3.11; cf. 10.4.2; Goode 1973). *Typha latifolia* and *Phragmites australis* cleared from the canals (11.5) could be introduced into such areas (cf. 10.4.4). This vegetation would be expected to be replaced eventually by species characteristic of more ombrotrophic situations.

3. Once the area to the south of the Southern Boundary Drain has been worked-out completely, it would be desirable to block this drain at its western outfall into Thorne Moor Drain (Fig. 1.2). The water should be diverted south along Angle Drain at the point where this drain and the Southern Boundary Drain intersect, thus permitting continued drainage from the north and east (Goode 1973).

11.7 CUTTINGS DOMINATED BY *JUNCUS EFFUSUS*

1. Cuttings dominated by *Juncus effusus* present few management problems. Black-headed gulls associated with these cuttings are unlikely to 'eutrophicate' areas of conservational importance because these are situated some distance away from *Juncus effusus* stands (3.3; 10.3.3). It would not be worthwhile, therefore, to attempt to eliminate stands of this species (10.5.4).

2. It should be emphasized that there is no evidence to suggest that *Juncus effusus* can become established in deep water areas (5.8; 8.4; cf. Rogers & Bellamy 1972; Goode 1973).

11.8 MANAGEMENT OF OTHER PARTS OF THORNE MOORS

Management prescriptions to perpetuate the floral and faunal interest of other habitats, including woodland on marginal areas, peat baulks outside the pNNR, tramways, warpland and the eastern end of Cottage Dike are set out by Goode (1973) and Bonner (1978).

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APPENDIX 1

Percentage occurrence of species present in ten vegetation noda generated by classification MS.


Calluna vulgaris
Betula pubescens
Erica tetralix
Phragmites australis
Andromeda polifolia
Molinia caerulea
Vaccinium oxycoccus
Eriophorum angustifolium
% occurrence within nodum
0
20
40
60
80
100
1 2 3 4 5 6 7 8 9 10
number of nodum

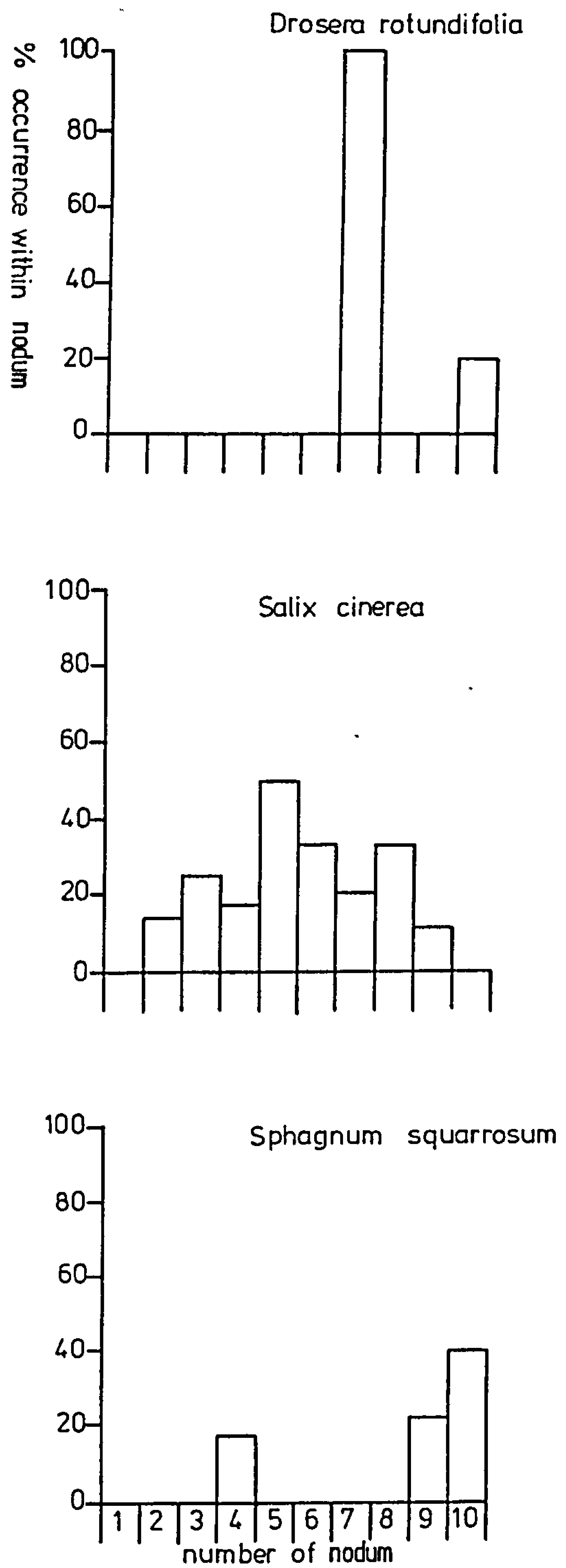

Eriophorum vaginatum
Sphagnum cuspidatum
Carex curta
Sphagnum fimbriatum
Juncus effusus
Sphagnum recurvum
Pteridium aquilinum
Campylopus introflexus
% occurrence within nodum
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
number of nodum


Pohlia nutans
Polytrichum piliferum
Polytrichum commune
Aulacomnium palustre
Polytrichum alpestre
Drepanocladus revolvens
Polytrichum juniperinum
Drepanocladus fluitans
% occurrence within nodum
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
number of nodum


Cephalozia bicuspidata
Sphagnum subnitens
Calypogeia trichomanis
Campylopus paradoxus
Sphagnum papillosum
Calamagrostis canescens
Rhododendron ponticum
Potentilla palustris
% occurrence within nodum
0
20
40
60
80
100
1 2 3 4 5 6 7 8 9 10
number of nodum

APPENDIX 2

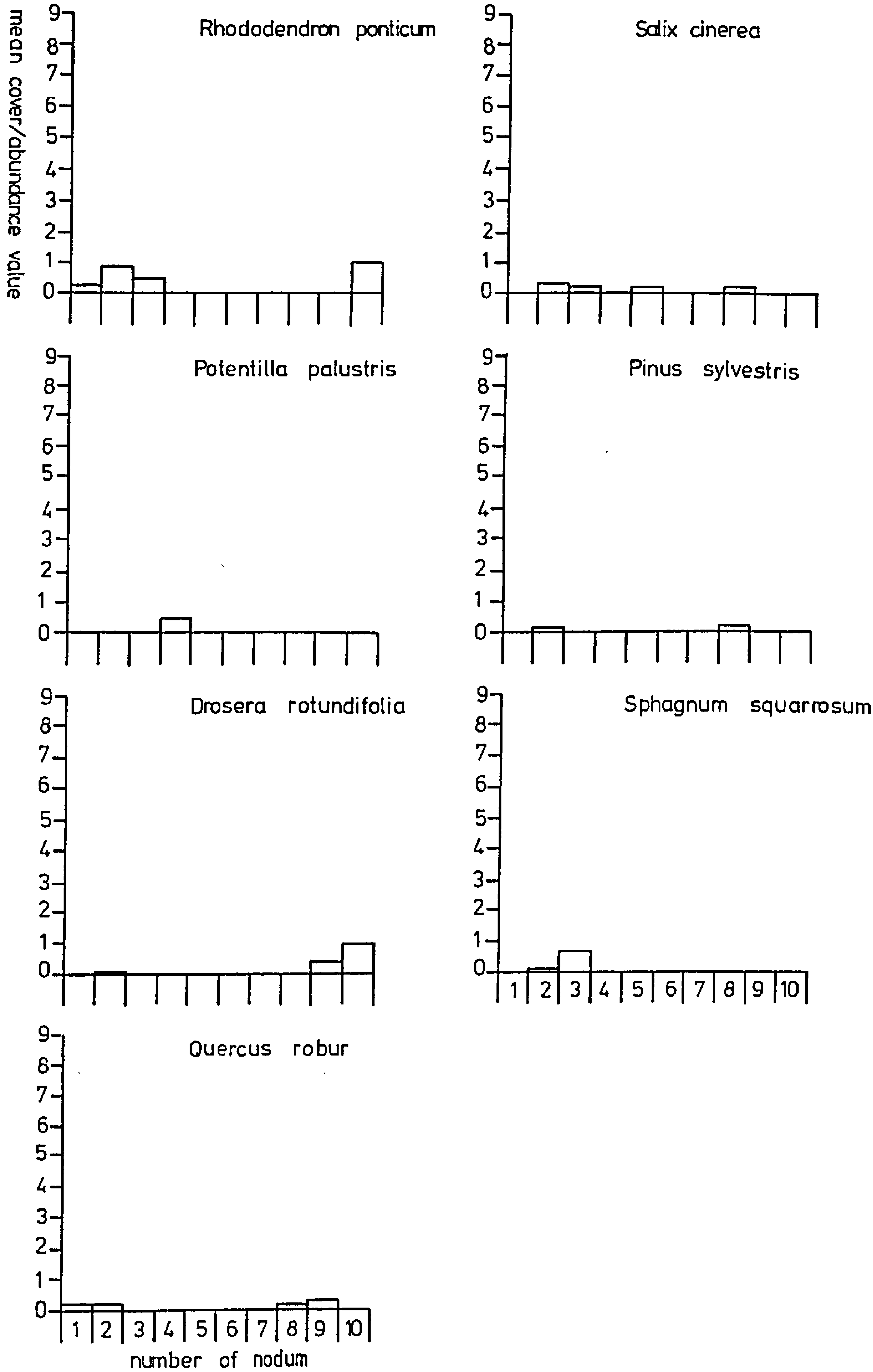
Mean cover-abundance values of species in ten vegetation noda generated by classification AC.


Drosera rotundifolia
Quercus robur
Salix cinerea
Pinus sylvestris
Sphagnum squarrosum
% occurrence within nodum
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10
number of nodum


mean cover/abundance value
Calluna vulgaris
Phragmites australis
Erica tetralix
Molinia caerulea
Andromeda polifolia
Eriophorum angustifolium
Vaccinium oxycoccus
Eriophorum vaginatum
Betula pubescens
Carex curta
number of nodum
number of nodum


mean cover/abundance value
Juncus effusus
Campylopus introflexus
Pteridium aquilinum
Pohlia nutans
Sphagnum cuspidatum
Polytrichum commune
Sphagnum fimbriatum
Polytrichum alpestre
Sphagnum recurvum
Polytrichum juniperinum
number of nodum


mean cover/abundance value
Polytrichum piliferum
Calypogeia trichomanis
Aulacomnium palustre
Sphagnum papillosum
Drepanocladus revolvens
Sphagnum subnitens
Drepanocladus fluitans
Campylopus paradoxus
Cephalozia bicuspidata
Calamagrostis canescens
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
number of nodum
number of nodum


mean cover/abundance value
Rhododendron ponticum
Salix cinerea
Potentilla palustris
Pinus sylvestris
Drosera rotundifolia
Sphagnum squarrosum
Quercus robur
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
number of nodum

APPENDIX 3

Monthly rainfall totals in millimetres recorded at Crowle, Dirtness pumping station (Nat. Grid Ref. SE 474409)

	1980	1981	1982	AVERAGE
JAN	80.6	27.3	34.1	48.0
FEB	82.8	45.7	12.2	40.0
MAR	75.5	126.0	67.3	35.0
APR	8.5	79.9	10.2	40.0
MAY	34.3	69.6	11.9	43.0
JUNE	114.3	25.2	144.5	44.0
JULY	22.5	28.8	23.6	55.0
AUG	87.6	72.3	81.7	66.0
SEPT	31.0	85.5	-	50.0
OCT	87.4	57.1	-	45.0
NOV	65.9	40.1	-	59.0
DEC	15.8	41.3	-	43.0
ANNUAL TOTAL	706.2	698.8	-	568.0

Monthly averages and the average annual total refer to the period 1941-70.

