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THE HYDROLOGY OF WICKEN FEN

A project carried out for the National Trust

FINAL REPORT

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1 Introduction

Wicken Fen is a 605-acre tract of calcareous fenland lying on the periphery of the Black Fens, and in the ownership of the National Trust. The Fen consists of three sections: Wicken Sedge Fen, the area lying to the north of the Wicken Lode, and two areas of lower ground to the south of the Lode, Adventurers' Fen and St Edmund's Fen. This report refers only to Wicken Sedge Fen. A long period of cropping for "sedge", the great fen sedge *Cladium mariscus*, for thatching and "litter", a mixed herbaceous community containing reed *Phragmites communis* and purple moorgrass *Molinia caerulia*, for animal bedding had created a broad expanse of open fen vegetation, which has largely succeeded to carr in the years since the decline of cutting. The history of the exploitation of Wicken Fen for peat, sedge and litter has been discussed in detail by Rowell (1983)[1]. Today a significant area (44 acres of litter and 26 acres of sedge out of a total of 330 acres on Wicken Sedge Fen) is maintained as fen by cutting, a labour-intensive operation, which is now justified on conservation grounds rather than as an economic activity.

The Fen owes its preservation, in the face of increasing agricultural use of the East Anglian peatlands, to early designation as a nature reserve and its position adjacent to high-level channels, the Wicken Lode and Monk's Lode. The Wicken Lode is linked directly into the internal dyke system of the Fen: this is not the usual arrangement in the Fens, and may owe its origin to the use of the larger dykes for the transport of peat, sedge and litter. Wicken Fen represents a remnant of a once-extensive landscape, an almost vanished habitat and a traditional way of life which is now known to the general public only through rural museums.

Wicken's historical associations and conservation value are further enhanced by the detailed scientific work carried out on the Fen over the years. Some of the results of these investigations, particularly those of Professor Sir Harry Godwin and his associates, have been used in the maintenance of the semi-natural habitats of the Fen, by careful cutting and cropping practices; nevertheless changes have occurred in the fen vegetation since the 1920's when the most significant studies were performed. Large areas of the Fen have developed carr vegetation, a trend noted by Godwin in 1931, and there are now signs of acidification of the surface horizons, indicated by the presence of acidophilous mosses, particularly in those areas covered by carr. It is possible that these changes are associated with a decline in the fen water table relative to surface level, or a change in the pattern of variation of water levels over the year.

A recent management proposal for part of the Fen, based on scientific conclusions by Godwin and Bharucha, was the removal of peat by a commercial extractor, followed by the replacement of the surface peat containing the seed bank. The fen community could thereby be recreated at a lower level, with a higher relative water level. However, the scheme was not without its dangers, not least of which was the possibility of the establishment of a new fen community less diverse than the old.

The hydrological behaviour of Wicken Fen was first investigated by Godwin and Bharucha over the years 1928-30, and has since been the subject of rather discontinuous work, summarised by Gowing (1977). Thus, when the new management proposal was advanced, it was without the support of the archive of hydrological information that could have been built up over the last fifty years if the early work had been followed up on a routine basis and related more firmly to Ordnance Datum.

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1 Rowell T A (1983) The history and management of Wicken Fen - Discussion Paper 1 Land use at Wicken Fen since c1600, Dept. of Applied Biology, University of Cambridge.

The Institute of Hydrology was commissioned to conduct a further investigation of the water regime of Wicken Fen, to establish a firmer basis from which to examine management proposals. The IH work was to take place over three years, and to cover several aspects of the natural behaviour and possible management of the Fen. In particular, it was essential to explore the relationship between the components of the water balance of the Fen, which would have a significant effect on the chemical composition of water in the peat, and to determine the relationship between dyke water levels, flows from and into the dykes and the groundwater level in the Fen.

Since the start of the study, the original proposal to lower the ground level of part of the Fen has been superseded by a collaborative venture between the National Trust and the Anglian Water Authority to improve the bank separating the Fen from drained agricultural land to the north, at a lower level than the Fen. This engineering work has undoubtedly improved the chances of maintaining high water levels in the northern part of the Fen, and if followed up by work on the southern bank of the Wicken Lode the problem of lowered water levels could be solved. However, the IH study will still be of benefit in deciding the way in which the dyke network is used to control fen water levels.

This final report describes the results of three years' work, which has comprised installation of hydrological instrumentation on the Fen, and the collection of regular measurements by National Trust staff. The interpretation of the data is discussed in detail, and significant results have emerged from the consideration of water level relationships and the water balance. This has also been a unique opportunity to add to the archive of information on Wicken, and to explore further the ideas advanced by Professor Godwin so many years ago.

1.1 Past hydrological work at Wicken

In 1928 Godwin set out to make accurate measurements of the variation of water level at Wicken, and installed a continuous recorder in litter vegetation near the junction of Drainer's Dyke and the Main, or Sedge Fen, Drove. For two and a half years he recorded the effects of rainfall, a seasonal drift, and regular diurnal fluctuations (Godwin 1931)[2].

Godwin used the response to rainfall to give an estimate of the effective porosity, or specific yield, of the peat, by comparing the magnitude of the rise in water level for a given rainfall input. The rise in groundwater level was generally between 7 and 12 times the rainfall, suggesting that the effective porosity is around 10%.

The most significant deduction from the seasonal pattern was that the summer fall in water level in the fen was related to the increased transpiration, and not to reduced rainfall in summer, or to any manipulation of levels by the lock-keeper at Upware. The seasonal variation repeated itself quite closely from year to year.

The final and most convincing piece of evidence relating the summer fall in fen groundwater level to evaporation was the presence of diurnal fluctuations, with a fall in level during the middle of the day and a partial recovery at night. The effect became marked during July and August, and ceased by the end of September. A more sensitive, but not continuously recording, apparatus was set up in a burnt area, and in developing carr, to test the hypothesis that transpiration was largely responsible for the daily change in water level.

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2 Godwin H (1931) Studies in the ecology of Wicken Fen - I The groundwater level of the Fen, *J Ecology 19*, 447-473.

A lysimeter was set up in the litter community to measure the transpiration effect without the added complication of the lateral inflow that could cause the overnight recovery in level. This experiment confirmed that in the absence of lateral flow, the water level fell during the day and did not demonstrate any recovery.

Further confirmation of the controlling factors for the diurnal fluctuations was obtained by moving the recorder to two sites further away from drainage channels: at these sites there was no appreciable overnight recovery. Measurement of the daily fall in groundwater level, making allowance in the case of the litter community near the dyke, for the lateral inflow by extrapolating the overnight rate of rise, Godwin concluded that carr transpired at less than half of the rate of the litter, and that this might have significant effects on the local water levels within the Fen.

Godwin and Bharucha (1932)[3] followed up the earlier study with a more intensive investigation of local spatial variations in groundwater level, using a network of pits dug at various distances from Drainer's Dyke. Over a short period in May 1930, rainfall had a dramatic effect on the water table, and this rain was followed by flooding caused by increased levels in the Lode, which was deliberately penned. The most rapid changes in water level during the subsequent period of drainage were confined to a strip about 25 metres wide along the bank of the dyke, the interior of the fen, distant from drainage channels, being largely unaffected by changes in dyke water levels. The high groundwater level on the fen expanse during winter and spring led Godwin & Bharucha to the conclusion, which is certainly not valid in summer, that "the fewer dykes are kept open, the wetter the fen will be".

During the summer of 1930, more measurements were taken of water level in the pits across the Fen. These disclosed that the fen water table acquired a "saucer" shape, with the water level distant from the dyke being between 0.4 and 0.8 m lower. There were pronounced local variations in water level, which Godwin & Bharucha attributed to differences in transpiration and in the permeability of the peat. In winter there was standing water in places and much more opportunity for the movement of water on the surface and through the more permeable surface layers of the peat, leading to a much more uniform water level over the Fen.

In 1974, Gowing (1977)[4] installed a continuous water level recorder of a similar design to Godwin's, re-commissioning Godwin's "litter" station near the junction of Sedge Fen Drove and Drainer's Dyke. This site had by then been colonised by *Frangula* carr. In 1976 a second recorder was installed in a triangle of land close to the confluence of Drainer's Dyke and the Wicken Lode: this recorder was sited on a pit that was connected directly with the dyke, and was an indicator of Lode water level. Gowing found that the groundwater level at the carr site varied between 1.5 mOD and 2.3 mOD, while the dyke level varied over a much narrower range, between 1.75 mOD and 1.95 mOD.

Gowing attempted to compare his results with those of Godwin, but he had doubts about changes in the ground level, possibly caused by peat shrinkage or wastage. However, Rowell (1983) noted that Godwin almost certainly referred his personal "Fen Zero Level" to the Liverpool datum, so that Gowing's measurements could be compared directly. Assuming that there was no change

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3 Godwin H & Bharucha F R (1932) Studies in the ecology of Wicken Fen - II The Fen water table and its control of plant communities, *J Ecology 20*, 157-191.

4 Gowing J W (1977) The hydrology of Wicken Fen and its influence on the acidity of the soil, unpublished MSc thesis, Cranfield Institute of Technology.

in the surface level, Gowing's results suggested that average Lode levels had fallen by about 200 mm, and summer fen groundwater levels were correspondingly lower.

Gowing's estimates of the effective porosity, obtained by the same method as Godwin's, but with an uncertainty deriving from possible interception of rainfall by the carr canopy, varied between 10 and 33%, but the more reliable estimates in his table lay in the range 10 to 15%, with the latter figure being favoured.

Perhaps the most surprising aspect of Gowing's results was the absence of the overnight recovery in groundwater levels during a period of strong diurnal fluctuations. He concluded that the lowering of groundwater levels had reduced the lateral flow from the dyke. The autumn rise in levels, which was attributed by Godwin to the excess of lateral flow over transpiration, was also delayed, and there was no rise in the absence of rainfall, even when daily evaporation was very low.

However, Gowing recognised that the recorder in the carr was showing levels as much as 300 mm above those in the fen expanse. Observations of water level along transects between Drainer's Dyke and the eastern edge of the Fen showed water table levels between 1.5 mOD and 1.7 mOD, with curvature of the water table within 40 m of the Lode. These measurements suggested that inflow was still affecting the recorder in the carr.

1.2 The present study

Many years have passed since Godwin's work, and the present study was aimed at determining the hydrological behaviour of the Fen as it is now, without undue reliance on data obtained at a time when communities, and possibly dyke levels, were very different. It was important in the context of the present study, to obtain data simultaneously from many different areas of the Fen, and, although continuous water level recorders of the required sensitivity are now available "off the shelf", it was not possible to install, maintain, or process the data from, more than a couple of continuous recorders. The major part of the observation network, therefore, was composed of tubewells, penetrating well below the water table, read by National Trust staff using an electric contact gauge at weekly or fortnightly intervals. These wells were supplemented by staff gauges installed on the major open water bodies.

2 The measurement program

When the IH study started, there was no routine measurement of water level at Wicken, in spite of its obvious importance as a controlling variable. The first priority was the establishment of a network of stations for water level measurement, at which frequent and regular observations could be made. For reasons of cost and travelling time, it was not possible for IH staff to be involved in the routine collection of data on the Fen, so it was agreed that the National Trust would provide a person to undertake the measurements, generally on a weekly basis. A data form was prepared so that the measurements could be entered in order on a tour of the Fen: the more remote stations around New Dyke were visited an alternate weeks.

In May and June 1984, a team from IH installed a network of shallow boreholes for groundwater level measurement, staff gauges on the Lode and principal dykes, and two continuous water level recorders on boreholes near the centre of the Sedge Fen. So that the boreholes could be used to study the relationships between dyke levels and fen groundwater levels, they were not distributed evenly around the site, but were generally grouped in straight transects perpendicular to dykes, with an interval of about 10 metres between the boreholes in each transect. This layout provides a basis for comparisons between the new data and Godwin's early work. Two observation pits dating from Gowing's (1977) work were included in the observation network, and one of these had been located by Gowing at the site of one of Godwin's more significant recorder stations. Thus a small element of continuity has been incorporated into the study, though conclusions on long-term changes in water level must necessarily be guarded.

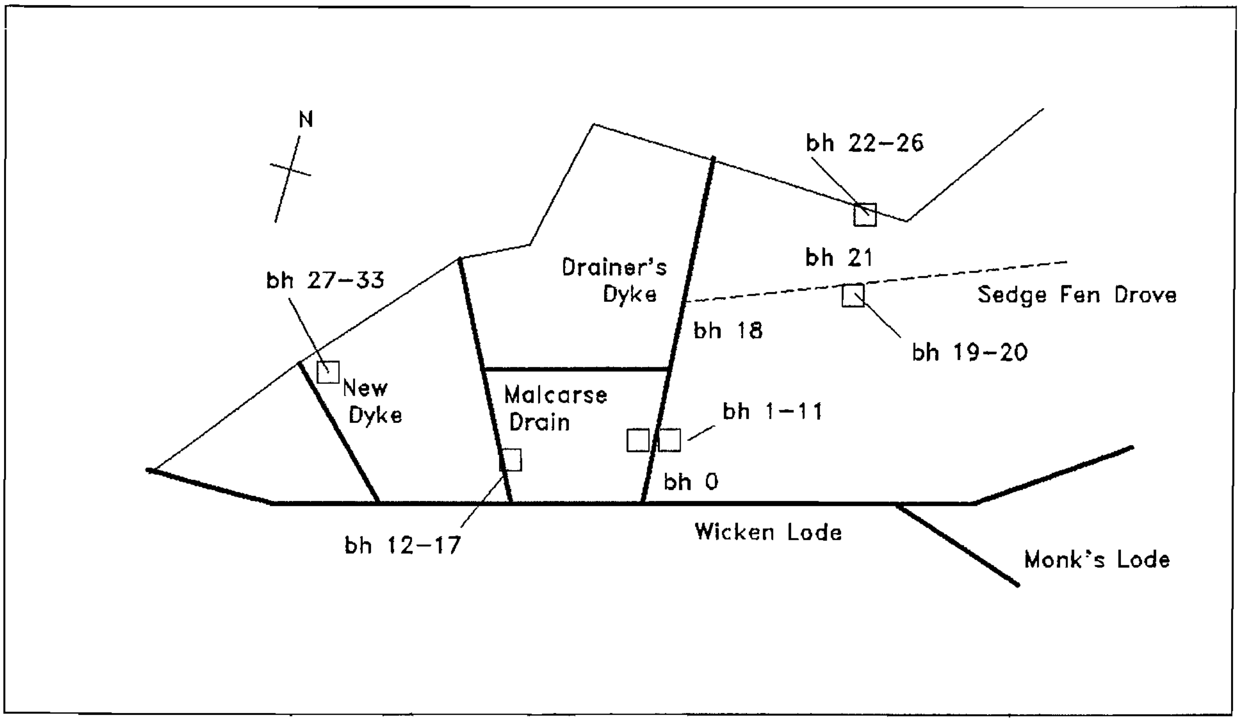

Figure 1 Location map of installations on Wicken Sedge Fen

Figure 1 shows the stations in the network, while the following is a brief description of the stations in the order in which they appeared on the observer's data form:

(i) Wicken Lode 'near' gauge board (sg 1)
A 1-metre staff gauge was installed in the Lode a short distance from the William Thorpe Building. This gauge, fixed to a stake and concealed among emergent vegetation, was read daily, and often more frequently.