APPENDIX 4

1. METHODS FOR CHEMICAL ANALYSIS OF PEAT WATERS

a) pH

pH was measured electrometrically using a Pye Model 79 pH meter. The glass electrode was inserted directly into a sub-sample of the water sample.

b) Conductivity

Electrical conductance of water samples was measured using an EIL conductivity meter, type MC 1 MK V with automatic temperature compensation to 25°C. The approximate contribution of hydrogen ions to the conductivity was subtracted from the measured conductivity using values quoted by Golterman *et al.* (1978), where the pH of the water sample was below 4.5. Corrected conductivity results (K_{corr}) are expressed in μ S cm^{-1}.

c) Nitrogen

The concentration of nitrogen was determined using the semi-micro Kjeldahl distillation method (Black 1965). 20 ml of the water sample was steam distilled with magnesium oxide to measure ammonium-N. A further aliquot was steam distilled with magnesium oxide and Devarda's alloy to measure (ammonium + nitrite + nitrite)-N. The first 25 ml of distillate was collected in 5 ml of boric acid-indicator solution and titrated with 0.01 M sulphuric acid.

d) Phosphorus

Soluble reactive phosphorus in undiluted water samples was estimated colorimetrically. A molybdenum blue complex was developed using antimony as a colour enhancing agent and ascorbic acid as the reductant (Stainton, Capel & Armstrong 1977). The absorbance (1 cm light path) was measured at 885 nm using a Pye-Unicam SP 550 spectrophotometer. The background absorbance resulting from the dark natural colour of the peat waters was subtracted from the measured absorbance of the phospho-molybdate complex.

e) Calcium and Magnesium

Ca^{2+} and Mg^{2+} in water samples were measured using atomic absorption flame spectrophotometry. To prevent interference, a solution of lanthanum chloride, calculated to give a final concentration of 800 mg l^{-1} La^{3+}, was used to dilute the samples. The samples were diluted to fall within a range of 0 - 4 mg l^{-1}. The absorption was measured at 422.7 nm for Ca^{2+} and 285.2 nm for Mg^{2+} on a Pye-Unicam SP 190 atomic absorption spectrophotometer calibrated with mixed standards which were also diluted with lanthanum chloride.

f) Iron and Manganese

The concentration of iron and manganese in peat waters were measured as in (e) above. The samples were diluted with deionised water to fall within a range of 0-2 mg l^{-1}. Absorption was measured at 248.3 nm for iron and 279.5 nm for manganese.

g) Sodium and Potassium

Na^+ and K^+ were measured simultaneously by flame emission spectrophotometry using an EEL 227 integrating flame photometer. This measures the amount of light emitted by Na^+ and K^+ when these elements are excited by a flame. The water samples and standards were diluted with lithium chloride to give a final concentration of 100 mg l^{-1} Li^+. The instrument was calibrated over the range of 0-10 mg l^{-1} Na^+ and 0-1 mg l^{-1} K^+.

h) Sulphate

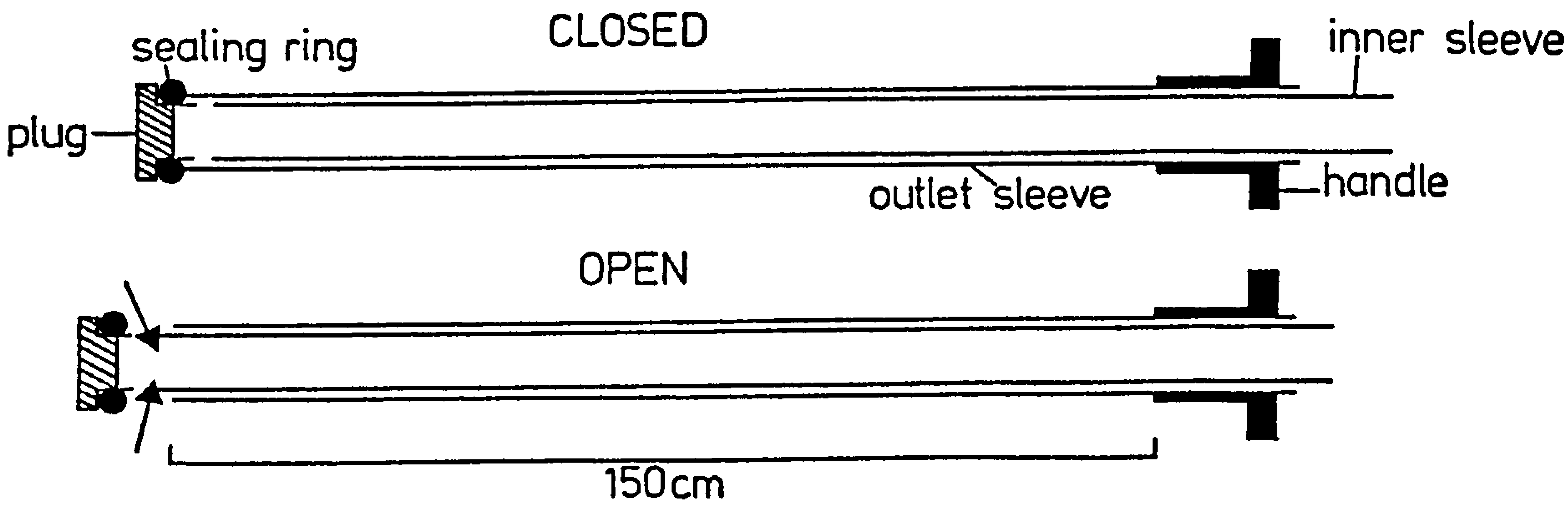
Sulphate concentrations in water samples were measured using a turbidimetric method involving precipitation of barium sulphate in an acid solution (Golterman *et al.* 1978). Samples were diluted to fall within a range of 0-10 mg l^{-1} SO_4^{2-}. The absorbance was measured with a white light source using an EEI Nephalometer Head and Unigalvo type 20 galvanometer.

i) Chloride

Chloride in water samples was titrated with mercuric nitrate using a diphenylcarbazone-bromophenol blue indicator solution. At the end point the excess Hg^{2+} produces a violet colour with diphenylcarbazone (Golterman *et al.* 1978)

2. SAMPLER FOR EXAMINATION OF VERTICAL STRATIFICATION OF PEAT WATERS

The sampler was constructed from two, closely fitting lengths of ABS pipe:



3. METHODS FOR DATA PROCESSING

One-way analysis of variance was performed on data sets of each chemical variable, at each time of analysis, using the SPSS MK 6 package sub-program ONEWAY. Duncan's New Multiple Range Test was used to separate the sites at the $P < 0.05$ level of significance. The Bartlett Box-F test was used to assess the heterogeneity of error variances, also at the $P < 0.05$ level of significance. The CLUSTAN IC package was used to compute cluster analyses with Ward's method of hierarchical fusion (Ward 1963).

APPENDIX 5

METHODS FOR THE DETERMINATION OF THE CONCENTRATION OF BISULPHITE IN RAINWATER

1. Principle

The method used to determine bisulphite concentrations is a modification of that formulated by West & Gaeke (1956) to measure sulphur dioxide concentrations. The principle of the method is the reaction of bisulphite (in rainwater) with sodium tetrachloromercurate (II) solution to form stable, non-volatile disulphitomercurate (II). This produces a red-violet colour when it reacts with *p*-rosaniline hydrochloride-hydrochloric acid mixture and formaldehyde; the absorbance of the resulting solution can be measured.

2. Procedure

Samples of rainwater were collected, by means of a funnel, into polyethylene bottles containing 2 ml of sodium tetrachloromercurate (II) solution. These were diluted to 20 ml with a known volume of deionized water and reacted with 2 ml of 0.01% *p*-rosaniline hydrochloride-hydrochloric acid mixture and 2 ml of 0.05% formaldehyde. The absorbance (1 cm light path) was measured at 560 nm using a Pye-Unicam SP 550 spectrophotometer. The measured absorbance was compared with that of a range of sodium metabisulphite standards (buffered to pH 4-6). All measurements were made within 48 hours of the fall of rain.

APPENDIX 6

DANES MOSS:

Report of site visit and management prescription

JUNE 1980

1. INTRODUCTION: DANES MOSS

Danes Moss is situated c. 3 km S.W. of Macclesfield, Cheshire. It comprises an area of cut-over raised bog approximately 200 acres (81 ha) in extent. Fisons Ltd., who carried out the commercial exploitation of the peatland, ceased cutting the moss in the 1950's.

The depth of the remaining peat is thought to be 1.3 m over most of the area. Subsequent to abandoning peat cutting operations, Fisons Ltd. gave the Cheshire Conservation Trust a section of the southern end of the moss. The northern part of the area is used as a rubbish dump by Cheshire County Council. The remaining central area of Danes Moss (Fig. 1), still belongs to Fisons and consists of dry cut-over peat colonized by *Betula pubescens* and a dense covering of *Molinia caerulea*. This area tends to be burnt off by local children at least once a year - and indeed was still smouldering after a recent burn at the time of this site visit.

2. DESCRIPTION OF CHESHIRE CONSERVATION TRUST RESERVE OUTLINING PREVIOUS MANAGEMENT

2.1 The flooding of the Trust Reserve

The original vegetation cover of the Trust Reserve was apparently very similar to that of the area immediately to the north of the Reserve - i.e. *Betula pubescens* with a dense covering of *Molinia* as already mentioned. In 1976/7, however, the water

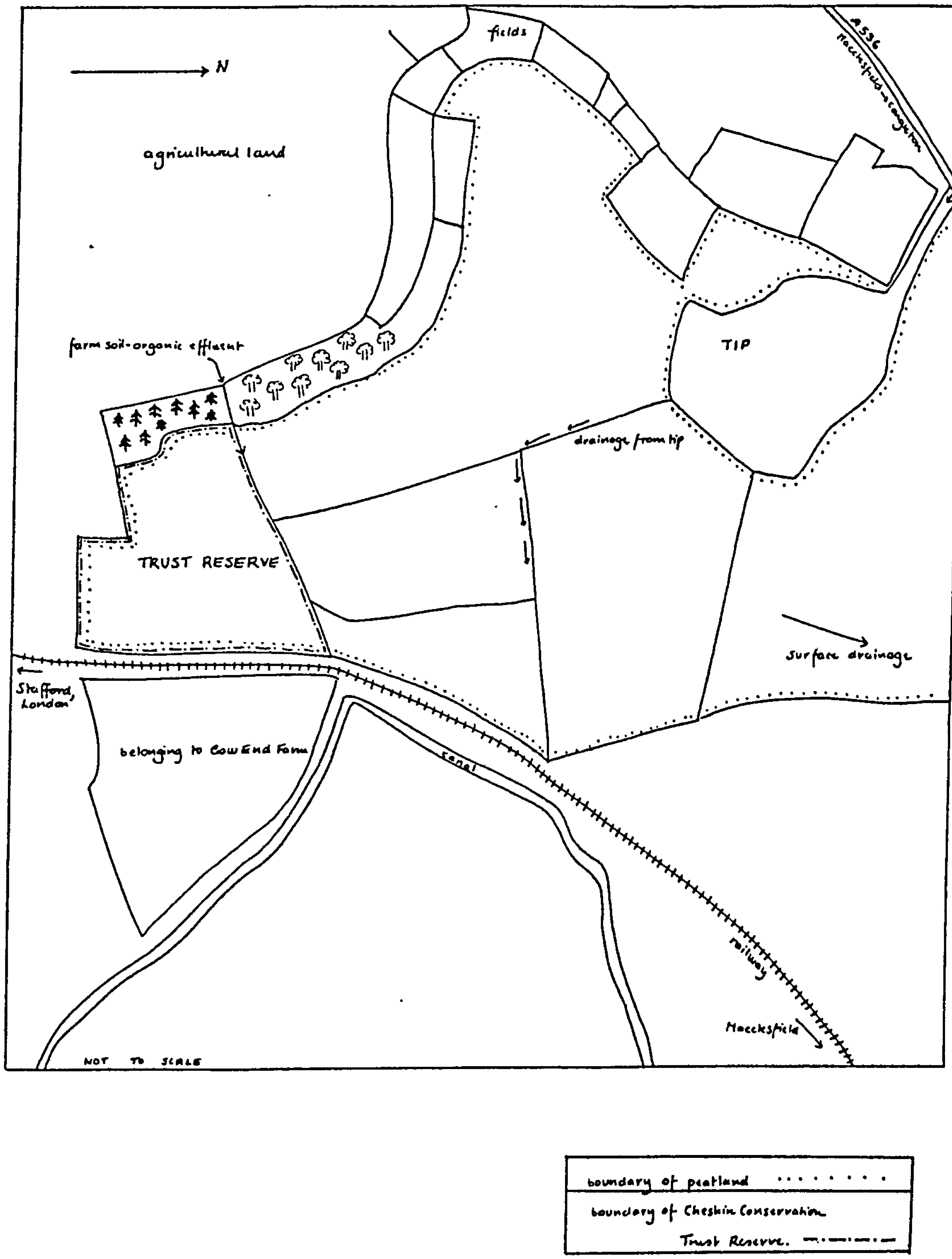


Fig. 1 Danes Moss.

table in the Reserve was substantially raised by the construction of strategically placed dams (Fig. 2). This was done with the aim of encouraging water fowl into the area and to encourage the growth of plants characteristic of an undisturbed mire surface and, indeed, other wetland plants.