(ii) Gowing's triangle recorder site (bh 0).
The floats for Gowing's continuous recorders were mounted in shallow pits with wooden linings. One of these pits, connected by a pipe with Drainer's Dyke, was located in a triangular patch of scrub at the junction of Drainer's Dyke and the Lode. In recommissioning this pit, it was subjected to the same 'development' procedure as freshly-installed boreholes: a pump was used repeatedly to extract all the water in the pit, until the accumulated sludge had been removed. A good hydraulic connection with the surrounding peat was indicated by a steady influx of relatively clean water. Measurements of depth to water level are taken in this pit and the boreholes of the network using an electrical contact gauge, referring all measurements to a marked point on the rim of the casing. This station was considered as an indication of the level of the Dyke.

(iii) Drainer's Dyke borehole transects (bh 1-11)
A transect of boreholes was installed at each side of the dyke, that on the east extending into a litter field reclaimed from carr in 1981 and 1982. This field had been cut twice in 1983. The western transect extended into sedge fen cut in 1983. Each borehole was excavated to a depth of two metres using a Jarrett post-hole auger, and a perforated plastic casing was inserted. The boreholes were developed by pumping, and capped to exclude rainfall.

(iv) Wicken Lode/Malcarse Drain staff gauge (sg 2)
Another staff gauge was installed at the junction of the Lode and Malcarse Drain, to give another indication of Lode levels, and to show if there were seasonal changes in water surface slope.

(v) Malcarse Drain borehole transect (bh 12-17)
A transect of six boreholes was installed in dying carr to the east of Malcarse Drain, south of Cross Dyke. Since installation this area has become essentially a litter community.

(vi) Godwin Main Drove recorder (bh 18)
Godwin, and much later Gowing, sited a recorder on a pit near the junction of Drainer's Dyke and the Sedge Fen Drove. This pit, now surrounded by carr, was developed by pumping in the usual way, and was dipped on a weekly basis.

(vii) Drainer's Dyke 'top' staff gauge (sg 3)
A staff gauge was installed at the northern end of Drainer's Dyke, close to the point at which pumped drainage water from adjacent agricultural land is introduced into the Dyke.

(viii) Continuous recorders (bh 19 and 20)
Two Ott R16 continuous groundwater level recorders were set up on boreholes in an area of 'litter', cut in 1983, adjacent to the Sedge Fen Drove. The more easterly of the two boreholes (Bh 20) was in 'litter' vegetation that was scheduled to be cut again in 1984 and thereafter in alternate years, while the other (Bh 19) was in a field that would be cut in alternate years from 1985.

(ix) Godwin wrecked recorder (bh 21)
North of the Sedge Fen Drove, close to a sinuous drove cutting through to the Spinney Bank, the wreckage of what was almost certainly one of Godwin's water level recorders was found. One of Godwin's recorder pits (number 6a) was sited some 100 metres to the west of this spot. A borehole was installed near the wreckage to form a link between the Drainer's Dyke transect, the newly-installed recorders and the Spinney Bank stations.

(x) Spinney Bank borehole transect (bh 22-26)
The Spinney Bank forms the northern boundary of the Fen, against agricultural land at a much lower level. A farm ditch at the foot of the Bank drains the agricultural land, and a ditch in a rather overgrown condition separated the reserve path from the summit of the Bank. Five boreholes were installed in the first instance, extending from the Bank into the carr, and, with the farmer's permission, into the field towards the farm ditch. However, one of these boreholes (bh 23) was damaged, probably by a vehicle, and was not used after the first few weeks.

(xi) Spinney Bank staff gauges (sg 4 and 5)
Staff gauges were installed on the reserve ditch at the top of Spinney Bank, and on the farm ditch at the foot of the Bank.

(xii) New Dyke borehole transect (bh 27-33)
New Dyke is the most westerly and probably the newest of the north-south dykes dividing the Fen, and was recently cleared over part of its length. While the work was proceeding, it was noticed that the Dyke was channelling Lode water rapidly into an area adjacent to the western edge of the Fen, along Howe's Dyke, and work was stopped. The southern end of the Dyke is now blocked by a wooden dam. At the northern end of the Dyke, near Howe's Dyke, a transect of boreholes was installed leading from the New Dyke into the fen. A second proposed transect, perpendicular to Howe's Dyke, could not be set up, as the carr bordering the fen was impenetrable.

(xiii) New Dyke staff gauge (sg 6)
A staff gauge was fixed to the Dyke side of the New Dyke dam, to indicate the difference in levels between the Dyke and the Lode.

2.1 Weekly measurements

2.1.1 Drainer's Dyke transect (east)

The boreholes on this transect were read weekly, and a full record of seasonal variations over three years was obtained. Five sets of results from the two Drainer's Dyke transects are plotted as Figure 2, taking the records from bh 0 to represent the dyke water level. The water levels in the two transects are broadly symmetrical, though there is a suggestion that summer low levels may be less rapidly approached in the sedge fen (west) transect.

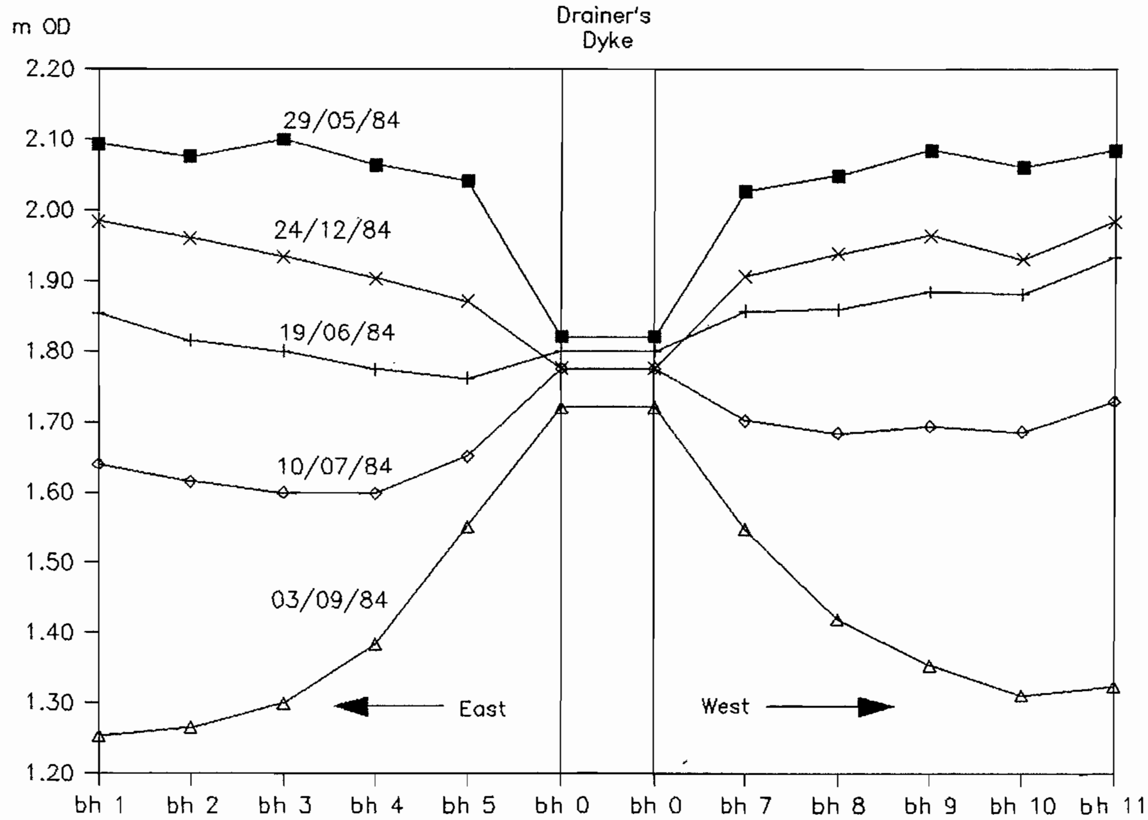

Figure 2 Drainer's Dyke transect cross-section, 1984

The transition between dyke-controlled and evaporation-controlled behaviour is clear, and the records support Godwin and Bharucha's (1932) assertion, based on a series of water level pits about 250 metres north of this transect, that the dykes exercise control only over a 50-metre strip around the perimeter of fen areas. In Figure 2 it can be seen that the dominance of the seasonal evaporation factor is well established within 10 metres of the Dyke.

The annual variation in water levels in the transect is shown by Figures 3 to 6: bh 2 and bh 3 have been omitted in the interests of clarity, but results from these two boreholes lie between those for bh 1 and bh 4, as might be expected from the cross-section in Figure 2.

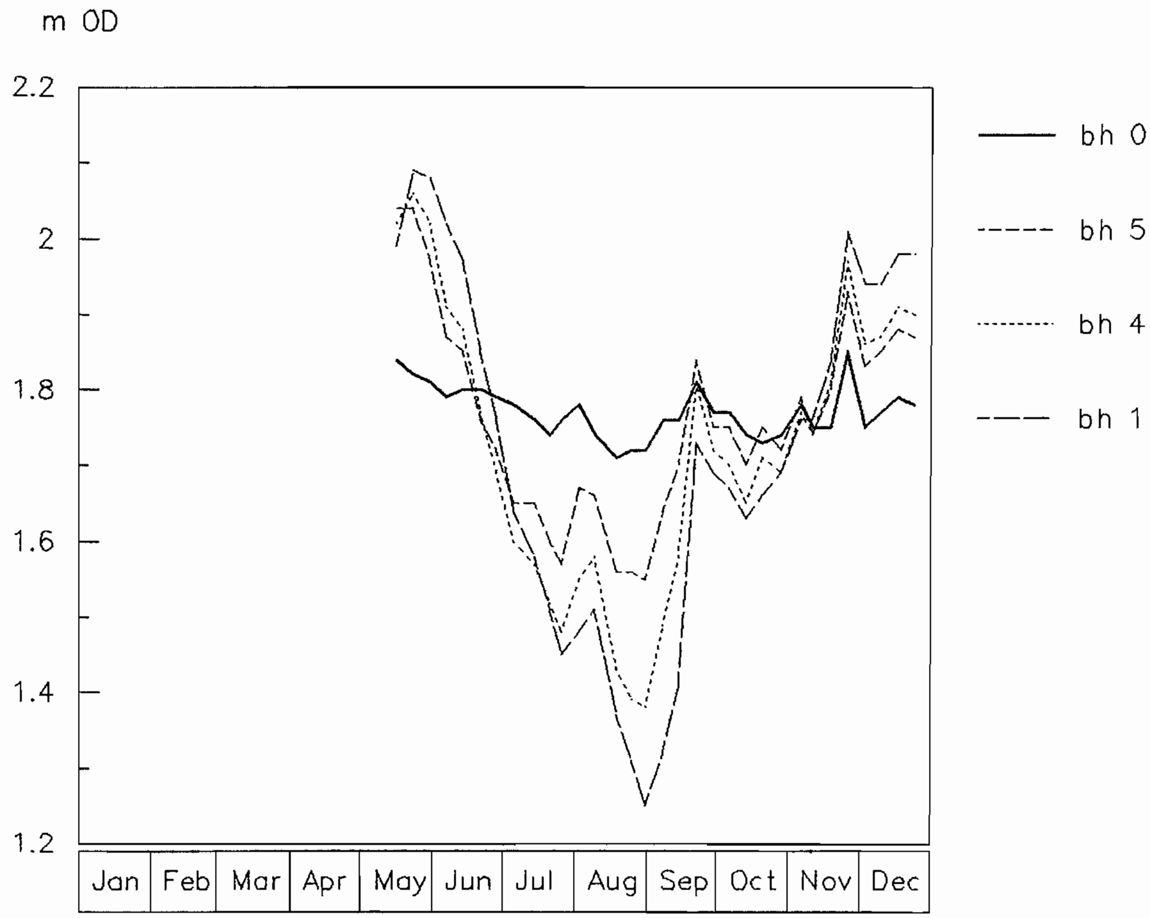

Figure 3 Drainer's Dyke transect (east), 1984

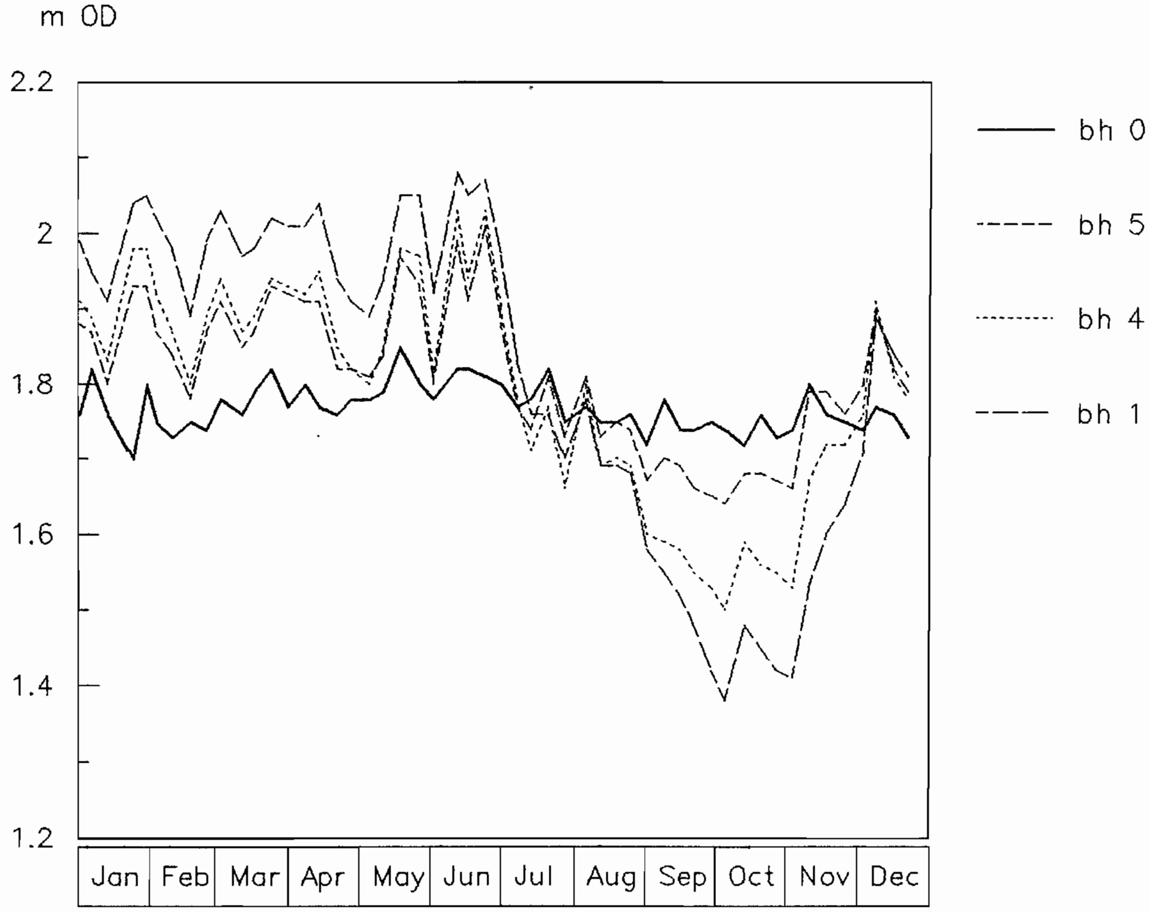

Figure 4 Drainer's Dyke transect (east), 1985

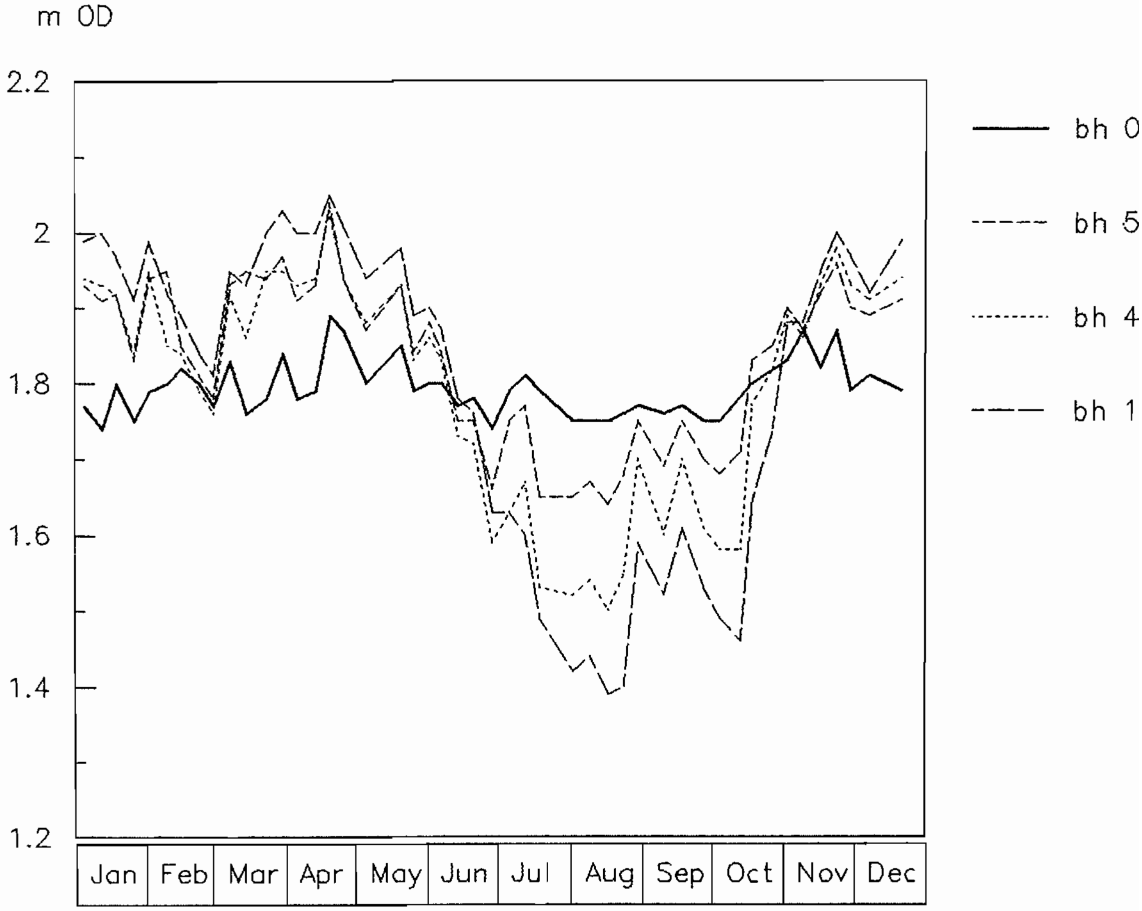

Figure 5 Drainer's Dyke transect (east), 1986

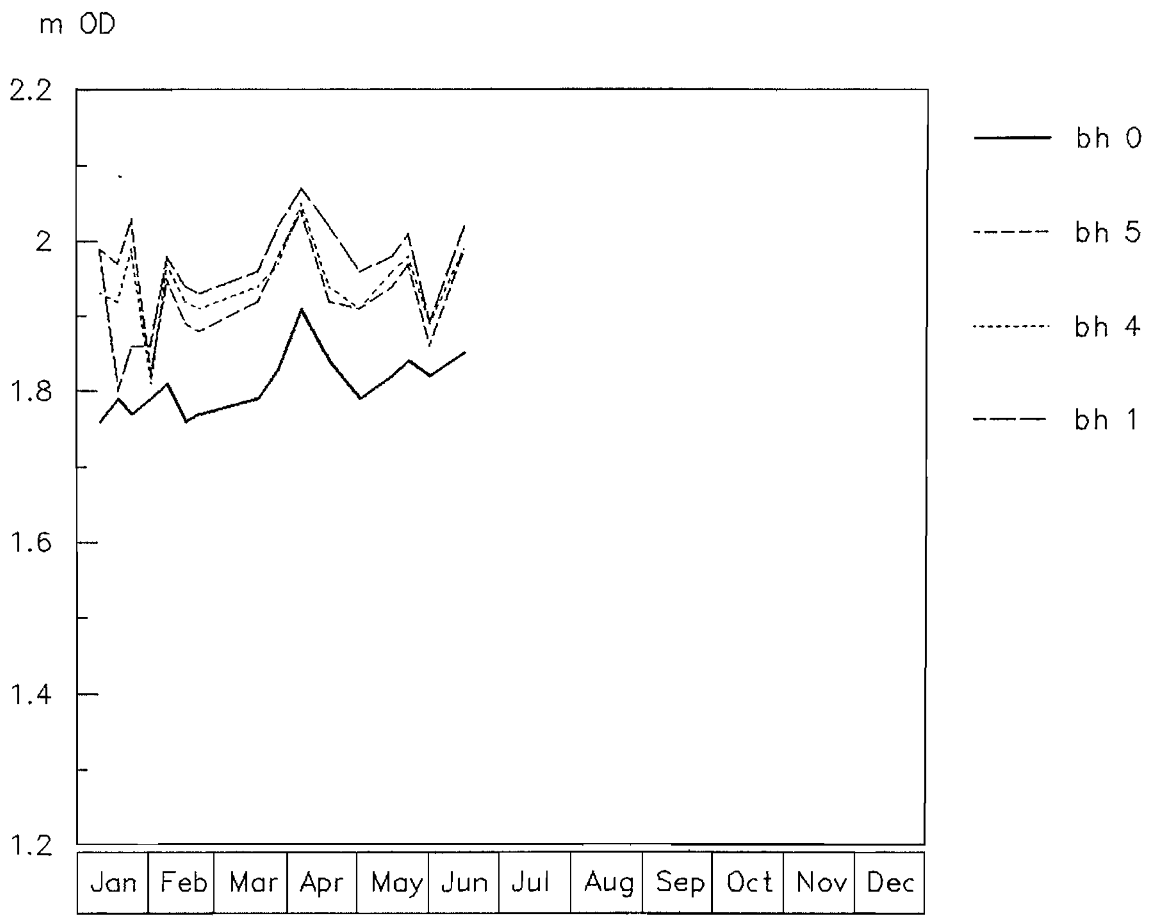

Figure 6 Drainer's Dyke transect (east), 1987

The pattern is one of winter levels up to 0.25 m above dyke level in winter, falling to between 0.4 and 0.5 m below the dyke level in the summer. The effects of rainfall in August and September 1984, July, August and October 1985, and July, August and September 1986 should be noted, as disturbances on a general pattern that is established by transpiration rates. Table 1 shows the extreme levels attained in the winter and summer seasons in the dyke and bh 1, which can be taken to represent the litter field.

Season		bh 0	bh 1
Summer 1984	Min	1.71	1.25
Winter 1984-5	Max	1.85	2.07
Summer 1985	Min	1.70	1.38
Winter 1985-6	Max	1.89	2.05
Summer 1986	Min	1.74	1.39
Winter 1986-7	Max	1.91	2.07

Table 1 Extreme levels in Drainer's Dyke transect (east)

The range between maximum and minimum levels in bh 1 is 0.82 m, compared with 0.87 m for the continuous recorder on bh 19. The slightly smaller range in bh 1 is almost certainly due to the proximity of the Dyke, as there is no difference in vegetation community: this suggests that the curvature of the water table surface continues beyond the 50 m zone, though the further fall is slight. By contrast, the Dyke water level varies over a range of only 0.21 m.

2.1.2 Drainer's Dyke transect (west)

Figures 7 to 10 show the annual variation in levels in the boreholes of the western Drainer's Dyke transect, with boreholes 9 and 10 omitted. The pattern is similar, but the slightly higher summer levels in 1984 give rise to much higher levels in 1985 and 1986, as can be seen in Table 2. It must be concluded that this is due to the cutting of the sedge in this field in summer 1985, resulting in a reduction in transpiration rates over at least two summers.