The depth of water in the flooded area varies because the water is covering old cuttings, peat baulks and drains, running in a north-south direction. The tops of old peat stacks emerge from the water and are colonized by *Calluna vulgaris, Molinia caerulea* with some *Erica tetralix* and bryophytes such as *Cephalozia bicuspidata.* The irregular nature of these peat stacks seemingly allows colonization by a variety of plant species which have different requirements in relation to the height of the water table.

The open water area contains many young birch trees which seem to be dying (presumably as a result of water-logging) and tussocks of *Eriophorum vaginatum* which have built themselves up such that the live part of the plant is well out of the water. *Juncus effusus* clumps are in evidence but form dense stands only in the vicinity of a drain running parallel to the track which was apparently colonized by this plant prior to flooding. Emergent peat baulks are colonized by *Molinia, Betula pubescens, Calluna vulgaris* and bryophytes including *Sphagnum recurvum* and *Bryum pseudotriquetrum.*

It was gratifying to note the regeneration of *Sphagnum cuspidatum* which was present prior to flooding but had not been noticed in great quantities since then. This plant is evenly distributed throughout the water and in places emerges to give substantial inundated lawns.

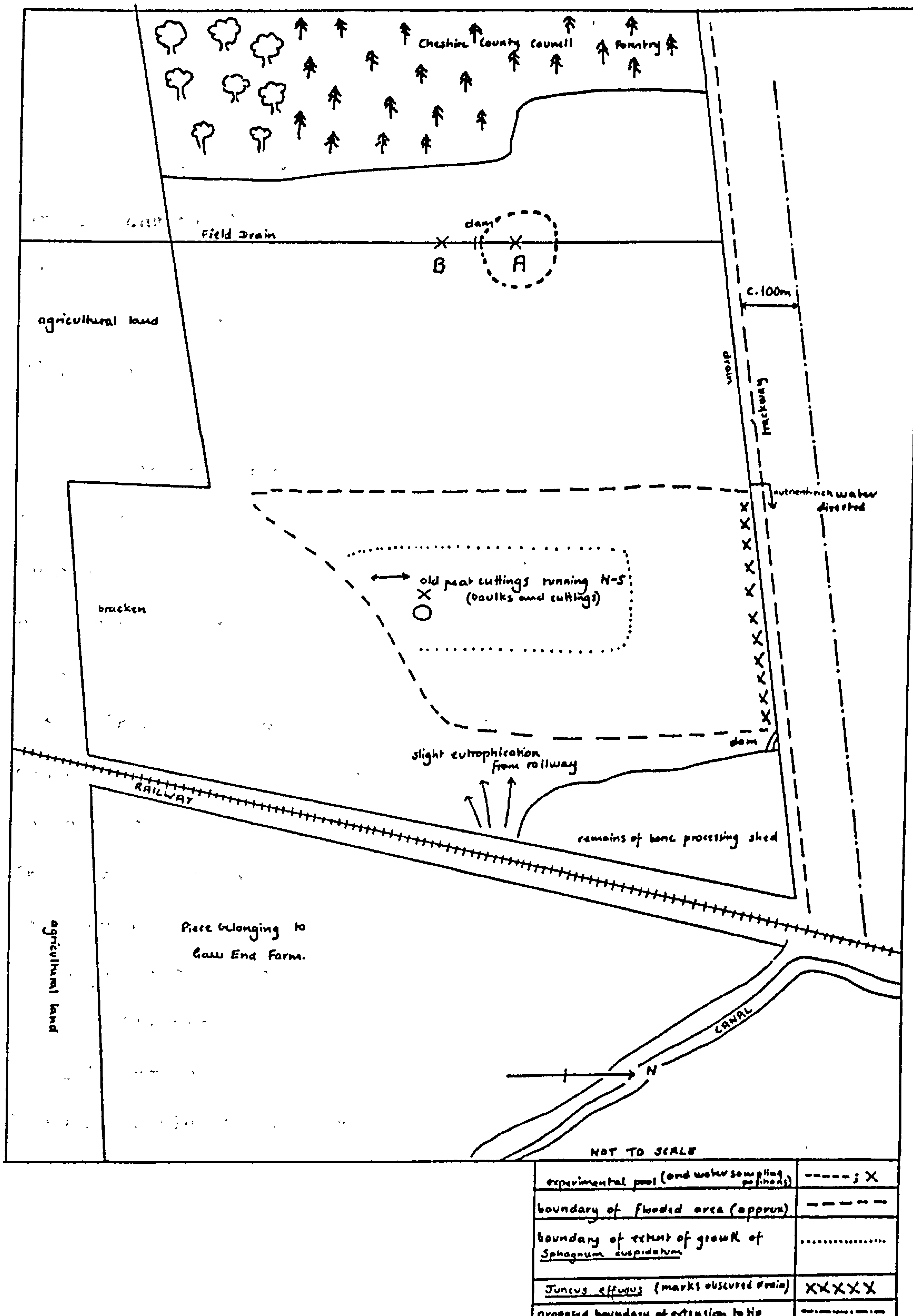


Fig. 2 Cheshire Conservation Trust Reserve.

In the vicinity of the western boundary of the flooded area, along the line of a now obscured ditch, a great quantity of *Drepanocladus fluitans* occurs. This gives the water a viscous green appearance. Before the area was flooded the aforementioned ditch used to back up with eutrophic water (from adjacent fields) and flood the northern part of the Reserve.

Other management practices implemented by Roger Meade, Reserve Manager at the time of flooding, were the nurturing of *Drosera rotundifolia* plants (some under a sheet of glass) and the placing of introduced hummock-building Sphagna (not present on Danes Moss), and *Andromeda polifolia* into a polystyrene box with a plastic netting base. The idea of the latter apparatus was to subject the plants to a constant water table (owing to the floating up and down of the polystyrene box) in the hope that seed and spores from these plants would colonize elsewhere. Unfortunately the box was eventually anchored down by *Eriophorum* roots penetrating the holes in the netting.

The water table in the flooded area fluctuates between about 100 mm in summer and 300 mm in winter. Some cation concentrations in water samples taken from this flooded area are given in Table 1.

2.2 The experimental pool

Drains carrying water onto and draining off the moss have also been subjected to some active management. Field Drain, running south-north from a farmer's field, runs into the drain adjacent to the main track; thereafter the nutrient-rich water is diverted away under the main track, so avoiding the flooded area. Tests on water samples have shown that there is a significant nutrient enrichment of Field Drain owing to runoff from the fields nearby. A pool has been excavated adjacent to, and continuous with Field Drain as shown on Fig. 2 and Fig. 3.

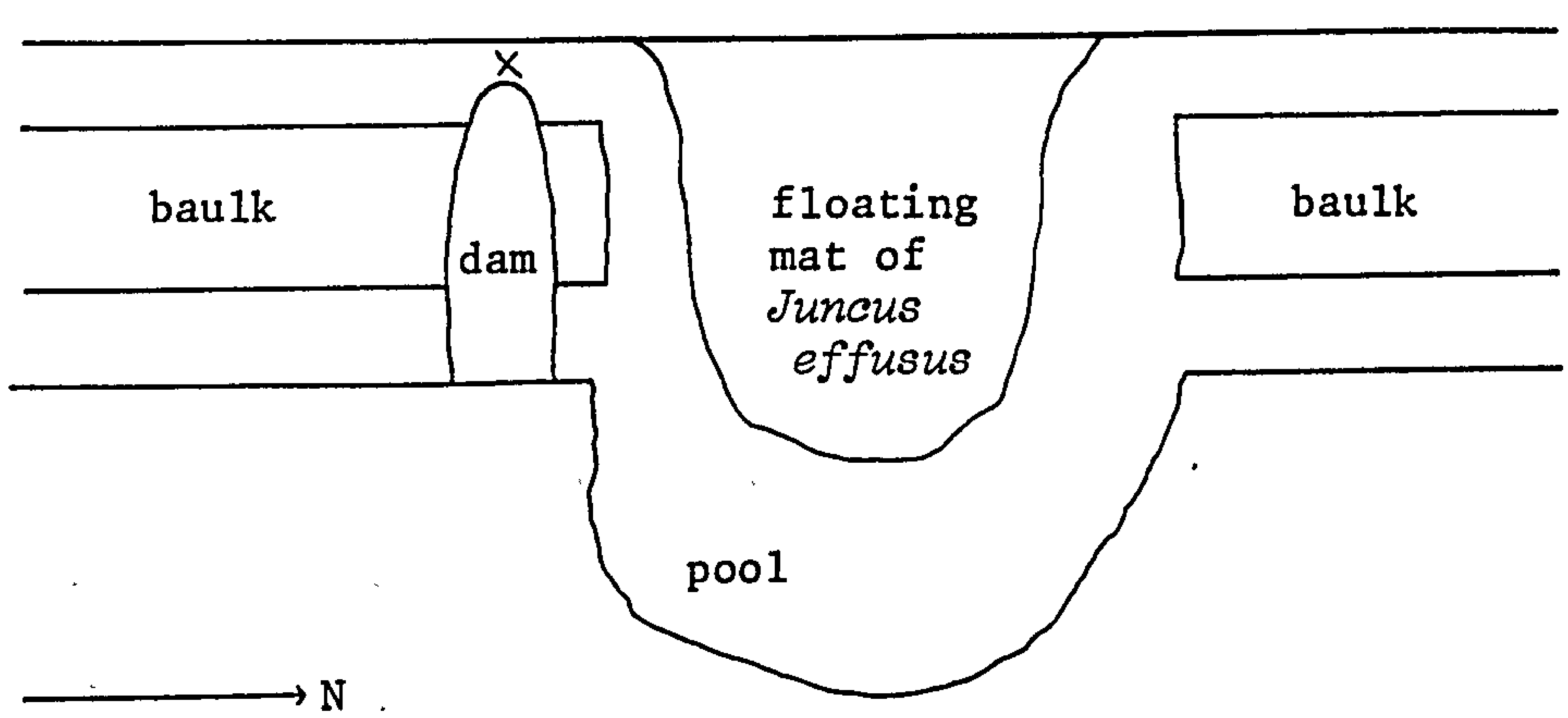


Fig. 3 Plan of the experimental pool (Fig. 2).

2.3 Other observations

The ditch adjacent to the railway appears to be slightly enriched owing to run-off from the railway ballast. Among the plants growing here are *Typha latifolia*, a species of *Callitriche*, *Juncus bulbosus* and *Potamogeton polygonifolius*.

Numbers of water fowl on the Reserve are apparently on the increase. At least two pairs of Canada geese as well as Mallard are breeding.

3. ASSESSMENT OF THE POTENTIAL FOR RECLAMATION AND CONSTRAINTS

3.1 The Cheshire Trust Reserve

In the Trust Reserve much of the management potential has already been realised - by the flooding of a substantial part of the area initially covered mostly by birch scrub and *Molinia*. It now seems all important to monitor the site and the floral and faunal response to flooding. One constraint here is the lack of a suitably qualified person to do the job.