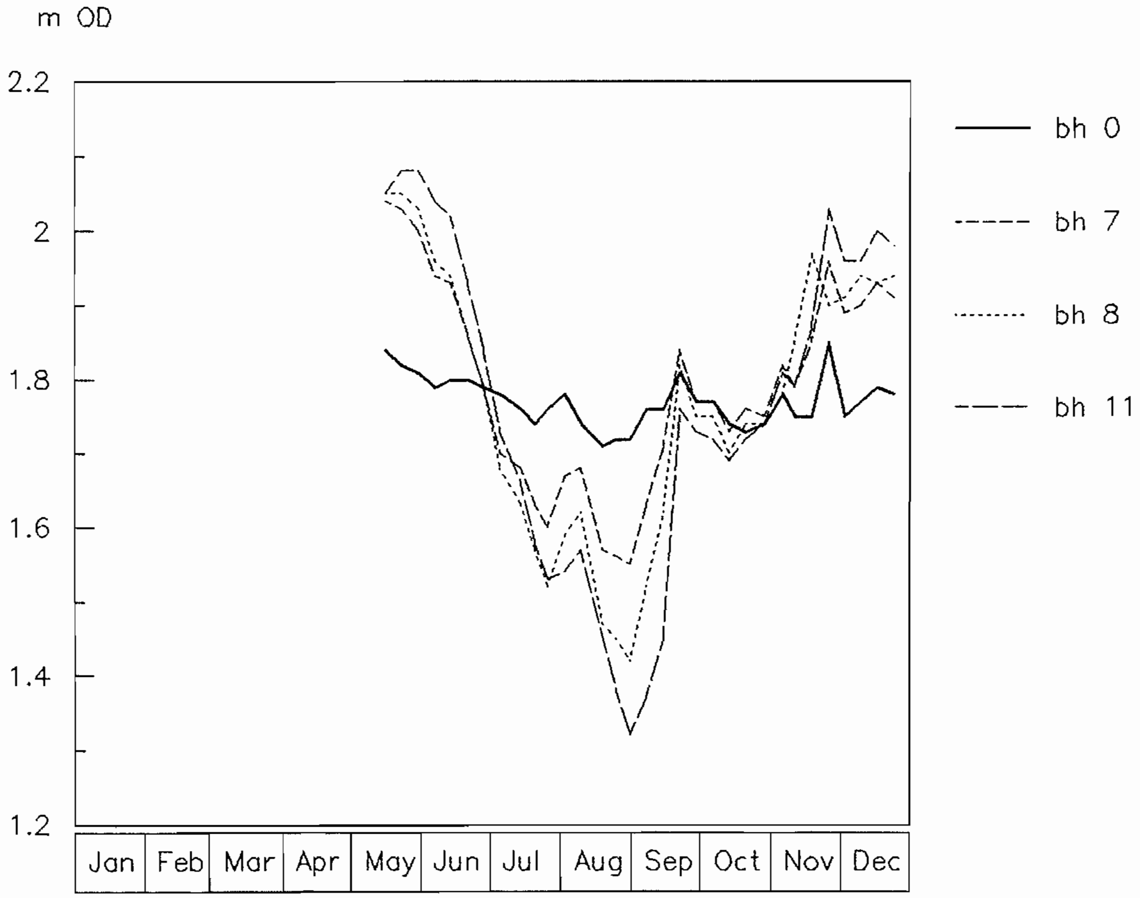

Figure 7 Drainer's Dyke transect (west), 1984

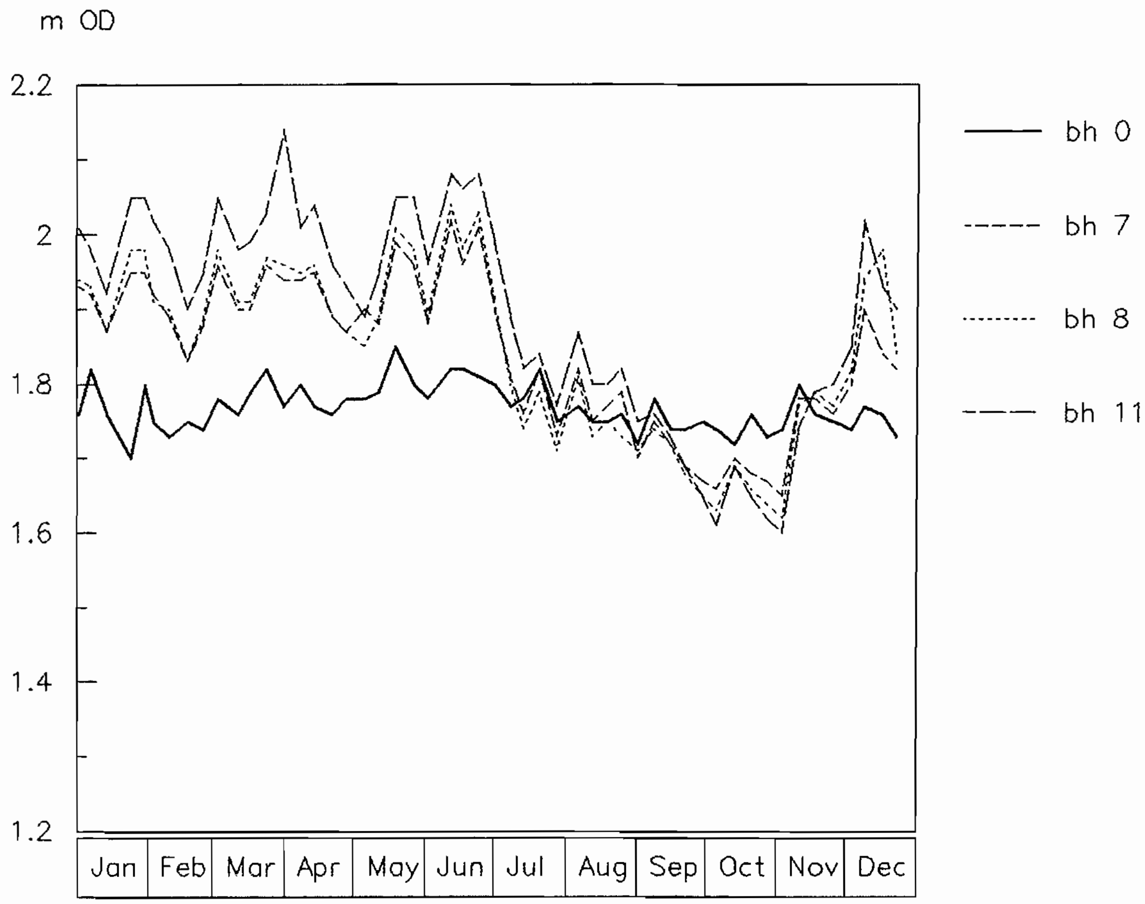

Figure 8 Drainer's Dyke transect (west), 1985

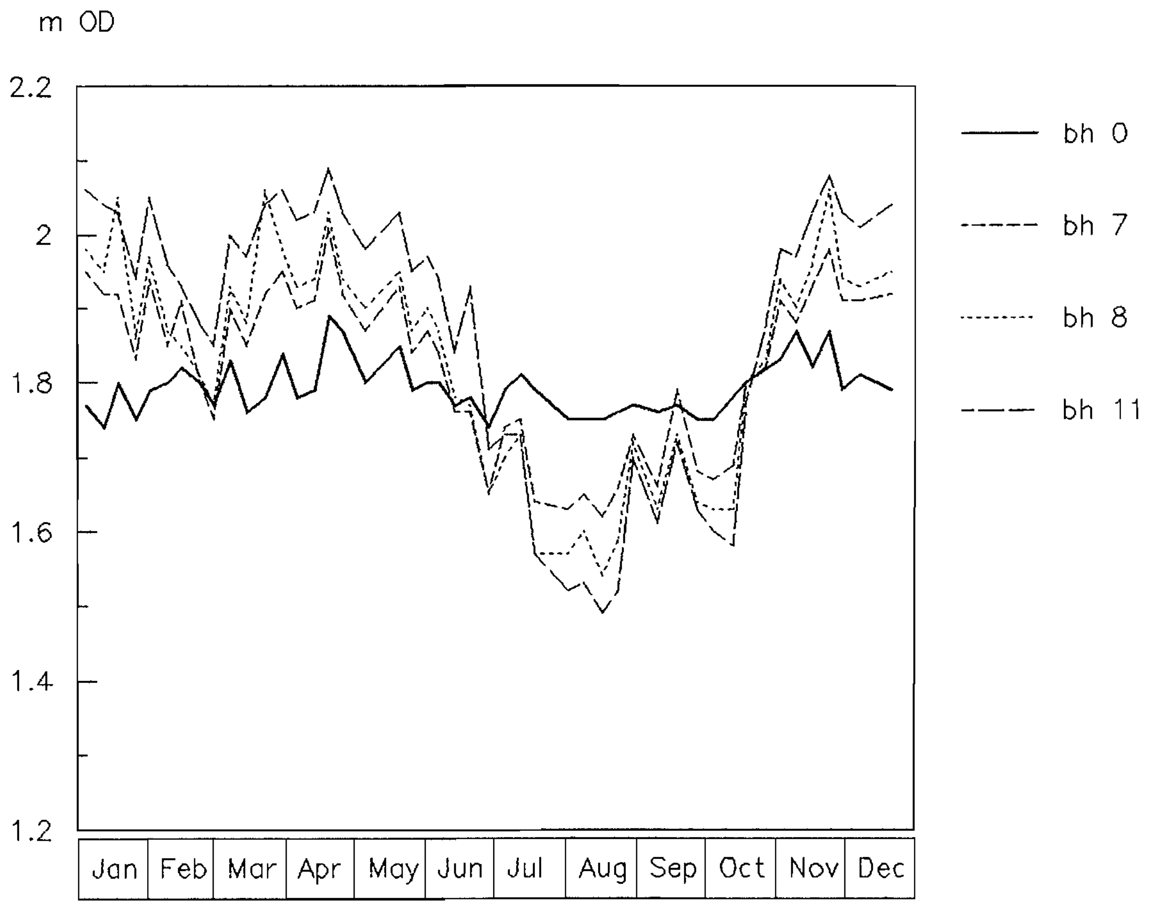

Figure 9 Drainer's Dyke transect (west), 1986

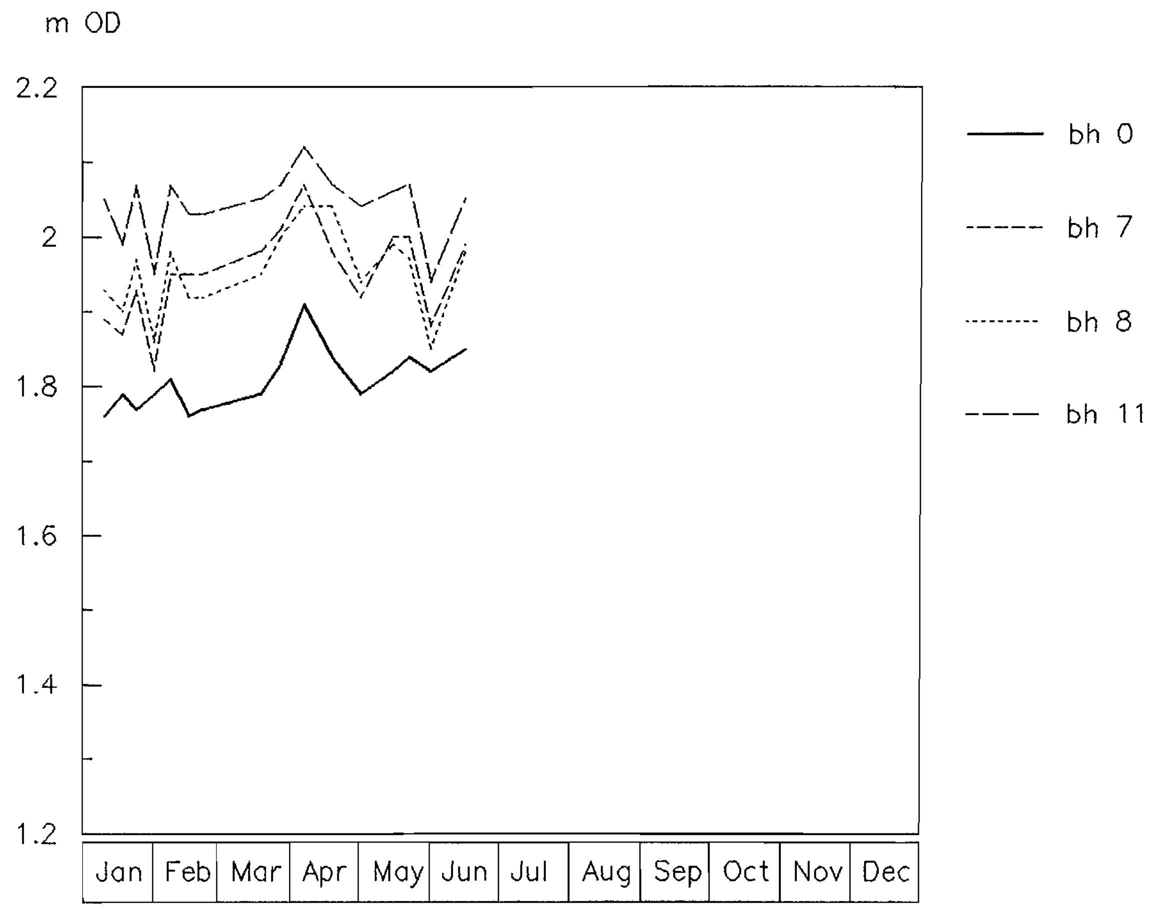

Figure 10 Drainer's Dyke transect (west), 1987

Season		bh 0	bh 11
Summer 1984	Min	1.71	1.32
Winter 1984-5	Max	1.85	2.08
Summer 1985	Min	1.70	1.60
Winter 1985-6	Max	1.89	2.09
Summer 1986	Min	1.74	1.64
Winter 1986-7	Max	1.91	2.07

Table 2 Extreme levels in Drainer's Dyke transect (west)

2.1.3 Malcarse Drain transect

In 1984, the Malcarse Drain transect was in dying carr, with little ground vegetation, and the decline in levels over the summer was less than in the litter field. The decline in transpiration rates appears to have continued into 1985 and 1986, and it may be that transpiration will not pick up until much of the dead wood has fallen and light levels have risen. The cross-section, Figure 11, shows a slow decline in groundwater levels over the summer of 1984. Figures 12 to 15 show the annual variation in level: bh 0 has been taken as the level of the Lode, and boreholes 15 and 16 are omitted for clarity.

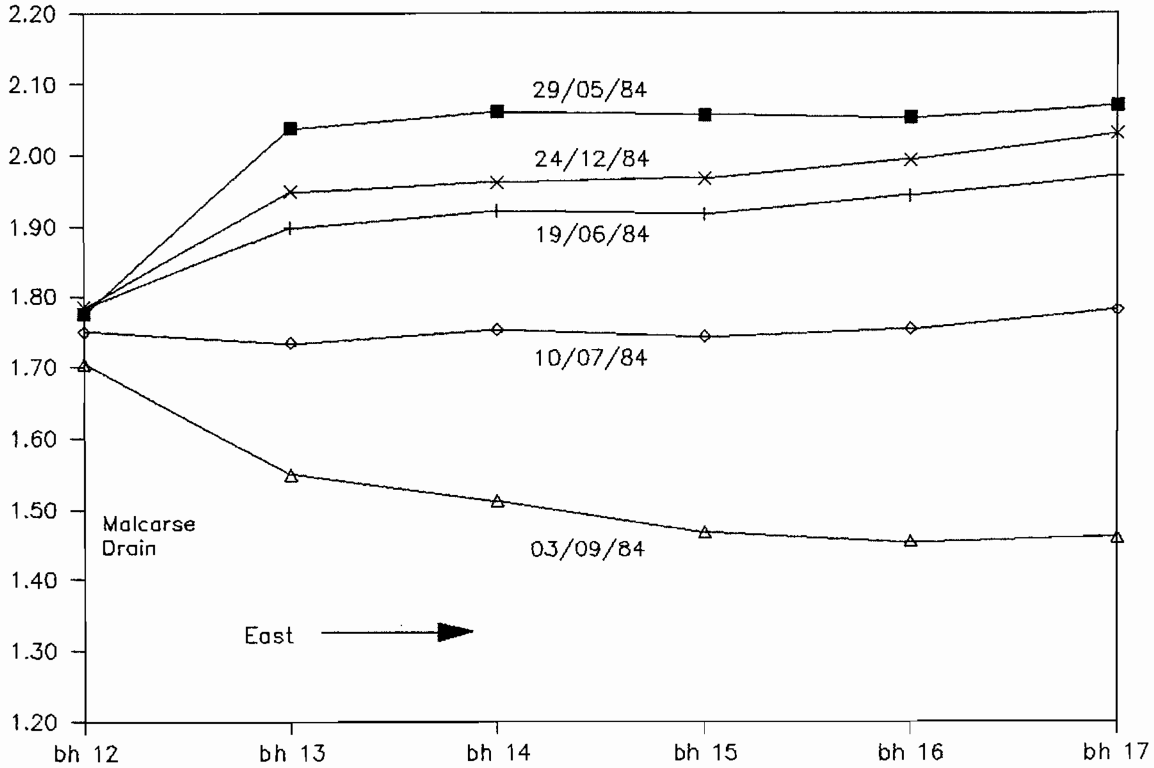

Figure 11 Malcarse Drain transect cross-section, 1984

Season		bh 0	bh 17
Summer 1984	Min	1.71	1.46
Winter 1984-5	Max	1.85	2.11
Summer 1985	Min	1.70	1.56
Winter 1985-6	Max	1.89	2.08
Summer 1986	Min	1.74	1.61
Winter 1986-7	Max	1.91	2.10