It is suggested by Roger Meade that a porous box full of limestone chippings is placed in Field Drain in the place marked X on Fig. 3. The aim of this would be to increase the calcium concentration of the water entering the pool in order to encourage the growth of a poor fen vegetation.

3.2 The peatland area to the north of the Trust Reserve

In spite of objections made by Cheshire Conservation Trust, it appears that Cheshire County Council will extend the rubbish tip to within 100 m of the track forming the northern boundary of the Reserve (Fig. 2). It was felt that the wildlife potential of this area could be enhanced further if it were flooded in a similar fashion to the Trust Reserve. It is likely that this area will constitute a 'no man's land', and as such may be fairly easy to negotiate over with the relevant bodies. It was felt that it would be infinitely more preferable to have a strip approximately 200 m in width; this width also corresponds to a drain which could, in theory, act as a boundary drain. The close proximity of the rubbish tip constitutes problems to this area - whether flooded or left unflooded - as well as to the present Trust Reserve.

At present, the northern area of peatland is drained as shown on Fig. 1. It is possible, particularly with an increase in size of the rubbish tip, that the drains from the tip will become more polluted. This would then affect the strip it is proposed to flood and possibly the Trust Reserve as well. At present it is known that drains are polluted at least 200 m from the current tip front. Many invasive species have become established. A colony of Black-headed gulls also constitute a problem in that they may well be 'eutrophicating' the northern peatland area as well as the Reserve area. Again - an increase in size of the tip is likely to increase the scale of this problem.

4. MANAGEMENT PRESCRIPTION

4.1 The Cheshire Conservation Trust Reserve

In order to gain information on the effect of raising the water table in a cut-over peatland area (the aim of which is to encourage the re-establishment of species characteristic of undisturbed mires), the following is recommended:

1. Monitoring of the vegetation in the Reserve paying particular attention to the flooded area.

2. Monitoring of the water chemistry at several sites in the area including the previous sample sites in Field Drain and the area where water runs off from the railway ballast. The latter may shed some light on the effect of the nutrient input from railway ballast run-off. In addition, the effects of pollution owing to gulls or polluted drains from the rubbish tip may be determined.

3. The placing of a box of limestone chippings in Field Drain as already mentioned. The effect of an increase in Ca^{2+} ions should be monitored by observation of vegetational and water chemistry changes.

4. Particular attention should be paid to the progress of introduced plants such as *Caltha palustris*, *Carex rostrata*, *Menyanthes trifoliata* and *Potentilla palustris*. It may be thought desirable to introduce further species if these establish successfully.

4.2 The peatland area to the north of the Trust Reserve

It is recommended that the strip of derelict peatland between the proposed extension to the tip and the current boundary of the tip be managed. (It is understood that this would entail declaring the Reserve and the area under discussion a SSSI and negotiations with Fisons Ltd. and Cheshire County Council).

1. It is recommended that water levels be carefully raised. The aims of doing this would be the same as those given in 4.1. In addition the use of flooding to eliminate *Molinia* could be carefully monitored. The death of acres of vigorous *Molinia* tends to be exploited by algae and fungi, and 'blooms' occur which are detrimental to *Sphagnum* growth. On the Trust Reserve conditions have taken about 4 years to normalize - only now is *Sphagnum cuspidatum* re-establishing. Flooding this site has the further advantage that little is being put at risk by such an action (that is, no plants of any importance would be destroyed by water-logging).

2. No. 1 would entail a survey of the hydrology of the area to determine where dams should be placed to raise and control the water table. In addition the area should be sealed off from pollution from the rubbish tip.

3. Subsequent to flooding,monitoring of the vegetation and water chemistry is recommended (for the same reasons as given in 4.1).

APPENDIX 7

OBSERVATIONS ON CUT-OVER AREAS OF SOME CUMBRIAN PEATLANDS

NOVEMBER 1980

1. INTRODUCTION

The Cumbrian peatlands visited between 1 and 5 August 1980 were Glasson Moss, Wedholme Flow, Tarn Moss and Salta Moss. In every case the emphasis was on the cut-over parts of each peatland rather than on the intact and often more floristically diverse areas.

2. GLASSON MOSS, CUMBRIA (NY 2360; GRADE 1)

2.1 Site description and objective of visit

'Glasson Moss forms a small part (about 2.5 km^2) of a once extensive tract of raised mire along the south side of the Solway Firth. A good deal of the southern part of the mire has been cut commercially for peat, resulting in a dry surface with dominant *Calluna,* but the northern section has only been cut insignificantly around the margins' (Ratcliffe 1977).

The northern series of peat cuttings is shown in Fig. 1. The main objective of the site visit was to make observations on these peat cutttings which were presumably cut for fuel a number of decades ago. Unfortunately the precise time of cutting is unknown.

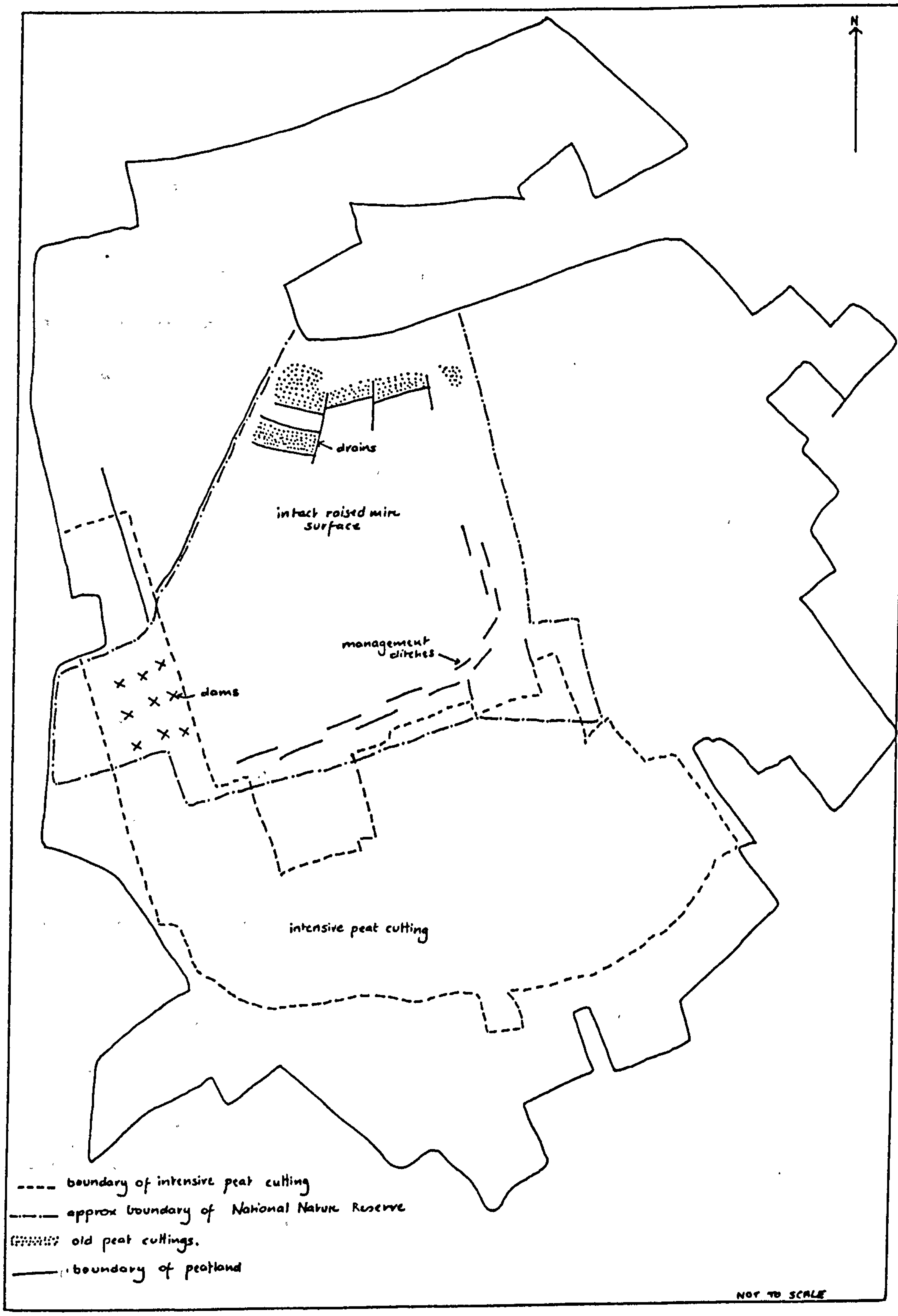


Fig.1 Sketch map of Glasson Moss NNR to show position of old peat cuttings.

2.2 Description of cuttings

The cuttings comprise a series of rectangular holes, typically measuring c. 3m x 4m. The regenerated surface is about 0.5 m below the surrounding peat. The original cutting depth could perhaps be determined by means of a peat borer.

It appears that the shape of the peat cuttings has allowed water retention and spongy *Sphagnum* lawns have developed. It is interesting to note that the species of *Sphagnum* dominant in the cuttings varies considerably. Lawns comprising almost 100% cover each of *S. recurvum*, *S. magellanicum*, *S. papillosum* and *S. cuspidatum* were observed. This variation may arise because the cuttings were originally cut to a variety of depths relative to the water table.

Certainly, now, the height of the present water table relative to the revegetated surface is variable. The water table in the *S. cuspidatum*-dominated cuttings, for example, is higher than in the cuttings dominated by *S. magellanicum*. It may be that one type of cutting will develop into another by 'hummock' species such as *S. magellanicum* colonizing and, therefore, lifting the whole surface of the vegetation higher relative to the water table. In this case the length of time since peat cutting was abandoned may be of prime importance.

Associated with the species of *Sphagnum* already mentioned are bryophytes such as *Aulacomnium palustre* and *Polytrichum alpestre*. *Odontoschisma sphagni* was not found in these lawns. *Drosera rotundifolia* is abundant on the surface of the *Sphagnum*. Other species present in the wet cuttings include *Eriophorum angustifolium*, *Dryopteris carthusiana* - the Narrow Buckler Fern, *Carex nigra* and much *Molinia caerulea*. The last three species are scarce on the intact raised mire surface. In some instances *Vaccinium oxycoccus* and *Andromeda polifolia* have colonized the cuttings. It seems that a microtopography consisting of a mosaic of hummocks and hollows, characteristic of an undisturbed mire surface, may be developing. Surrounding the *Sphagnum*-filled cuttings are drier peat baulks colonized by *Calluna vulgaris*, *Erica tetralix*, *Betula pubescens* and *Potentilla erecta*. *Sphagnum tenellum* is present mostly beneath *Calluna* bushes and *S. compactum* was also observed. Towards the extreme edge of the peatland thickets of *Betula pubescens* are developing and bracken, *Pteridium aquilinum*, is invading.

2.3 Management prescription

Because of their floristic characters and other features, the old peat cuttings described here are of great interest in their own right. It was felt, therefore, that any management activities carried out on Glasson Moss NNR should include the area occupied by these peat cuttings.

It would be interesting to cut further peat cuts of similar dimensions to those described; firstly to study the process of recolonization and secondly because it would probably encourage the growth of species characteristic of an undisturbed raised mire surface. It is recommended that cuttings be made in areas which are otherwise considered to be of little conservation interest.

As already indicated, the study of the stratigraphy of these peat cuttings would probably yield very interesting results.

Concerning the 1976 fire it should be noted here that, fortunately, the old peat cuttings were untouched. The view of Rose (1978) that if Glasson Moss is to survive no more fires like the 1976 fire must occur is strongly endorsed. It is gratifying to note that the management prescriptions outlined by Lindsay (1977) are being carried out. These have involved the construction of strategically placed fire ditches.

3. WEDHOLME FLOW, CUMBRIA (NY 2151; GRADE 1)

3.1 Site description

Wedholme Flow, lying between the villages of Kirkbride, Oulton and Abbey Town, covers an area of rather more than 3 square miles, and is, after Bowness Common, the largest of the Cumbrian Solway raised bogs. A great deal of the eastern part of the Flow is now being cut for peat commercially whilst areas in the northern half were so cut many years ago (Grieg 1975; Ratcliffe 1977).

The main interest here was in the area of old peat cuttings denoted as Q by Grieg (1975) and the northern section of the site which has been cut for peat more recently (Fig. 2).

3.2 The western peat cuttings (Q on Fig. 2)

This area has been cut such that it is now 2-3 m lower than the adjacent peatland (which has also been cut). At first sight the area appears flat and featureless as there is no division into peat baulks and wetter cuttings.

The proportion of bare peat (10% in some areas) and the young age of the vegetation suggest that the area has been recently burnt. The border ditch is well marked by lush *Molinia caerulea* and *Narthecium ossifragum*. The area nearest the main peatland mass has much young *Erica tetralix* growing directly on a wet peat surface, and, to a lesser extent, *Calluna vulgaris*. Where small hollows have become filled with c. 5 cm of water there are lawns

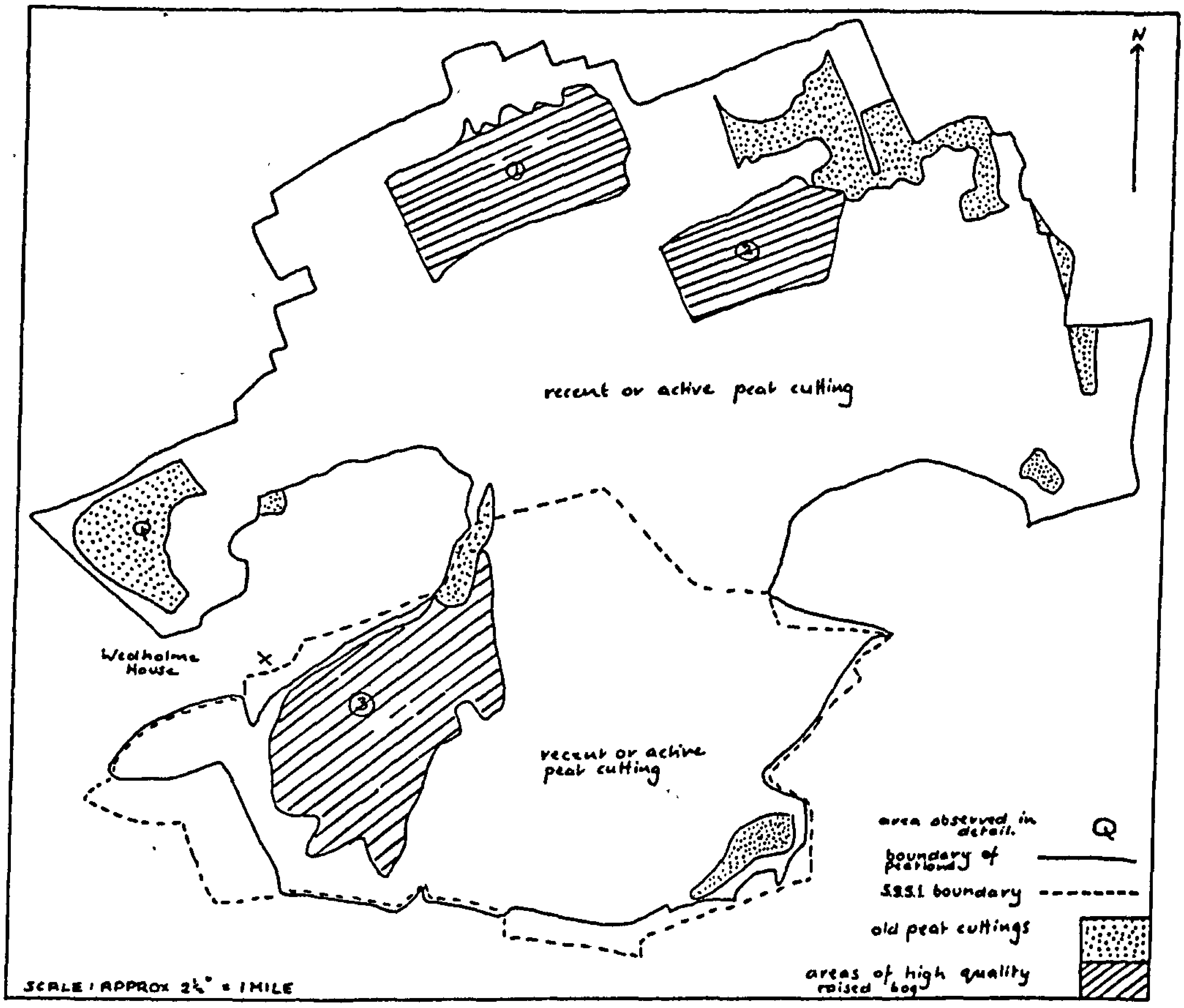


Fig. 2 Wedholme Flow: old peat cutting areas
(after Grieg 1975).

of *Rhynchospora alba,* and the lichen *Lecidea granulosa; Drosera rotundifolia* is in abundance growing on the peat. Of the Sphagna, only *S. compactum* and *S. recurvum* are at all well represented, the former growing on the bare peat; the latter associated with *R. alba* in the wet hollows. *Trichophorum cespitosum* and *Eriophorum angustifolium* are scattered evenly over this area. As has already been implied, the water table is approximately at the surface of the peat.

Towards the edge of the peatland, to the south-west, the nature of the vegetation changes, as that described above grades into a *Salix/Alnus* carr, on the very edge. Well developed hummocks of *Leucobryum glaucum* are present and vast tussocks of *Molinia* make the terrain quite treacherous. Where bare peat is visible here *Vaccinium myrtillus* is present. Other species include *Galium palustre, Sphagnum palustre, Polytrichum commune, Potentilla erecta, Dryopteris dilatata* and *Carex nigra.*

3.3 The northern peat cuttings (Fig. 2)

This band of peat workings spreads across the bog from west to east between two sections of good raised bog (marked 1 and 2 on Fig. 2). This area is outside the present SSSI boundary. Ratcliffe (1965) states that the 'northern half of the Flow was extensively worked for peat long ago, and has been repeatedly burnt, so that its vegetation belongs to the drier range from Callunetum to various types of damp heath'. Grieg's view (1975), that this area is in much better condition than Ratcliffe found it, is endorsed here.

The *Sphagnum* cover is rich and extensive - many substantial hummocks of *S. magellanicum* were observed. There are signs that a hollow/hummock microtopography is developing. *Drosera anglica, D. rotundifolia, Narthecium ossifragum, Andromeda polifolia* and *Vaccinium oxycoccus* are widespread and common.

3.4 Conclusions and management prescription

Considering firstly the northern band of peat workings, it appears that it has taken only fifteen years for an area almost dismissed by Ratcliffe (1969) to regenerate into an area of active raised bog. Clearly, the high quality raised bog areas (1, 2 and 3 on Fig. 2) will have acted as sources for the plants now growing in this region. The nature and rate of recovery here are both encouraging and interesting.

By contrast it seems that the area Q was too drastically disturbed originally to allow this sort of recovery. Some regeneration to raised bog may eventually occur, however, on the eastern-most margins, perhaps speeded up by the fact that the northern band of workings will more and more provide a seed/spore source.

To conclude, it is suggested that the SSSI boundary be extended to include the northern band of regenerating peat workings, and if possible the high quality intact areas (1 and 2). A full survey would need to be carried out to determine the precise limits of the area. This action is particularly recommended in view of Rose's high opinion of the S.W. lobe (Rose 1978), which, as he points out, is rather small.

3.5 Fauna

A Merlin was observed flying over the S.W. lobe of this site during this visit.

4. TARN MOSS, TROUTBECK, CUMBRIA (NY 4027; GRADE 1)

4.1 Site description and objective of visit

The Nature Conservation Review (Ratcliffe 1977) gives the following description of this site:

'This basin mire lies in a shallow, but apparently quite enclosed, elongated hollow in acidic glacial drift and is surrounded by poor quality upland pastures. The vegetation is mostly oligotrophic and the main interest of the site is the predominant poor-fen which forms a good example of this north British vegetation type. Very few true basin mires exhibit this type of vegetation and it is significant that here it is associated with a patchy development of acidophilous vegetation representing the initiation of still more oligotrophic surface'.

At Dr David Goode's suggestion, the aim of this site visit was to try to establish whether or not the area has been cut for peat. Very often a less oligotrophic vegetation type is linked with the removal of peat (as at Salta Moss or Thorne Moors, for example).

The site was entered from the eastern side by the road and was thoroughly explored for any sign of peat cutting. The ground was observed for baulks and depressions. None were apparent. On the western side, however, the ground is so tussocky with *Molinia caerulea* that any irregularities in the terrain would be obscured.

4.2 Conclusions

This site has not obviously been cut for peat. It is possible that the area was cut-away evenly, without the excavation of cuttings with alternating baulks, and in this case the detection of previous peat cutting is made very difficult. The idea that there has been some previous cutting activity is perhaps supported by the presence of the acidophilous nuclei previously mentioned which support, for example, *Calluna vulgaris*, *Erica tetralix*, *Empetrum nigrum*, *Andromeda polifolia* and *Sphagnum papillosum*. These nuclei suggest that this mire may be in a state of flux - that is that the succession is proceeding such that the poor fen is developing into an ombrotrophic mire. By this reasoning it may be the case that the poor fen constitutes a regenerating cut-over area moving back to its original state - that of ombrotrophic mire. One theory to account for acidification in the Norfolk Broads (themselves old peat workings) follows this reasoning.

Clearly a stratigraphical study of this area would be worthwhile.

5. SALTA MOSS, CUMBRIA (NY 0845; GRADE 3)

5.1 Site description

This is a coastal peatland lying within 1 km of the Solway shore. The moss lies over glacial sand deposits which cover the Permian Sandstone plain; the drainage water is nutrient poor with only moderate enrichment locally.

The whole area is much modified, with numerous overgrown peat workings and ditches, and it has been repeatedly burnt. This, along with the fact that the moss is probably intermediate between raised mire and valley mire (the ground rises markedly to the west and east), probably accounts for the extremely varied flora that exists here.

The vegetation ranges from highly acidophilous heath to mire, with local development of poor fen and intermediate communities, and at the eastern margins there are transitions to damp herbaceous meadow (Ratcliffe 1974).

5.2 Description of areas previously cut for peat

These areas could be picked out as lower-lying wetter areas into which irregular shaped,*Calluna vulgaris*-dominated,peat baulks jutted. A clear-cut pattern of peat workings could not be discerned (aerial photographs were not available, unfortunately, at the time of this visit).

Luxuriant lawns of *Sphagnum recurvum* have developed on the cut-over areas. This moss occurs with *Eriophorum angustifolium*, *Menyanthes trifoliata* and some *Juncus effusus*. *Hydrocotyle vulgaris* is also characteristic of the cut-over areas along with *Typha angustifolia*. In some places these lawn areas are extremely treacherous - it appears that a 'schwingmoor' type of regeneration has occurred whereby a carpet of vegetation has grown over open water.

The type of community described here can be termed poor fen, rather than ombrotrophic mire. This is perhaps because it developed on peat richer in nutrients than peat found on the surface of intact raised bogs. The workings may have penetrated 'fen' or 'sedge' peats laid down early on in the successional history of this mire.

In addition, the present mire community has developed along the water course of this valley; the very fact that water is flowing means that more nutrients will be supplied to the mire. The area immediately flanking the water course contains plants which are more tolerant of the slightly higher nutrient levels, for example *Potentilla palustris*. Towards the edge of the site in drier areas than the peat cuttings is a zone characterized by much *Vaccinium oxycoccus* and *Sphagnum papillosum*. Perhaps these plants were more numerous before the area was cut for peat. No *Andromeda polifolia* was observed. It may well be, then, that the rather unusual community described here is a result of the cutting of the original peatland which both laid bare a richer peat substrate and allowed the water course to flow through the area.