Table 3 Extreme levels in Malcarse Drain transect

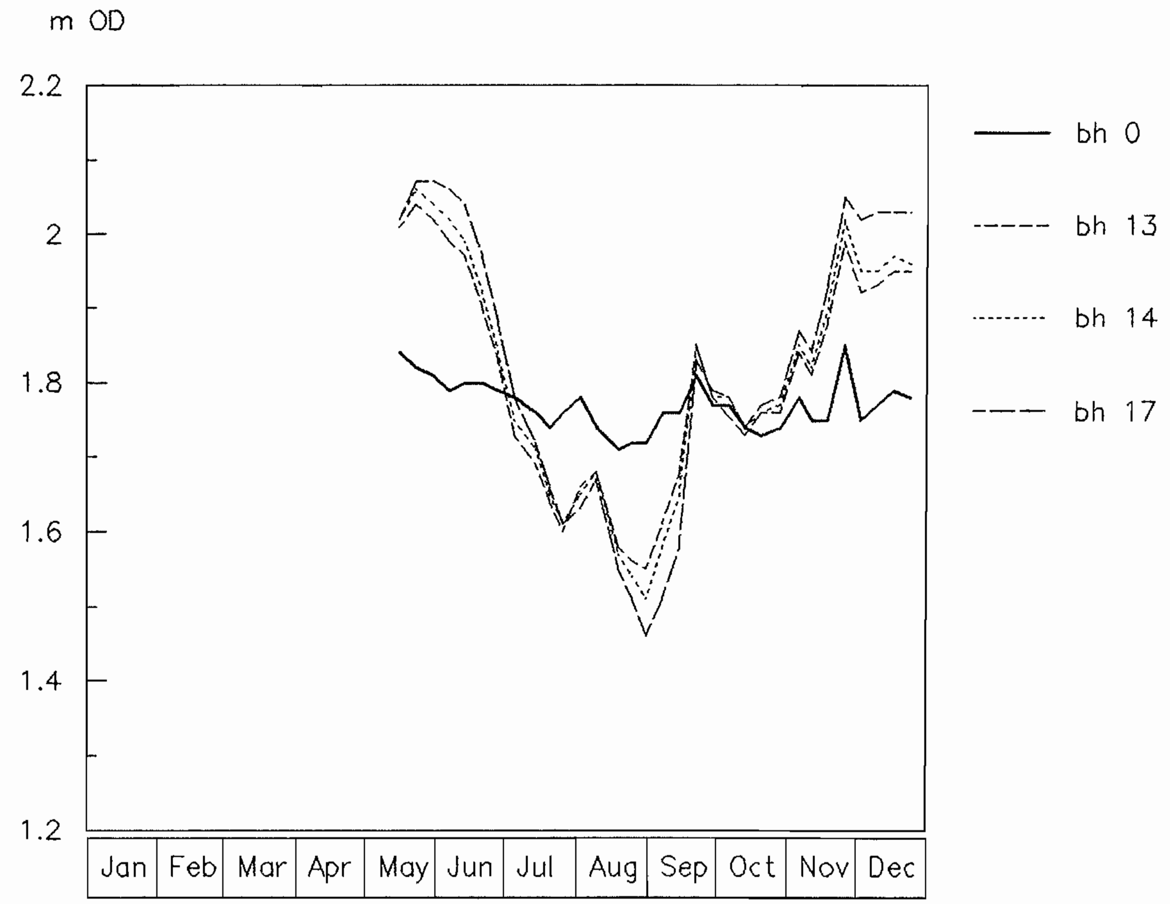

Figure 12 Malcarse Drain transect, 1984

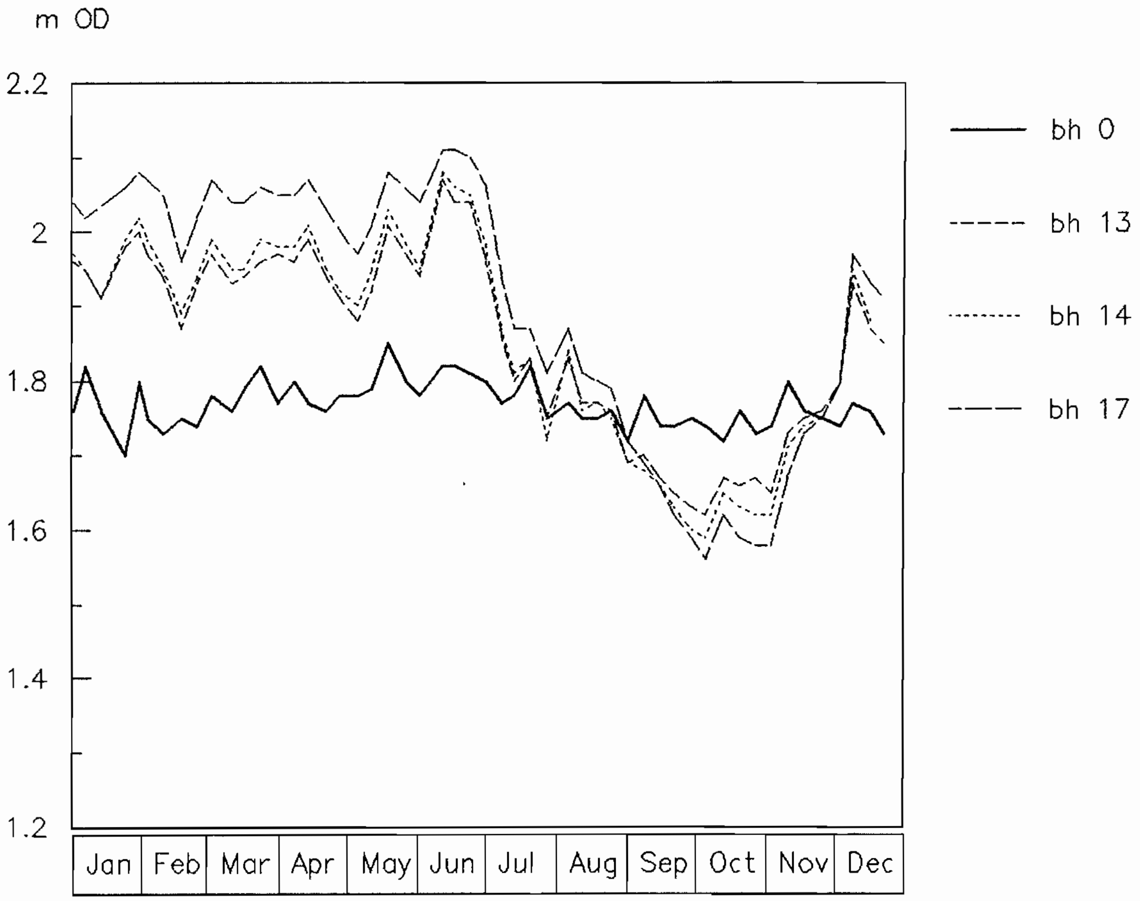

Figure 13 Malcarse Drain transect, 1985

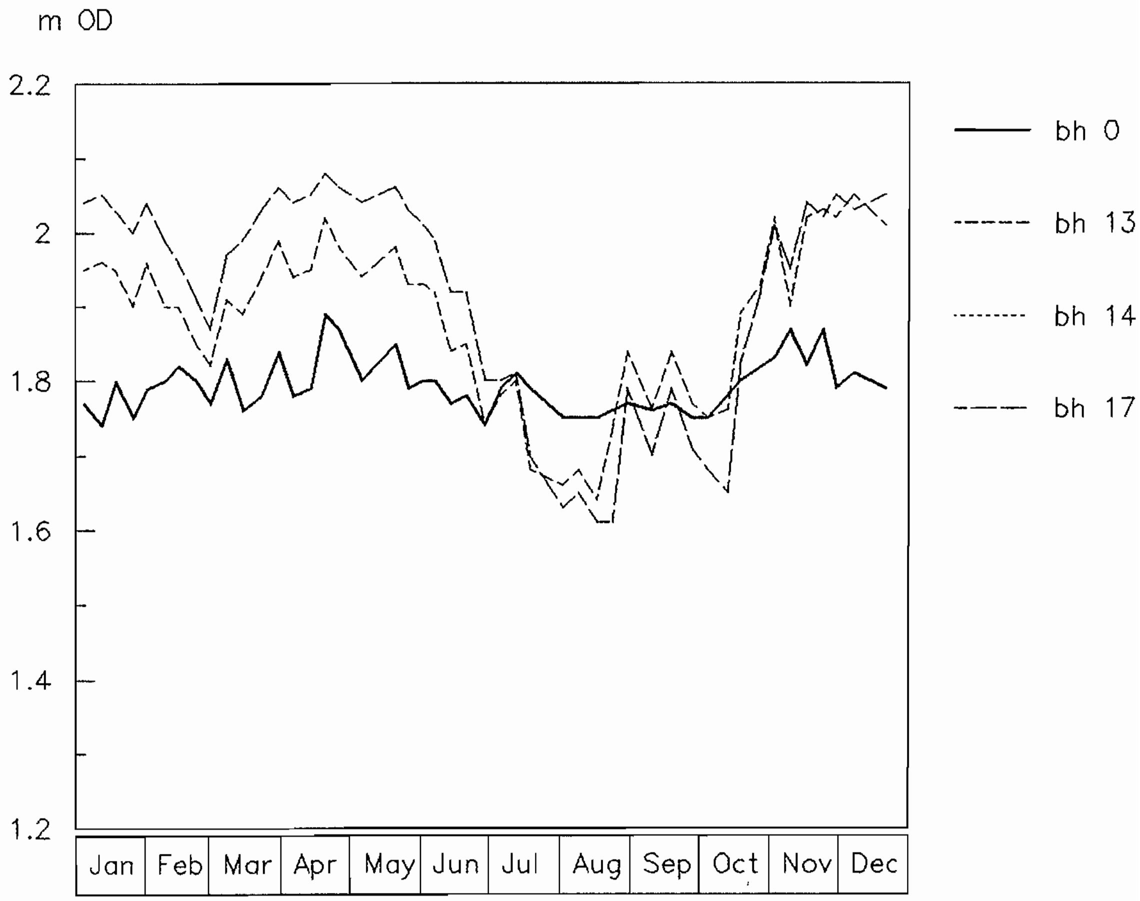

Figure 14 Malcarse Drain transect, 1986

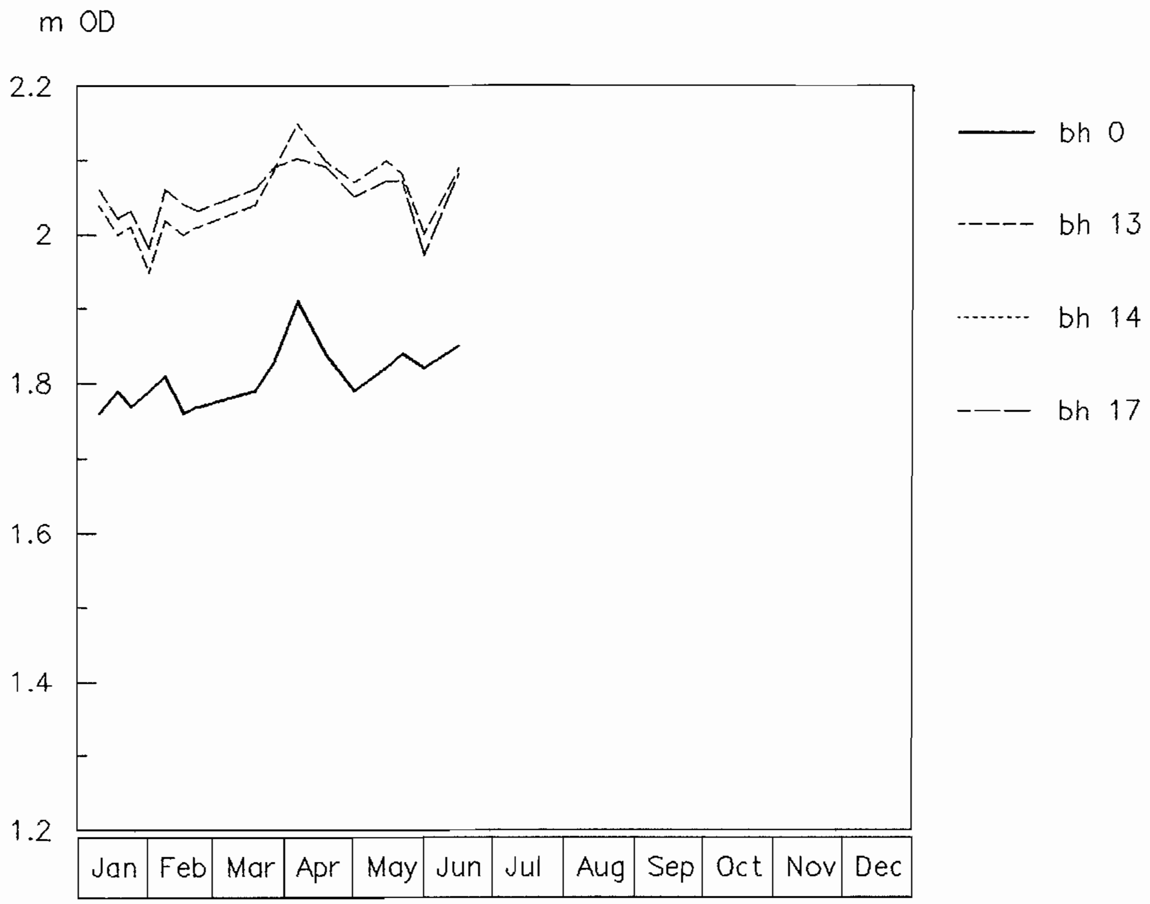

Figure 15 Malcarse Drain transect, 1987

2.1.4 Sedge Fen Drove

Three sites near the Sedge Fen Drove are conveniently grouped together: these are bh 18 (the Godwin/Gowing recorder site), bh 19 (the continuous recorder site) and bh 21 (near Godwin's pit 6a). The annual variation in level at these three sites is recorded in Figures 16 to 19: the continuous record for bh 19 has been digitised to give midnight values.