5.3 Management prescription

At the time of this site visit a fire had recently swept across the west of the moss leaving a substantial area of bare peat. Ratcliffe (1974) refers to a patch of c. 30 clumps of *Osmunda regalis* at NY 087450. This clump could not be found, despite an extensive search. It is possible (although not certain) that the fire has burnt at least the aerial parts. It is suggested that the clump of *Osmunda* be searched for during the next growing season.

An attempt has been made here to show that the vegetation growing on the cut-over areas forms a community which adds to the interest of the whole site. It would be informative to continue to monitor the regeneration of these peat cuttings. It may be interesting to remove some of the dry baulks and monitor the subsequent development of the vegetation.

As for most peatland areas, some form of protection from fire is desirable. However, the cost of excavating a ditch system along the lines of the one at Glasson Moss would probably be prohibitive.

5.4 Fauna

One adder, very dark in colour, was observed.

APPENDIX 8

FENN'S AND WHIXALL MOSS

Management prescription for cut-over and uncut areas of the moss

SEPTEMBER 1981

1. INTRODUCTION

The Fenn's and Whixall Moss complex is a much-modified raised bog occupying a comparatively shallow Late-glacial lake basin. The Clwyd/Shropshire border passes through the peatland; Fenn's Moss lies to the north in Clwyd and Whixall Moss to the south, in Shropshire. Bettisfield Moss, to the south-west of the Shropshire Union Canal, lies in both counties (Fig. 1). The area was designated a Site of Special Scientific Interest in 1957 and, following major boundary revisions in 1978, now covers an area of 608 hectares. Full botanical descriptions of these mosses and accounts of their history are given by Sinker (1962) and Day (1979).

Most of the site has been cut for peat to a greater or lesser extent. The wide range of peat cutting methods employed and dates of abandonment have led to the existence today of a diverse flora of considerable interest. This report is concerned with outlining a management prescription for a variety of cut-over areas and the few remaining regions of intact peatland on the site. Where relevant, comparisons are made with other cut-over peatland sites, especially Thorne Moors, S. Yorkshire. Areas discussed are located on Fig. 1; their precise extent, unfortunately, is unknown.

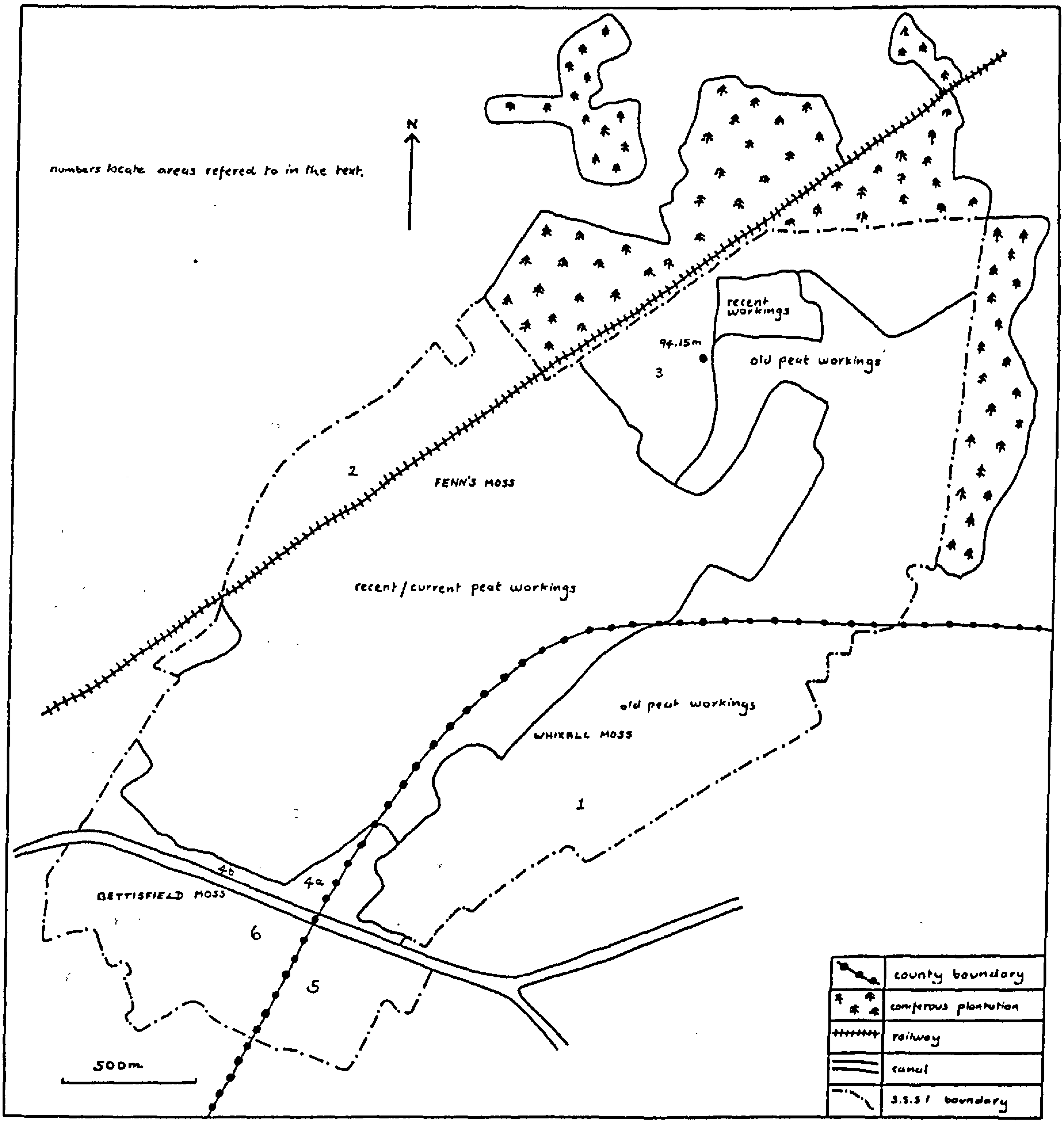


Fig. 1 Fenn's and Whixall Moss complex.

2. AREA 1

This area contains disused 'cases' (rectangular areas of cutting) very variable in shape and size. The cases are generally about 1 m in depth because interest has been and still is (peat is currently extracted at a slow rate) for the top layer of white peat for horticultural purposes. Below this layer is black or fuel peat.

The nature of the vegetation in the cuttings depends mainly on the depth of cutting, local hydrology (drainage), time of abandonment, ability of species to recolonize a suitable substrate and local burning history. The management procedure applied to these cuttings, in order to create communities characteristic of undisturbed raised bogs, will depend on the same factors.

Most of the cases have floors which lie approximately at the level of the internal water table of the bog. These parts tend to contain *Sphagnum papillosum, S. recurvum, Eriophorum vaginatum, Narthecium ossifragum, Erica tetralix* and *Drosera rotundifolia*. In other cuttings the water table is above the base of the cut. These water-filled cases bear *Sphagnum cuspidatum, Eriophorum angustifolium, Utricularia minor* and *Drepanocladus fluitans*. From the management point of view it is fortunate that the cases are mostly as described. Some, however, are quite dry indicating that the water level is below the floor. Here the cut should either be deepened to make it wetter or, if the water table is only just below the surface, be blocked off securely by a substantial wall of peat (about 1 m thick and as tall as the wall of the case). The latter treatment will cause the water table to rise slightly and impound collecting water. These cuttings lend themselves to this type of management because very often a case has only a small opening in the wall through which water may drain away. A few cuttings may contain a depth of water too great to allow colonization by bog plants. Here a drain should be cut to a depth that allows surplus water to flow away. The drain should be cut such that it can easily be blocked up should the cutting get too dry. Another means of promoting colonization of particularly wet cuttings is to place the surface sods on to the cut-over surface. This practice, sometimes known as 'shoeing' introduces the plants, allows them to grow on a firmer substrate and prevents oxidation of the exposed peat surface. Local peat cutters should be encouraged to do this, although in fact to some extent, they already do.

In the older cases many of the species of an undisturbed raised bog survive and flourish. Species such as *Rhynchospora alba*, *Empetrum nigrum*, *Sphagnum magellanicum* and *Aulacomnium palustre*, however, are absent from the workings. It is not clear why this should be so. On Thorne Moors atmospheric pollution in the form of bisulphite formed from sulphur dioxide may be preventing recolonization, particularly by the Sphagna, but such pollution is unlikely to be important in this area. Whatever the reason for the absence of the above species from the peat cuttings, it is worth trying to introduce them. Plants should be selectively removed from other areas of the moss where they are more plentiful and replaced at levels relative to the local water table equivalent to their natural position on an intact raised bog.

In the past a Dutch variety of *Molinia caerulea* (known locally as iron grass) has been deliberately seeded onto trackways to help bind the surface peat. This practice should be discouraged as this invasive plant has spread into the drier levels of the workings, thereby preventing colonization by other bog species. (As the tussocks and wiry roots of *Molinia* are an impediment to cutting, it seems likely that in any case re-seeding will no longer be carried out).

The use of burning, either to remove surface vegetation prior to cutting or to control the adder population (Sinker 1962), should be controlled and limited as fire encourages the spread of birch scrub.

In conclusion, cutting in this area, on this scale, is highly conducive to the attempted recreation of communities characteristic of undisturbed raised bogs. Cutting to 1 m allows the water table to be reached and in addition, because a substantial thickness of peat is left (probably at least 2 m; Day 1979) there is no chemical interference from the underlying mineral substrate. On Thorne Moors the shallow depth of peat in some areas appears to be restricting colonization by species characteristic of ombrotrophic systems. The various 'steps' and shelves remaining in abandoned cases could eventually be made to support communities which form equivalents to the microtopographic levels represented on an intact raised bog.

3. AREA 2

The area of Fenn's Moss to the north of the railway contains small workings similar to those in area 1. The cuttings were abandoned in the 1920's apart from a small area of about 2 ha which is currently being worked by hand. The management procedures outlined for area 1 should also be applied here.

Being nearer to the highest point of the moss complex (which occurs in area 3, at a point 94.15 m above sea level), this area is quite dry and the water table well below the surface. As such, the area has suffered periodic burning, both accidental and deliberate, which appears to have initiated the spread of birch. The removal of birch by a combination of cutting followed by chemical treatment of the stumps could be attempted. Seedlings of *Pinus sylvestris* appear to have spread from the 12 year old plantation to the north and east of Fenn's Moss onto the area. These should be removed as they will tend to dry out the area further.

Rubbish dumping, which has led to localized eutrophication and the introduction of plants uncharacteristic of peatlands, should be prevented wherever possible.

4. AREA 3

The north-eastern end of Fenn's Moss is the largest unworked area in the moss complex. It is the highest part of the whole site and is generally characterized by dry heathland communities, dominated by *Calluna vulgaris*, *Erica tetralix* and *Vaccinium myrtillus*.

Small, gentle-sided hollows and old ditches at the edge of the site contain species characteristic of wetter situations, including *Sphagnum papillosum*, *S. recurvum*, *Andromeda polifolia* and *Vaccinium oxycoccus*. These depressions may be former peat workings. If possible, small, similar shaped holes should be excavated near to the present area of hollows in order to create further similar communities.

Pine and birch invasion may have been encouraged by the repeated burning of the area in the past. Where possible, these invasive species should be controlled by methods outlined in previous sections.

5. AREA 4

A small uncut, triangular area at the south-western corner of Whixall Moss (area 4a on Fig. 1) preserves some trace of the hollow/hummock microtopography which the rest of the bog has lost. The *Sphagnum* cover is very good; extensive lawns of *S. magellanicum* and *S. papillosum* occur with many other species characteristic of undisturbed raised bogs, such as *Odontoschisma sphagni*, *Vaccinium oxycoccus*, *Narthecium ossifragum*, *Andromeda polifolia*, *Rhynchospora alba* and *Drosera rotundifolia*.

It is very important to protect this area totally. (Potential threats are burning, birch invasion, peat cutting and eutrophication following rubbish dumping). Apart from its intrinsic interest, the area will serve as a seed and spore source to the surrounding cut-over regions. In addition, observation of this area demonstrates the state of the original bog surface in terms of species composition and microtopography and will help to indicate the type of communities which ideally will be created in the cut-over areas. Many cut-over raised bogs, such as Thorne Moors, have no intact areas to allow such comparisons to be made.