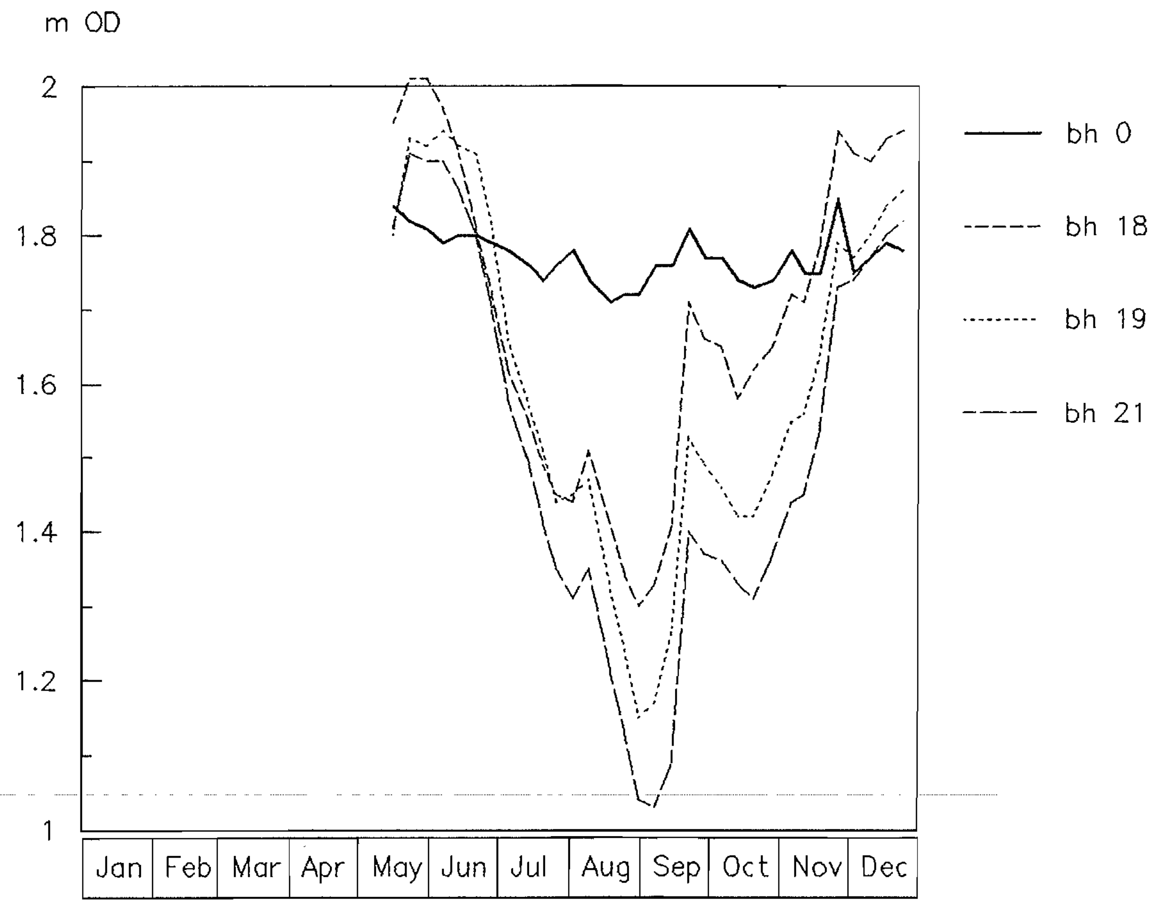

Figure 16 Sedge Fen Drove boreholes, 1984

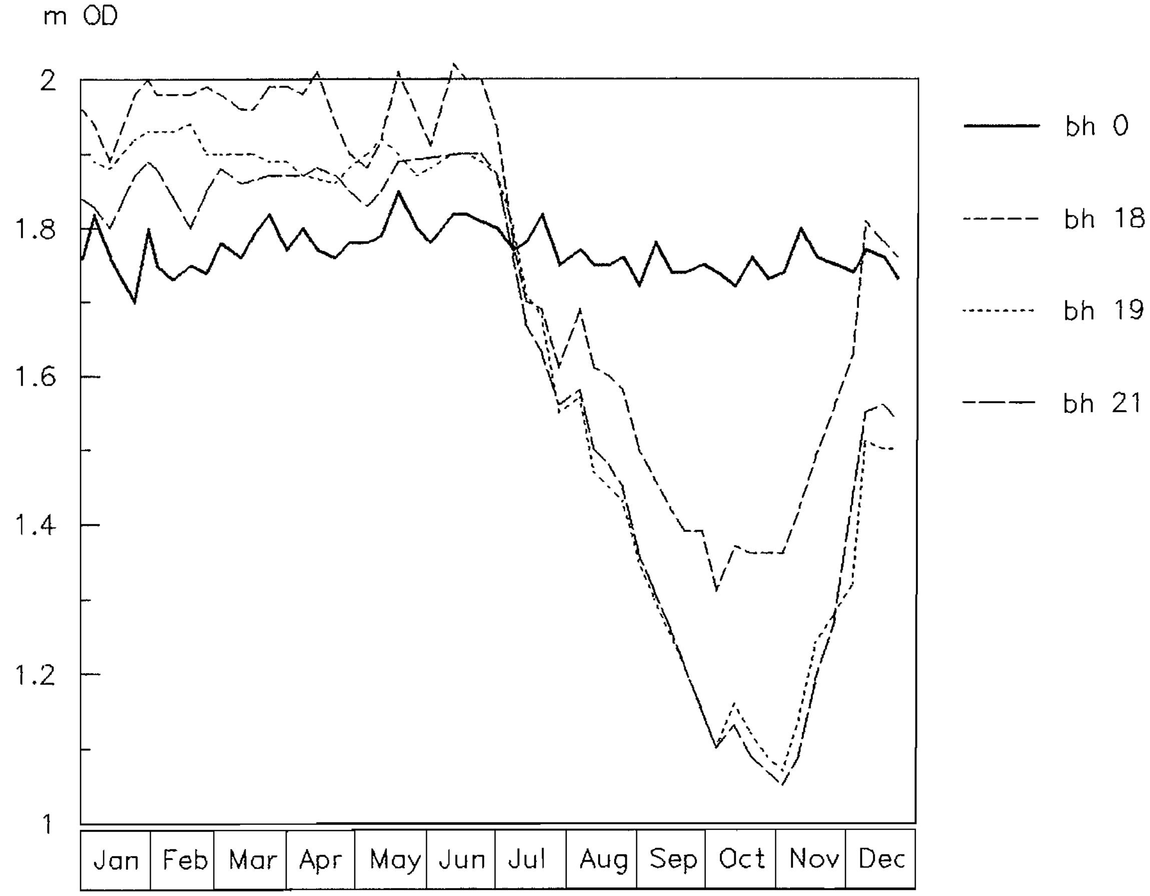

Figure 17   Sedge Fen Drove boreholes, 1985

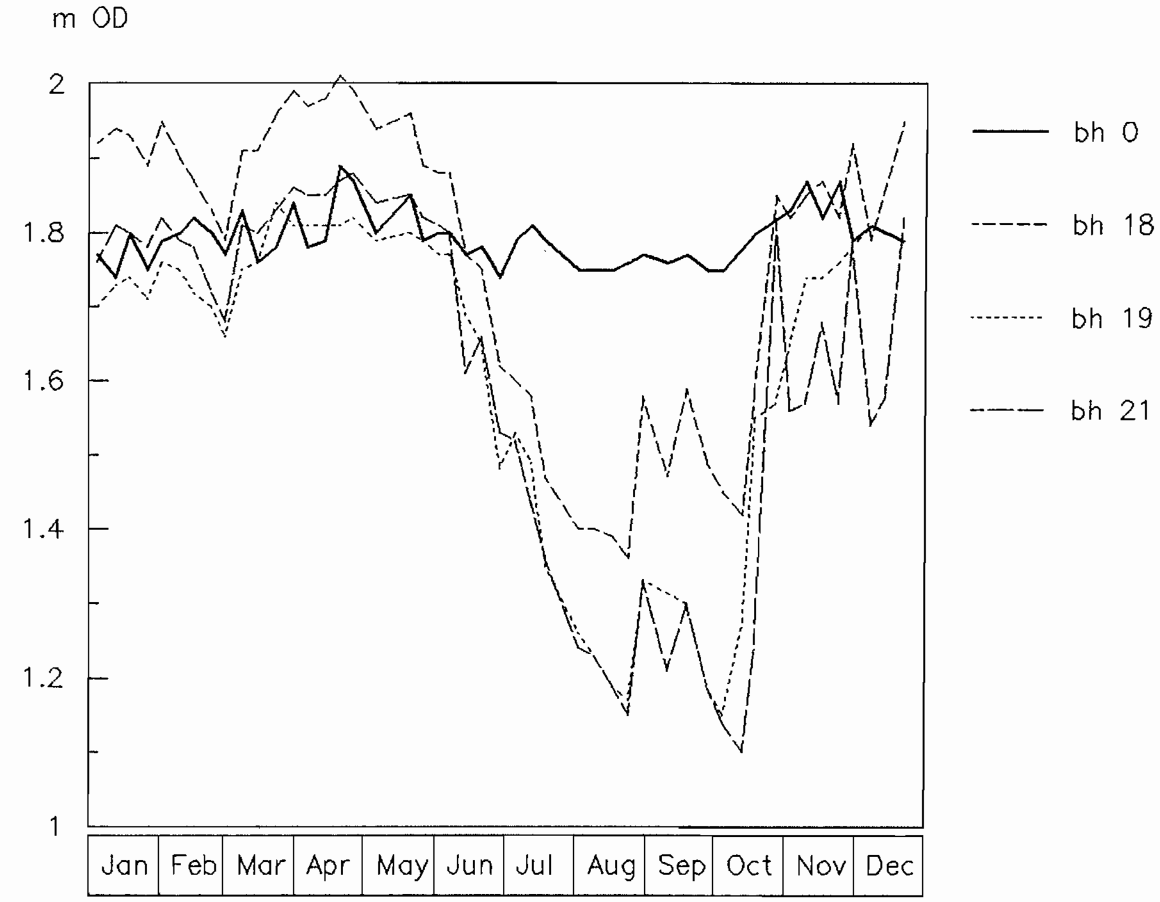

Figure 18 Sedge Fen Drove boreholes, 1986

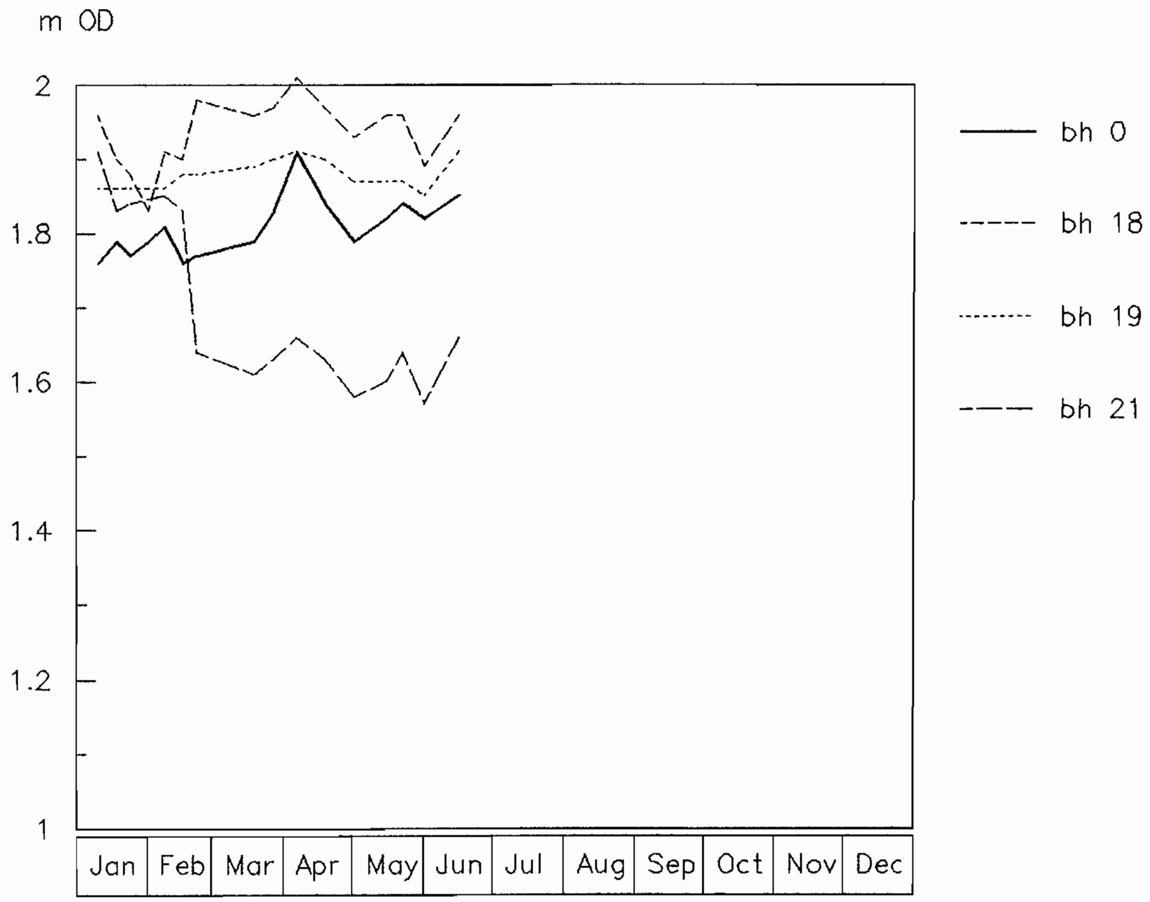

Figure 19 Sedge Fen Drove boreholes, 1987

In Figure 16, the three stations show a behaviour that is suggestive of increasing distance from the dyke network, but there is a change in the pattern in 1985 (Figure 17) and 1986 (Figure 18), which suggests an alteration of between 0.06 and 0.08 m in the datum of bh 19. Table 4 However, no evidence could be found of any disturbance to the recorder in July or August 1985, which is when the break occurs. It may be possible to resolve this problem by digitising the continuous record from bh 20.

Season		bh 18	bh 19	bh 21
Summer 1984	Min	1.30	1.15	1.03
Winter 1984-5	Max	2.02	1.94	1.90
Summer 1985	Min	1.31	1.07	1.05
Winter 1985-6	Max	2.01	1.84	1.88
Summer 1986	Min	1.36	1.15	1.10
Winter 1986-7	Max	2.01	1.91	1.91

Table 4 Extreme levels in Sedge Fen Drove boreholes

2.1.5 Spinney Bank transect

The three boreholes of the Spinney Bank transect south of the Bank all show a very similar behaviour to bh 21: a large annual range, relatively little altered by summer rainfall (Figures 20 to 23 and Table 5). This is consistent with the interception of a significant proportion of summer rainfall by the carr canopy. It is worth noting that despite known leakage through the Bank, winter maximum levels are little different from the fen to the south, while the summer levels do not show the increasing drawdown towards the Bank that would be expected if leakage were having serious effects.