The uncut area is bounded to the south by the line of the Shropshire Union Canal. Water percolating from the boulder clay embankment onto the moss has produced an alder-dominated marginal fen or carr. This area, of interest in its own right, is fully described by Day (1979). Beyond this 'lagg' is a strip of bog about 15 m wide (area 4b on Fig. 1), apparently cut to a slightly lower level than the natural surface. An 'edge effect' is shown by the presence of base-demanding species such as *Scorpidium scorpioides* and *Riccardia latifrons* (Sinker 1962). Apart from these species, however, the vegetation is not dissimilar to that of area 4a described above. Prominent hummocks of *Sphagnum magellanicum* and *Sphagnum subnitens* coexist with abundant *Rhynchospora alba, Erica tetralix,* and *Narthecium ossifragum.* As such it is recommended that the area be totally protected, for similar reasons, from the hazards outlined in relation to the small uncut section.

6. AREA 5

Area 5 is a large, enclosed area of open water dominated by *Eriophorum vaginatum* with *Sphagnum cuspidatum* and *S. recurvum*. The community may have arisen as a result of an unsuccessful attempt to create a 'duck pit' by explosion (Day 1979).

An area like this poses problems as do similar areas on Thorne Moors and to a lesser extent Danes Moss, Cheshire. The vegetation is not very diverse and the depth of standing water may be too great to allow the type of recolonization that is occurring on abandoned surfaces in areas 1 and 2. If the water table were lowered, however, invasion of pine and birch may occur from the surrounding woodlands. In addition, lowering of the water table may adversely affect other areas, notably area 6. It is recommended, for the time being, that the water table be kept at its present level and that regular checks be made to observe how the community composition is altering. (Day's (1979) site 22 information offers a good starting point). It would also be interesting to discover the fluctuation of the water table here. Intact raised bogs exhibit little water table fluctuation, and too great a fluctuation is thought to be detrimental to colonization by species characteristic of undisturbed bogs (Dr D A Goode 1980, personal communication). This could easily be achieved by inserting a piece of drainpipe about 1 m in length into the peat. After initial measurement of the height of the pipe from the peat 'floor', regular measurements of the water level inside the pipe could be made to ascertain the fluctuation occurring.

7. AREA 6

Extensive *Sphagnum* lawns cover this area, dominated by *S. recurvum* with some *S. papillosum* and *S. magellanicum*. Small pools contain *S. cuspidatum*. Associated higher plants include *Empetrum nigrum*, *Vaccinium oxycoccus*, *Andromeda polifolia* and young trees of *Pinus sylvestris*.

Day (1979) considers this area to be unworked but this is probably not the case. Amateur stratigraphy reveals that a loose *Sphagnum* carpet has developed over a firmer layer of *Eriophorum angustifolium* peat about 1 m down. The present day community seems to have developed over an abandoned cut-over area.

Pine trees are invading this area from the surrounding regenerating woodland. It may be that the wetness of the area, (presumably due to being near the lowest point of the moss complex), will kill off the trees naturally, by their sinking into the moss as they get older and heavier. If, however, the pine invasion continues, artificialcontrol should be pursued.

The existence of this area is interesting and the fact that such a community can develop on a cut-over area bodes well for the rest of the moss complex. This area should be protected, particularly from drainage, as well as from further cutting and fire.

8. GENERAL REMARKS

The current situation concerning planning permission to extend peat working is unknown.

If either of areas 3 or 4a is to be cut, it would be worth negotiating for small pieces to be left so that the complete vegetational history of the site (as provided by pollen and stratigraphical studies) may be preserved.

The collection of fresh *Sphagnum* by florists for packing purposes, which apparently still occurs, should be discouraged from all areas.

Finally, the management of areas undergoing mechanised peat extraction - mainly confined to Fenn's Moss - will have to be assessed when cutting is abandoned and the remaining peat depth and topography are ascertained.

NODUM NO.	1						2							4						5				8			6			7					10					3				9								
QUADRAT NO.	1	4	7	2	3	5	6	28	27	10	11	13	8	12	18	46	17	19	41	14	51	47	49	20	22	21	15	50	52	16	44	45	40	24	30	34	36	42	48	9	25	23	33	26	29	35	37	31	39	38	43	32
SPECIES																																																				
Eriophorum angustifolium	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Calluna vulgaris	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+
Eriophorum vaginatum	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Betula pubescens	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Erica tetralix	+	+	+	+			+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+	+	+	+
Polytrichum alpestre	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+			+				+				+	+	+		+		+	+	+	+	+	+			+	+	+	+	+	+	+	+	+
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Pohlia nutans		+	+	+	+	+	+	+	+	+	+	+	+					+	+	+	+	+	+		+	+				+	+	+	+	+							+								+			
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Campylopus introflexus	+	+			+	+	+	+													+												+	+																		
Calypogeia trichomanis	+	+	+	+	+	+	+												+																																	
Polytrichum juniperinum	+	+	+	+	+	+																																														
Polytrichum piliferum	+	+	+		+																																															
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Sphagnum recurvum						+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+		+	+	+	+			+		+		+	+	+				+	+	+	+	+	+	+	+	+	+	+	+	+
Sphagnum fimbriatum						+		+	+							+	+	+	+	+	+	+	+	+	+	+					+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
Sphagnum cuspidatum									+										+		+																			+	+	+		+	+	+	+	+	+	+	+	+
Drepanocladus revolvens																									+															+	+			+	+	+	+	+	+			
Drepanocladus fluitans																																	+												+	+		+			
Vaccinium oxycoccus										+																								+						+	+	+	+									
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Andromeda polifolia																+		+															+		+				+	+	+	+	+	+							
Juncus effusus												+												+	+	+	+		+	+				+						+	+	+	+									
Quercus robur			+			+														+	+	+	+						+																							
Molinia caerulea				+	+																			+	+	+																									
Salix cinerea													+					+		+	+					+	+					+								+											+	
Sphagnum squarrosum																		+																		+	+							+					+			
Aulacomnium palustre													+																				+										+								
Pinus sylvestris				+														+																																	
Carex curta																																									+	+						+			

Table 3.2 Vegetation survey MS: Species present in quadrats in peat cuttings and on peat baulks in the pNNR. Quadrat locations are shown in Fig. 3.3; nodum names are given in Table 3.4.

429.

APPENDIX 9

SHAPWICK HEATH NNR:

Discussion of current and possible future management policies

SEPTEMBER 1982

1. INTRODUCTION

1.1 The Somerset Levels

The Somerset Levels comprise some 169,000 acres (68,391 ha) of low-lying flats extending over the flood plains of three major rivers, the Brue, Axe and Parrett, which flow into the Bristol Channel. They are bounded by the Mendip Hills to the north and east, the Oolitic escarpment to the south-east and the Quantocks to the west.

In historic times the Somerset Levels consisted of a series of raised bogs with intervening areas of marsh and fen. Most of the area has now been drained and peat has been cut extensively. The remaining areas of scientific interest are now isolated blocks (Ratcliffe 1977).

1.2 Shapwick Heath NNR

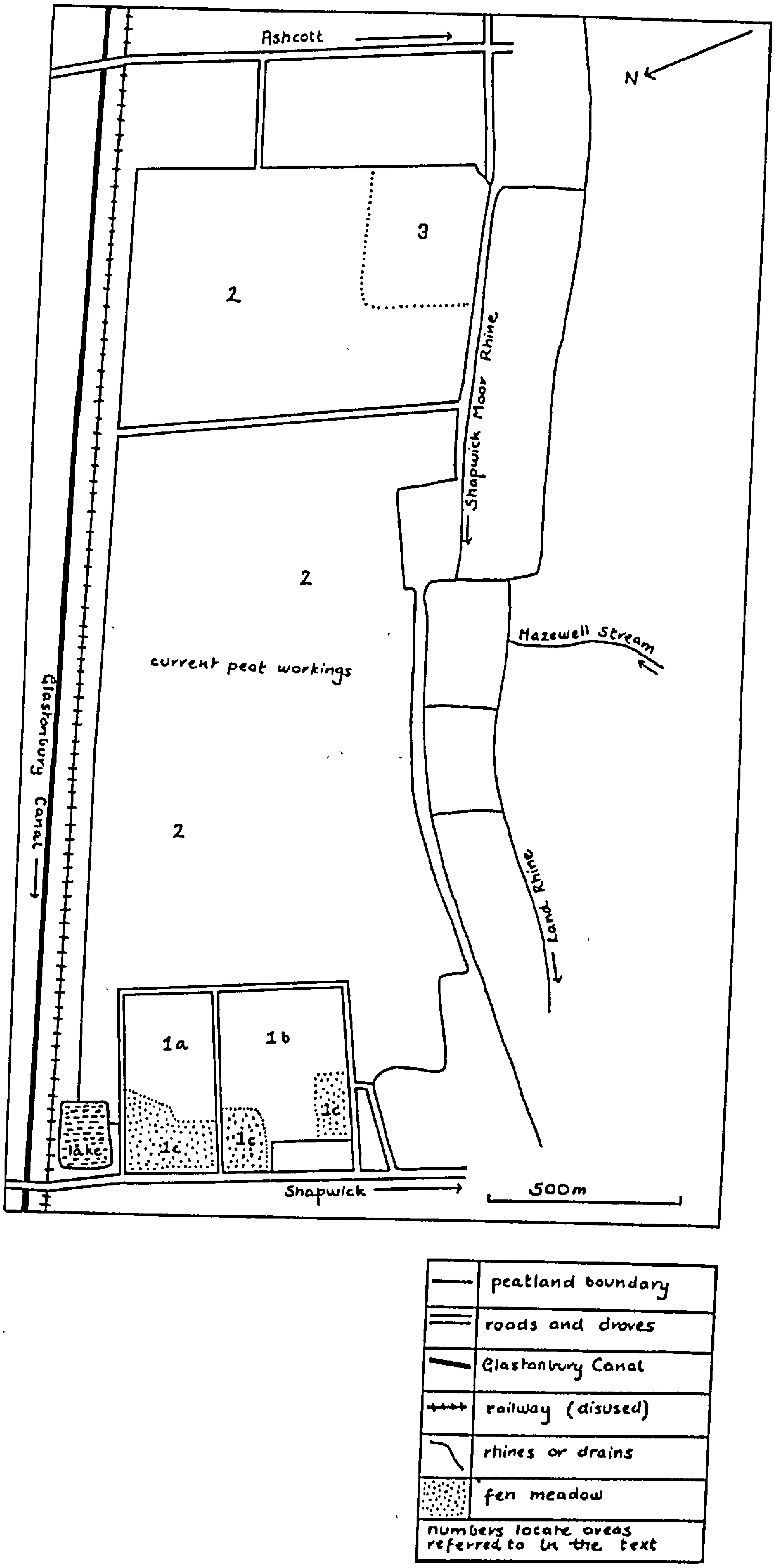
Shapwick Heath NNR, about 5 km west of Glastonbury, is part of the once-extensive peat moor which developed between the Wedmore and Polden ridges (Hope-Simpson, Newton & Ricketts 1962; Willis 1967). The southern margin of this much-modified raised bog almost meets the gentle slope of the Poldens; it covers an area of c. 2 km^2 and lies at an altitude of 4 m.

By 1961, when the Nature Conservancy negotiated a nature reserve agreement covering the majority (c. 500 acres; 202 ha) of the site, the whole of Shapwick Heath had been cut for peat to a greater or lesser extent (Hope-Simpson & Willis 1955). At this time, in fact, the site had existing planning permission for peat extraction but it was considered that, with the 'old fashioned' slow systems of working, this did not present a serious threat. Soon after, however, the land was purchased by Fisons Ltd., and by use of up-to-date methods, extraction rates rose dramatically. Today c. 450 acres (182 ha) are being worked commercially and it is unlikely that more than 72 acres (29 ha) of the original National Nature Reserve will survive undisturbed.