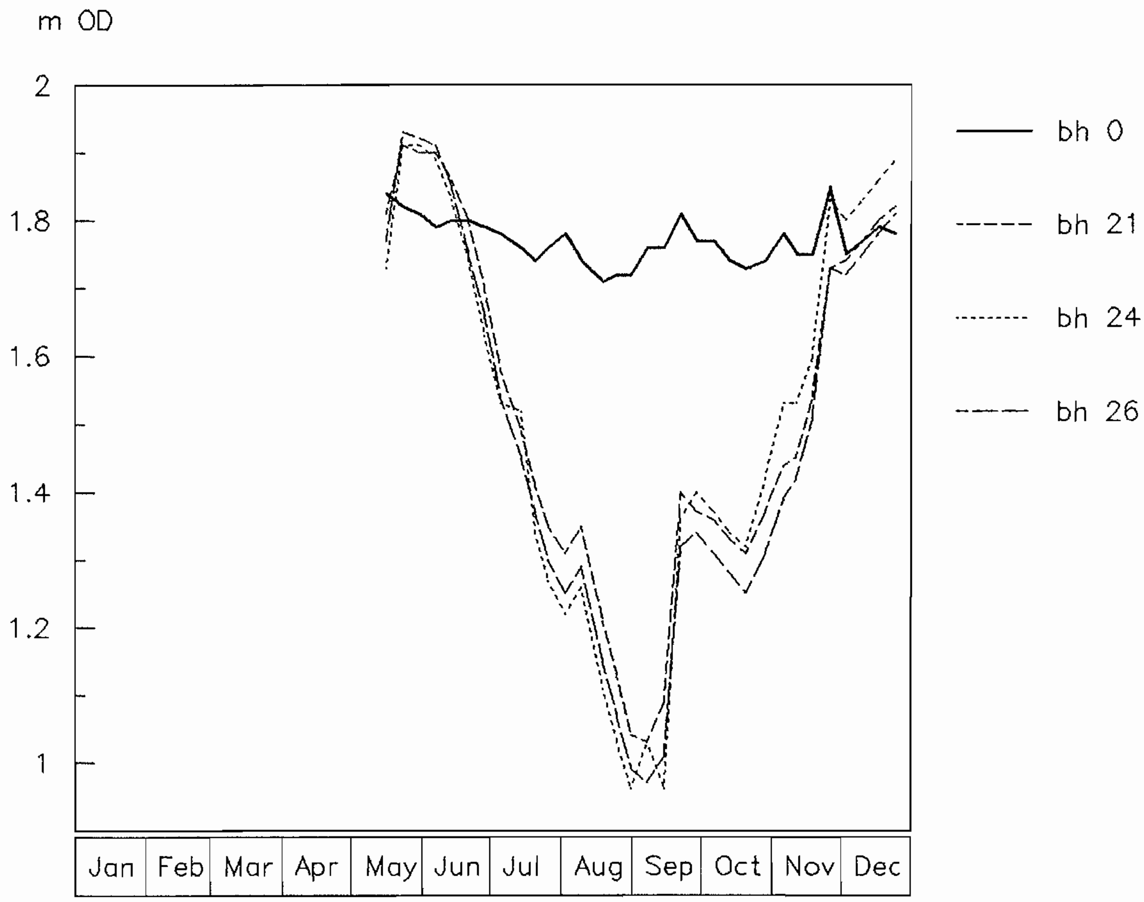

Figure 20 Spinney Bank transect, 1984

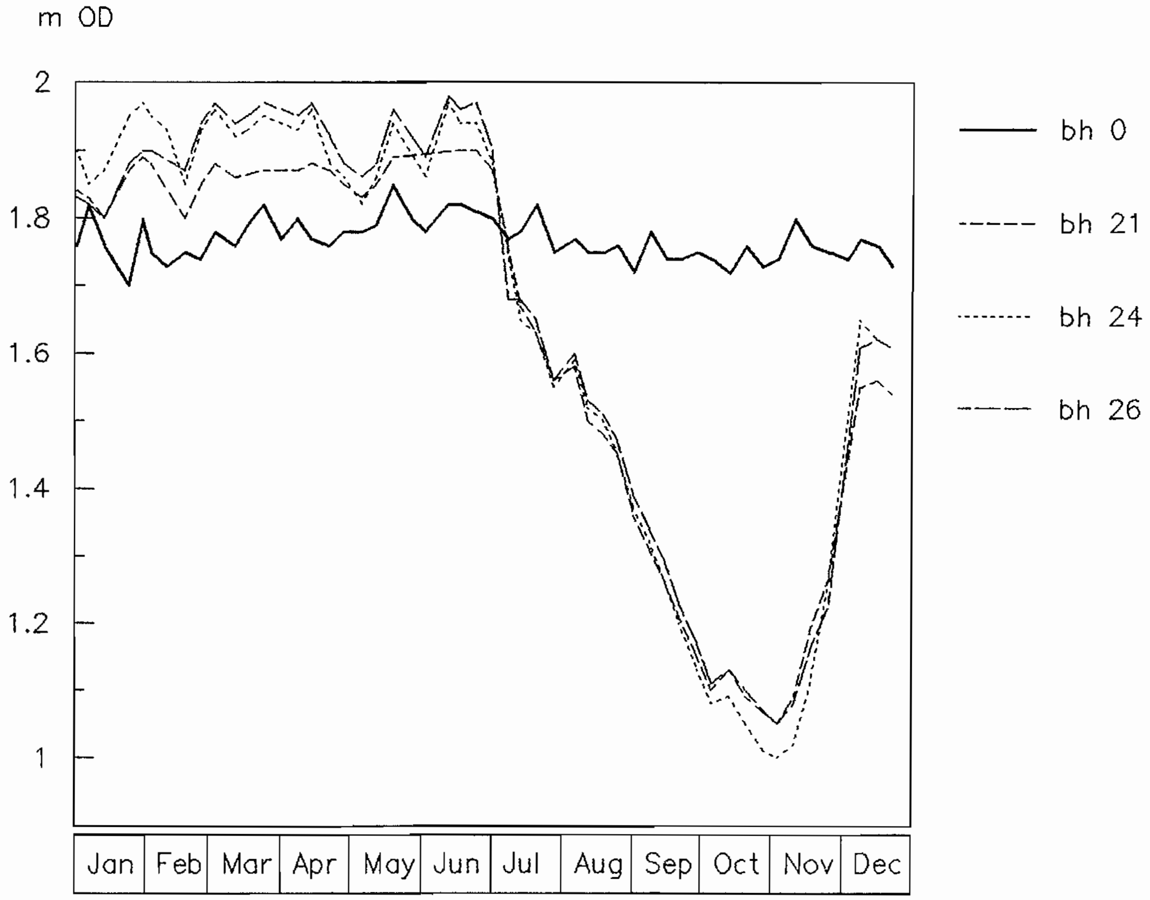

Figure 21 Spinney Bank transect, 1985

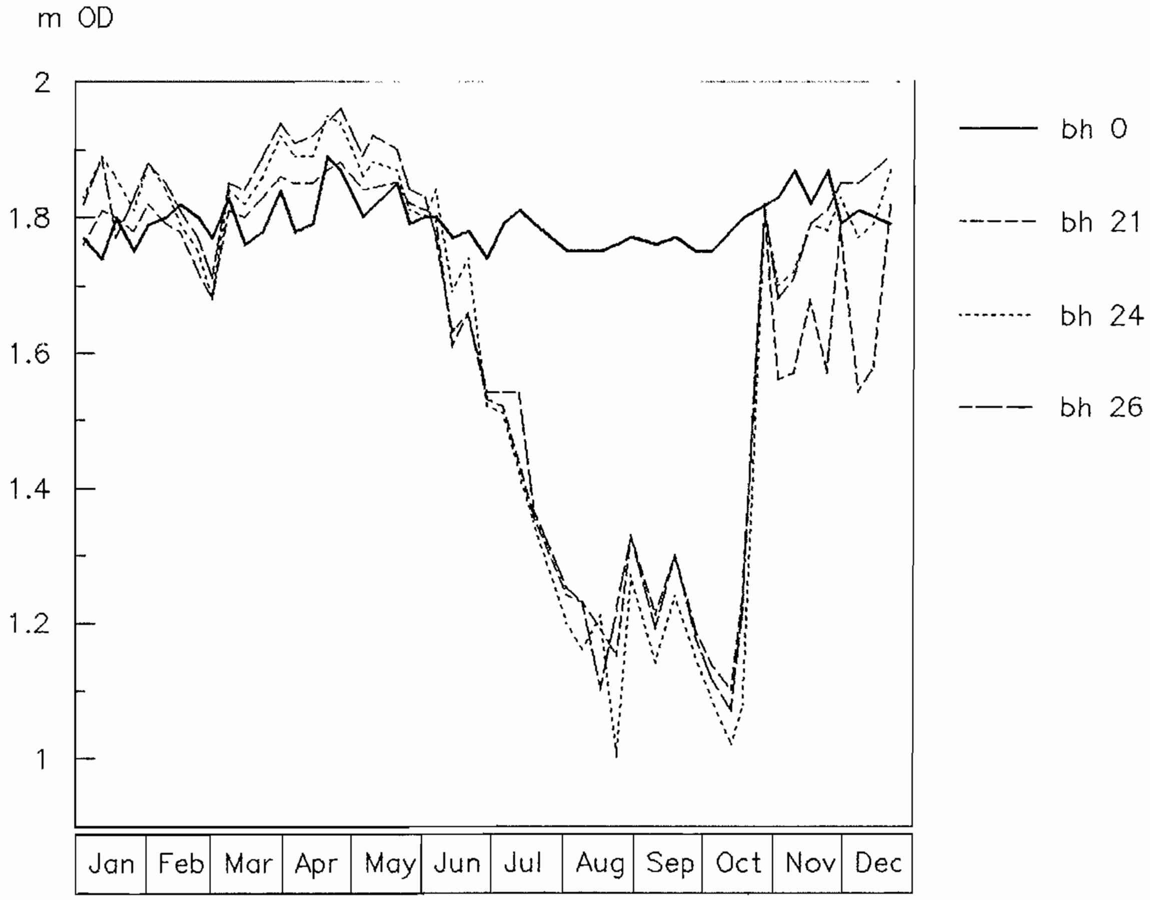

Figure 22 Spinney Bank transect, 1986

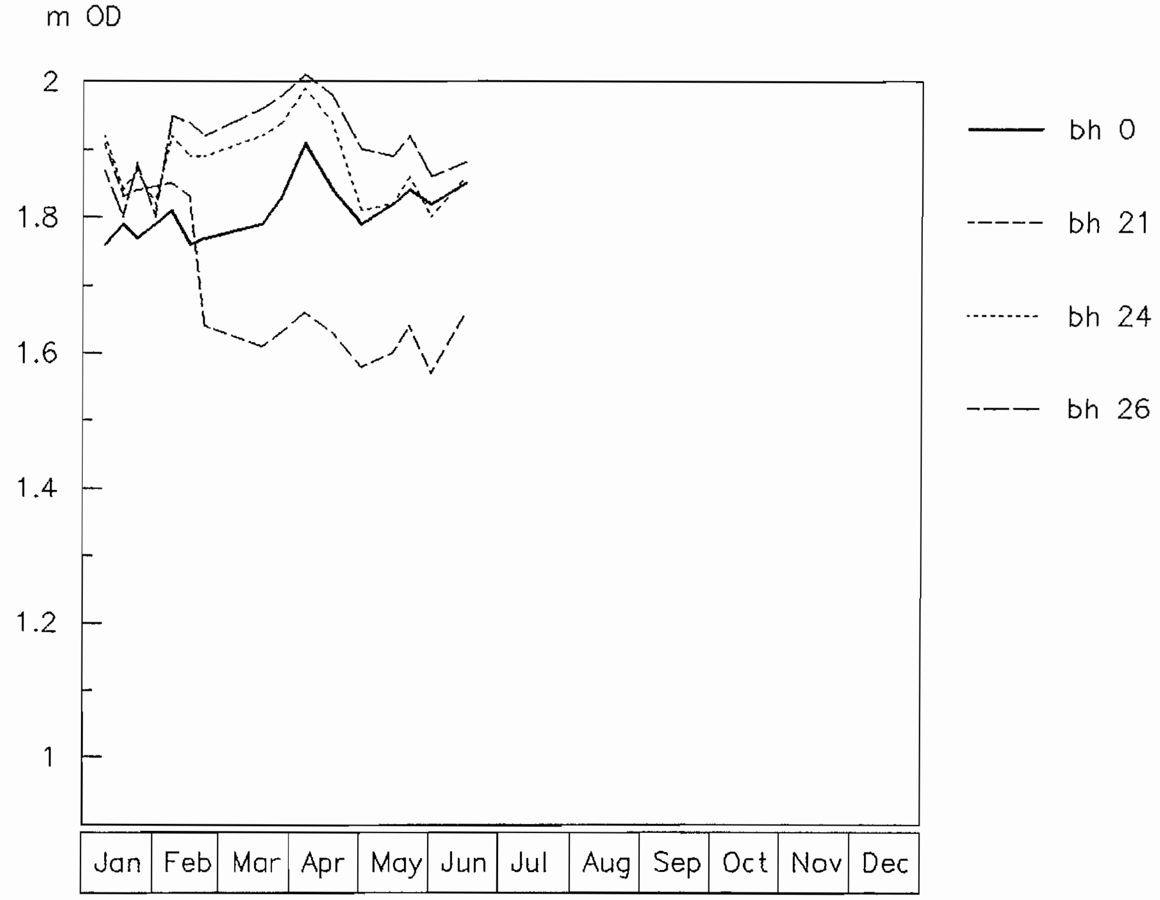

Figure 23 Spinney Bank transect, 1987

Season		bh 21	bh 24	bh 26
Summer 1984	Min	1.03	0.96	0.97
Winter 1984-5	Max	1.90	1.97	1.98
Summer 1985	Min	1.05	1.00	1.05
Winter 1985-6	Max	1.88	1.95	1.96
Summer 1986	Min	1.10	1.00	1.07
Winter 1986-7	Max	1.91	1.99	2.01

Table 5 Extreme levels in Spinney Bank transect

2.1.6 New Dyke transect

The boreholes of the New Dyke transect differ from those of the Drainer's Dyke and Malcarse Drain transects in that the dyke level is not related to the Lode, as the New Dyke is dammed at its intersection with the Lode. The pattern of water level variation followed the standard pattern in 1984, with a moderate evaporative drawdown in the fen expanse (Figure 24). This pattern is confirmed by the cross-section plot (Figure 25). The most obvious difference from the other transects occurred in October 1985 (Figure 26), when all levels dropped as work began on the Howe's Bank. 1986 and 1987 saw a continuation of this changed pattern (Figures 27 & 28).