1.3 Scope of this report

The problems involved with managing the areas that have not been cut for peat intensively and the after-use of the commercially worked out areas are discussed in this report. Where relevant, comparisons are made with other cut-over peatland sites, especially Thorne Moors, S. Yorkshire. Areas discussed are located in Fig. 1.

Fig. 1 Shapwick Heath NNR.



2. AREA 1

This area consists of a block of peatland, adjacent to the current peat workings (area 2), about 50 acres (20 ha) in extent. For more than 10 years Fisons Ltd. have deferred peat operations here, at the request of the Nature Conservancy Council, in order to protect the Shapwick fen meadows (area 1c).

2.1 Vegetation of areas 1a and 1b (Fig. 1)

The vegetation of areas 1a and 1b consists of a tall carr dominated by birch and sallow, developed on an area which has, at one time, been cut. Other species include *Myrica gale*, *Molinia caerulea*, *Potentilla erecta*, *Calluna vulgaris* and *Erica tetralix*. Several plants of *Peucedanum palustre* and one clump of *Osmunda regalis* were observed. Hummocks of *Sphagnum fimbriatum* and lawns of *S. recurvum* and *S. squarrosum* are common.

2.2 Management of the water table in areas 1a and 1b (Fig. 1)

In order to prevent this carr from developing into a woodland, and to encourage the growth of species characteristic of undisturbed raised bogs and fens, the water table should be kept as near to the surface as possible. Also, the peat in area 1a contains a length of ancient trackway, which, if it is to be preserved, must be kept continually wet. There is clearly a problem here as Fisons Ltd. actively pump to bring the water table below the current excavation level and this block of peat now lies about 2 m above that level. The water table is currently being maintained at as high a level as possible by means of pumping the water from Fisons' workings into area 1a, as shown in Fig. 2. Several problems, however, have been encountered in using this technique. Firstly, in spite of the building of a clay wall (c. 1 m thick) around the area and an arterial network of ditches designed to distribute water within the area, the water tends to back up in the direction of the pump. This is presumably because the water is being pumped into a relatively low-lying part of area 1a. The pressure of this backward movement of water may be one reason why a long fissure has developed in the 'wall' of peat above the current workings. The 'wall' presently threatens to collapse into the Fisons' area. Another problem with this system is that area 1b (which is higher than 1a) and the western end of 1a are not being kept wet enough.

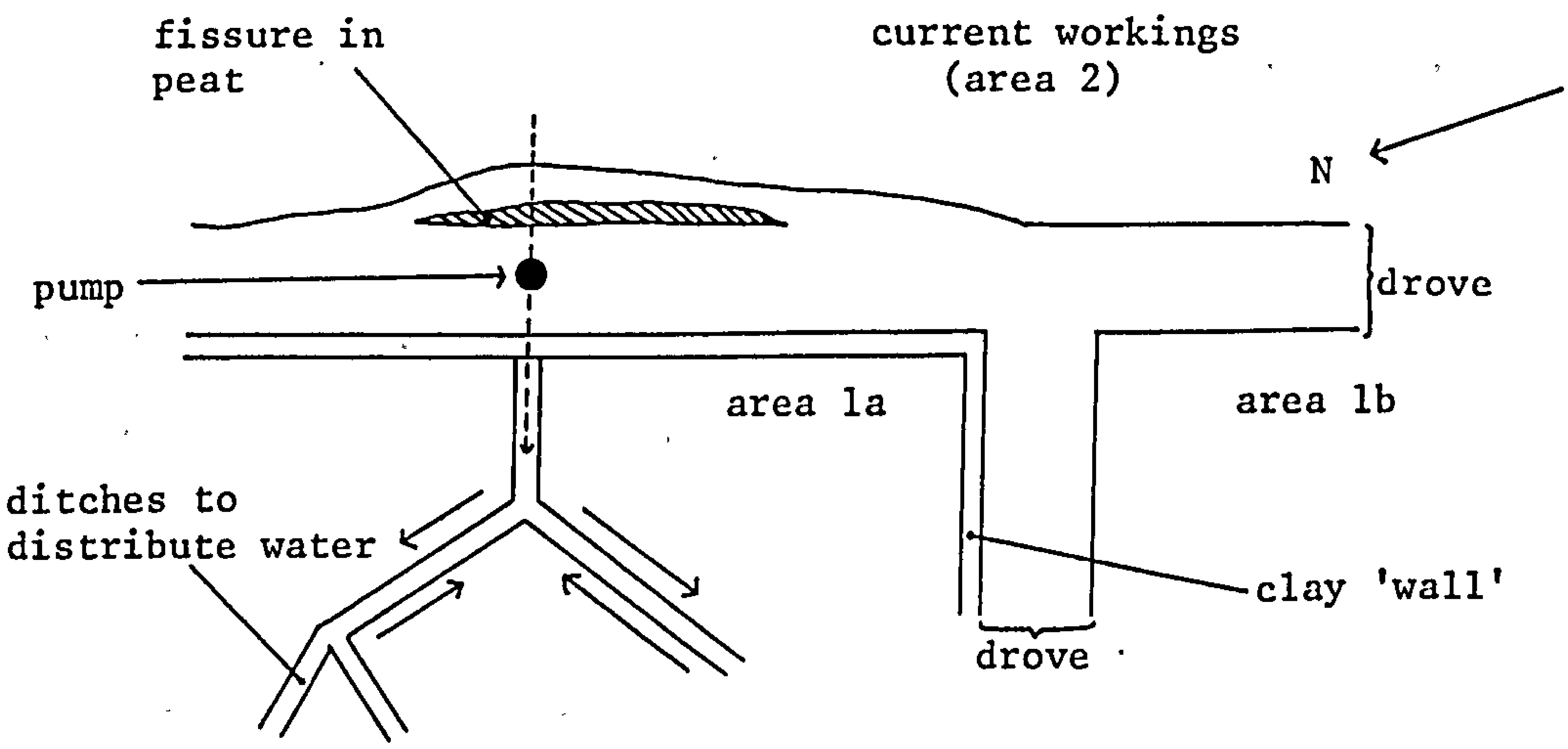


Fig. 2 Plan to show means of transferring water from the current workings into area 1a.

To solve these problems it is proposed to seal off the 'wall' of area 1 with a clay bund or embankment. Water would then be pumped directly into area 1b, percolating into area 1a and the fen meadows. A grant from the Somerset Archaeological Society, who wish to ensure the preservation of the section of ancient trackway, may be available for this work.

Once this scheme has been carried out it is recommended that checks be made on the pH and concentrations of chemicals within the circulating water. As Fisons Ltd. approach the clay underlying the peat in area 2, concentrations of certain nutrients may rise and these may have an adverse effect on the vegetation of area 1. If the water table does not rise sufficiently to initiate the eradication of birch, a policy of cutting, and perhaps chemical treatment of the stumps, should be pursued.

2.3 Shapwick fen meadows

Shapwick fen meadows are re-vegetated peat cuttings which have developed under the influence of base-rich waters from the surrounding hills. They exhibit a diverse vegetation characteristic of base-rich fens (Ratcliffe 1977) which is maintained by, and depends on, a traditional farming system of mowing or grazing. One deviation from the traditional methods practised here is the introduction of supplementary feed (hay) into the meadows. This invariably contains seeds of invasive, opportunist species which germinate and tend to eliminate the fen meadow flora. If possible the co-operation of the local farmer should be sought and the practice discouraged. In common with the rest of the area the water table should be maintained at, or just above, the peat surface.

3. AREA 2

Area 2 comprises c. 450 acres (182 ha) of peatland currently being worked commercially by Fisons Ltd.

3.1 The after-use of area 2

It seems likely that Fisons Ltd. will be able to remove all of the peat, right down to the underlying clay, as the lowest layers consist of soft *Phragmites* peat. By contrast, at Thorne Moors, S. Yorkshire, Fisons have abandoned areas covered by c. 50 cm of wood peat which their machinery is apparently unable to tackle. The situation at Thorne thus offers some possibilities for the rehabilitation of peatland plant communities. Given the situation at Shapwick, when Fisons have finished working the area, it would be desirable to attempt to establish beds of *Typha latifolia* and *Phragmites australis*, the latter being a vegetation type which must have covered large expanses of land in the Somerset Levels 8,000 years ago when peat began to form. Other fen plants could eventually be introduced in an attempt to re-create fen communities. Beds of *Typha latifolia* and *Phragmites australis* would also serve to lower the nutrient status of water being pumped into area 1.

3.2 The 'Avalon Lakes' scheme

Plans for the after-use of this area have, however, already been made. Since the mid 1960's the Wessex Water Authority (and formerly the Somerset River Board) have considered that there is a potential to use the worked-out Somerset peat excavations for flood water storage and water supply purposes. A recent strategy suggested by Somerset County Council proposes that (subject to successful feasibility tests) a series of 9 lakes covering a total of 2000 acres (809 ha) could be developed (Nature Conservancy Council, S.W. Region 1977). Dubbed the 'Avalon Lakes', it is suggested that these reservoirs would also cater for amenity interests such as recreation and wildlife conservation.

One lake has already been developed at Shapwick. It has been proposed that lakes within the boundaries of Shapwick Heath NNR be set aside for wildlife. This view is endorsed. The expanses of open water are likely to favour some species of birds but it is probable that problems will be encountered in attempting to establish vegetation in an artificial lake lined with plastic sheeting. However, an attempt could be made to establish peatland vegetation in isolated basins within lakes if it were possible to line them with a layer of peat. In addition, reed beds could be established in lakes lined with a clay substrate.

4. AREA 3

4.1 Vegetation of area 3 (Fig. 1)

Area 3, c. 20 acres (8 ha) in extent, consists of a matrix of fen meadows and a more ombrotrophic vegetation type developed on cut-over areas. The latter vegetation type is dominated by *Myrica gale*, *Molinia caerulea* and *Eriophorum angustifolium*. *Eriophorum vaginatum* is rare. This is perhaps fortunate; at Thorne Moors tussocks of *E. vaginatum* appear to exclude other species, particularly Sphagna. The area is divided into strips (perhaps reflecting past peat cutting methods) by slightly raised baulks generally colonized by birch, *Ulex europaeus*, *Calluna vulgaris* and *Potentilla erecta* and lower lying areas with sallow, *Erica tetralix*, *Sphagnum compactum* and *S. palustre*. Wet hollows and ditches contain *Equisetum fluviatile* and lawns of *Sphagnum recurvum* and *S. squarrosum*.

4.2 Management of area 3

The area is presently managed by cutting down gorse, birch, *Myrica gale* and sallow on a strip rotation basis. To prevent the development of this community into a birch or sallow carr, it is recommended that this is continued regularly. Ditches in the area were enlarged by the Conservation Corps in 1978 to prevent their becoming completely overgrown. The effect of this management policy has been to encourage the growth of *Sphagnum* lawns.

If possible, it is recommended that the Conservation Corps excavate hollows with sloping sides in the drier areas down to the water table, in order to encourage the development of *Sphagnum* lawns characteristic of the wetter areas. The presence of extensive *Sphagnum* lawns in the area might eventually cause the initiation of ombrotrophic nuclei which would allow species characteristic of undisturbed raised bogs to colonize and spread.

Any attempt by Fisons to cut this region should be strongly resisted because, apart from the existence of the present community, this area offers the greatest potential for the re-creation of raised bog communities.

5. GENERAL REMARKS

The re-creation of communities characteristic of ombrotrophic mires in any of the areas discussed will probably be rendered extremely difficult owing to the nutrient status of the water in the vicinity: the pH and concentrations of anions and cations in water pumped into area 1, inundating the fen meadows or associated with the underlying clay are likely to be greater than those which characterize ombrotrophic mires. In this case, a management policy of maintaining and creating poor (or even rich) fen communities should be pursued.

Further management problems may be encountered as the water table in the whole reserve is lowered by the continued attempt, in the whole of the Somerset Levels, to lower the water table to 'improve' agricultural land.

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Ph.D. Thesis

ENCLOSURES

TABLES 3.2 AND 3.3;

FIGS. 5.7a, b, c and 5.8a, b, c.

ENCLOSURES IN BACK POCKET APART FROM TABLE 3.2 UNAVAILABLE.