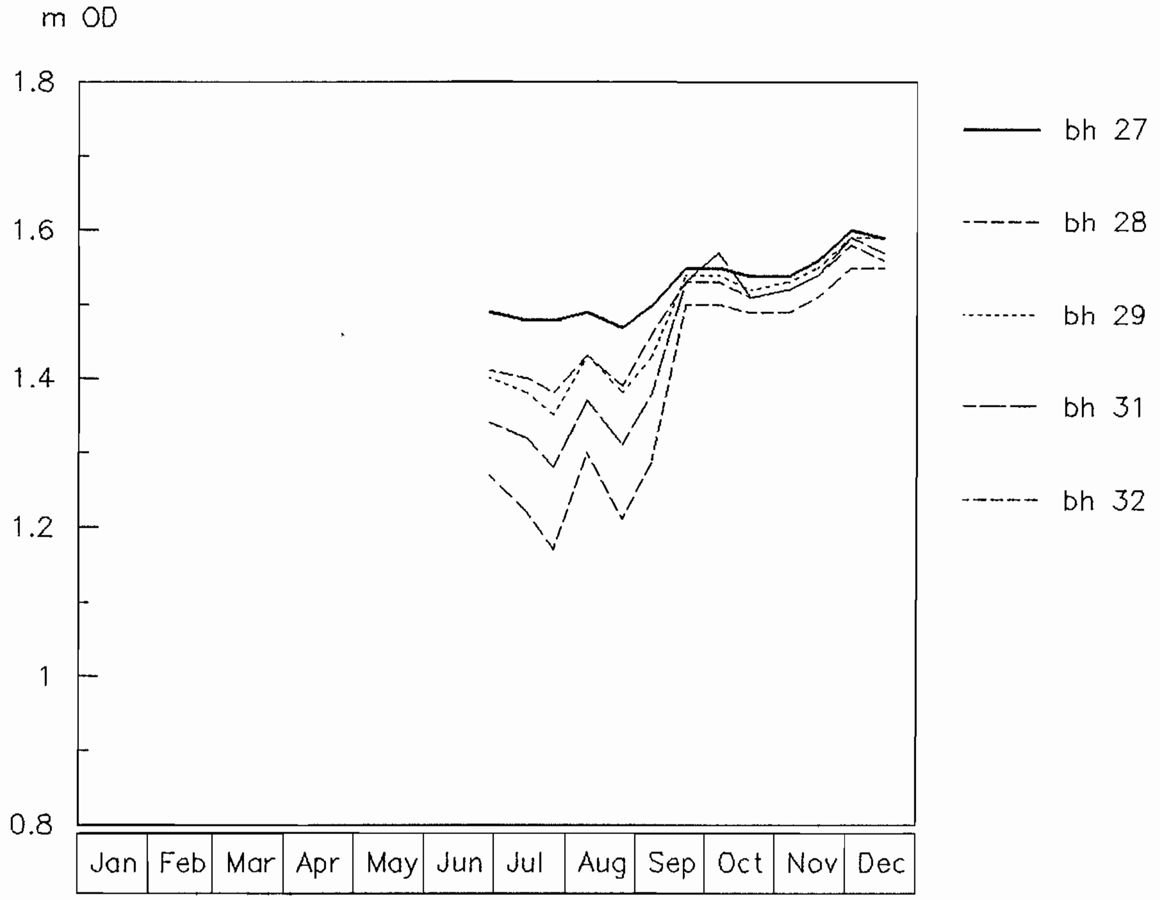

Figure 24 New Dyke transect, 1984

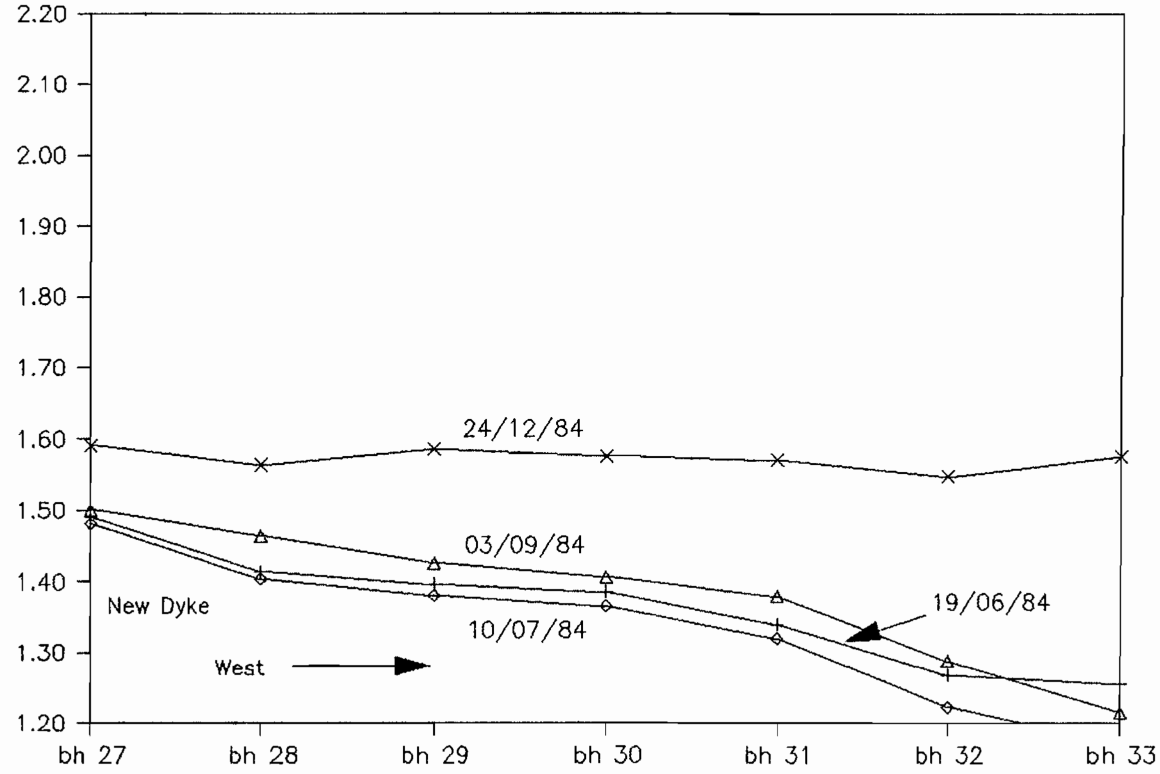

Figure 25 New Dyke transect cross-section, 1984

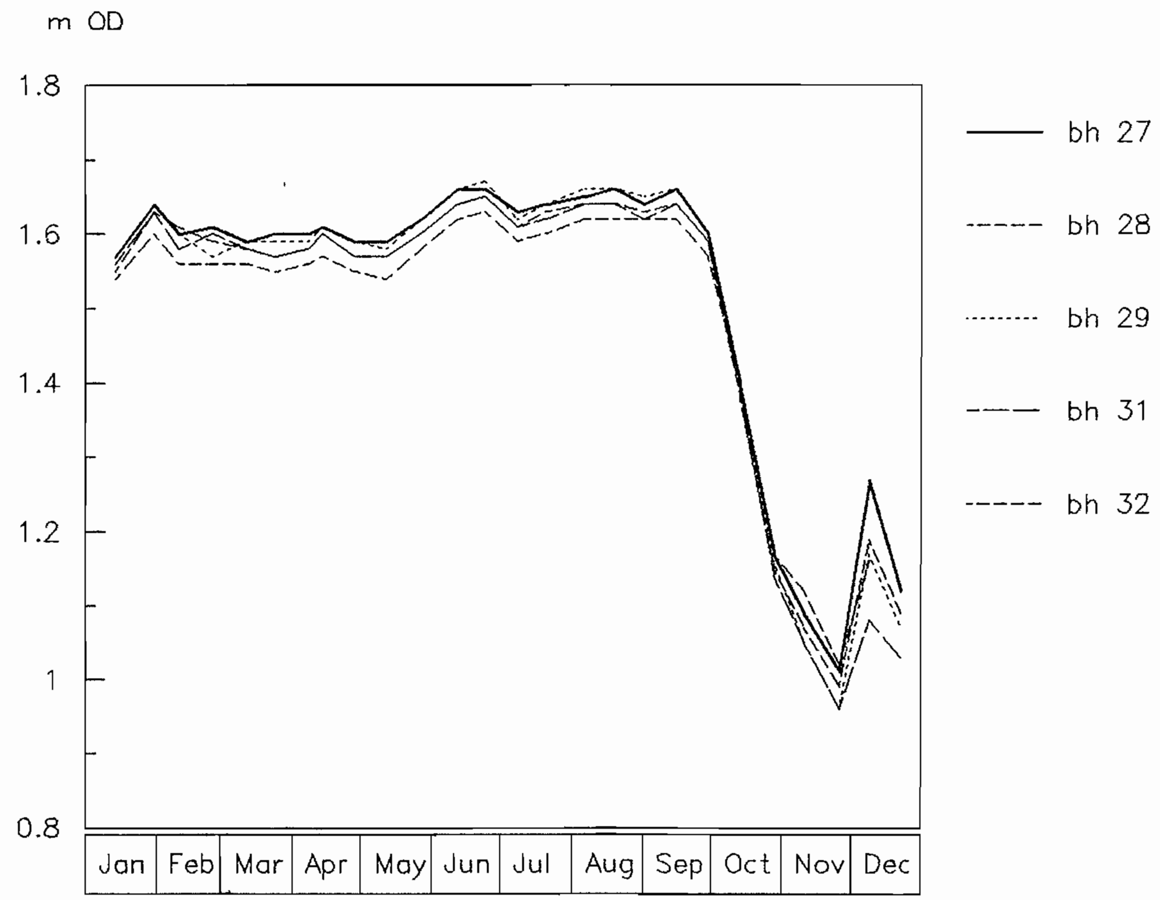

Figure 26 New Dyke transect, 1985

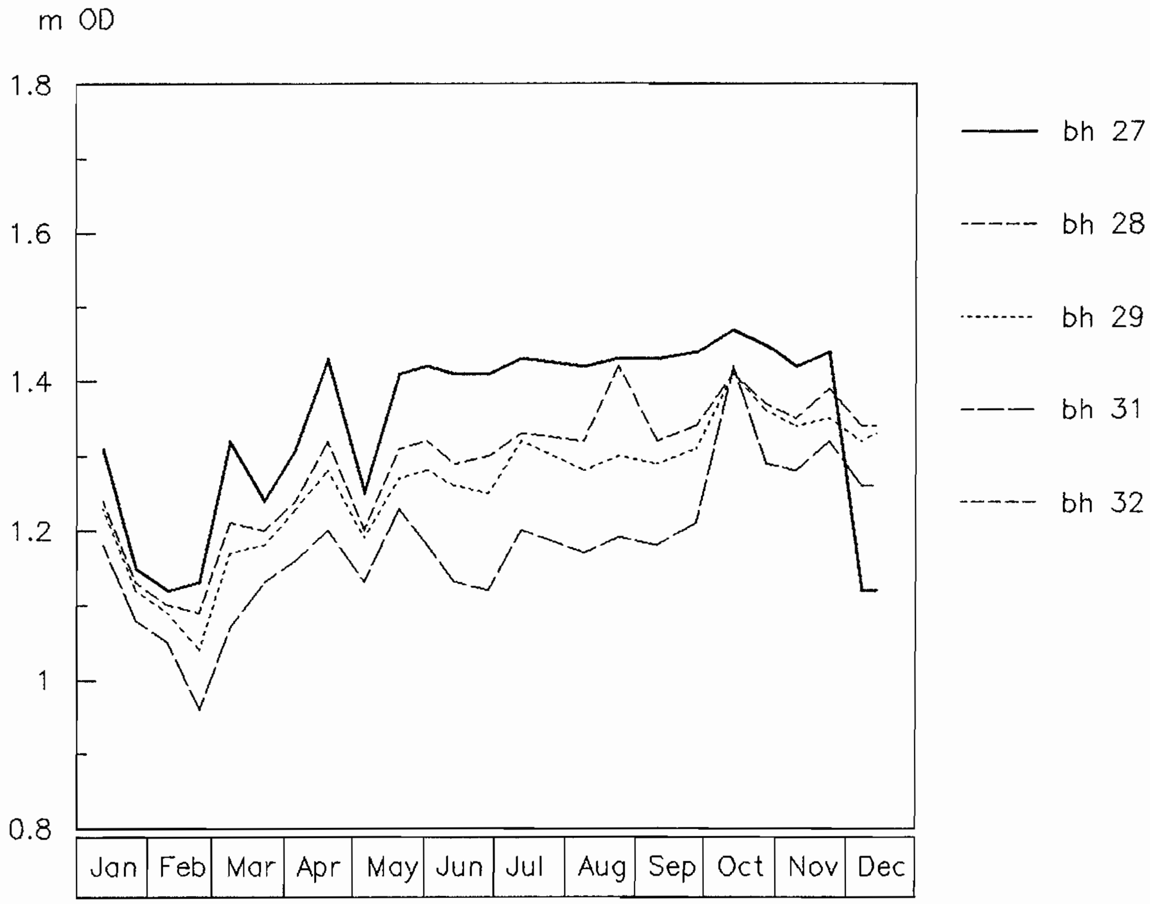

Figure 27 New Dyke transect, 1986

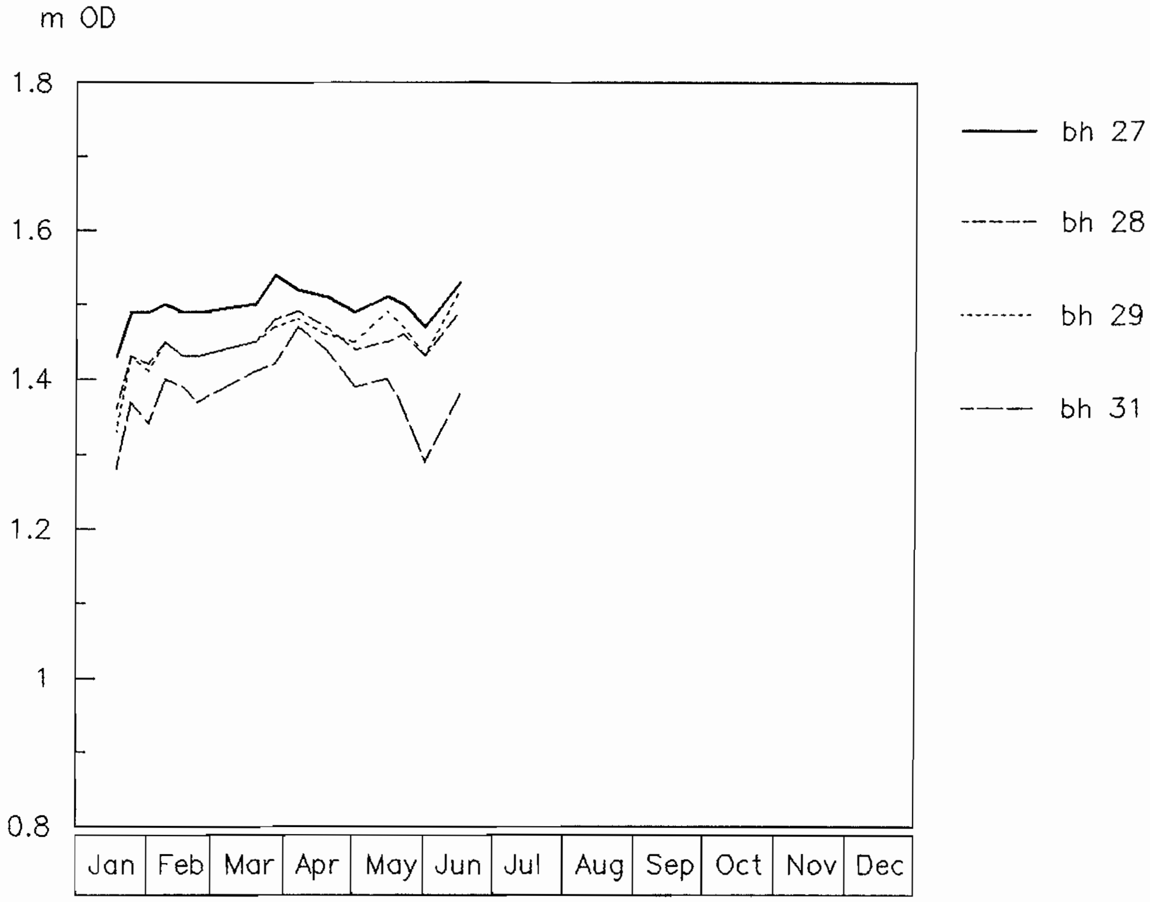

Figure 28 New Dyke transect, 1987

In the 1984 record, while summer levels fell below that of the Dyke, the fall was much less than that in other fen areas, the minimum level was reached in July, and the rainfall in September was enough to establish the winter regime, which was not completely attained until November in the sedge fen transects. Winter water levels showed little change with distance or time, indicating the uniformity associated with the inundation of a large proportion of the fen. The initial survey of borehole rim elevations appeared to be at fault in this transect, and results were corrected by assuming complete inundation and a uniform level on 31 January 1985. This manipulation can be justified by noting that the top of the casing of Bh 30 was 0.13 metres below the water level on this day.

The isolation of New Dyke from the main drainage system is demonstrated by its seasonal variation, not observed in other dykes, but it is clear that the Dyke is still receiving water during the summer, probably by leakage through or around the wooden dam.

It is not possible, from the records of the New Dyke transect, to come to any definite conclusion about the effectiveness of Howe's Bank, but the restricted summer decline in levels appears to indicate a surplus of water in this area, rather than a loss. There can be little doubt, however, that the lower land level around New Dyke and Howe's Bank will pose problems to any future dyke management scheme.

2.1.7 Staff gauges and indicators of dyke level

The staff gauges on the various branches of the connected dyke network showed such similar changes in level, while showing also slight inconsistencies in mean level, that it was decided to use bh 0 as a reference, as it is a better indicator of the level of the dyke network than the staff gauges which are liable to disturbance by ice. The rather doubtful datum levels of the Malcarse Drain transect were adjusted using a correction derived from the relationship between bh 12, close to the Drain, and bh 0.

The records from bh 0, which have been plotted on Figures 3 to 6, show little variation in level over the year, and the seasonal cycle, though present, is subdued.

The staff gauges on the Spinney Bank ditches were recorded throughout 1984 and 1985. The upper ditch, represented by sg 4, has lower winter levels, around 1.8 mOD to 1.9 mOD, than the fen as indicated by bh 24 to bh 26, and this is perhaps the clearest indication of leakage through the Bank. The lower ditch varied between 0.4 and 0.8 m below Ordnance datum.

2.2 Continuous recorders

A continuous record was obtained of water levels in bh 19 and bh 20, with very few gaps, and this is a credit to the observers, who were quick to spot and correct problems caused by the inevitable ink shortages and stuck floats. The whole length of the record can be used for daily water levels, though so far only bh 19 has been digitised in full, to yield an almost complete sequence of midnight water levels. The charts show clearly the rapid response of the Fen to rainfall, and give a clearer picture of the variations seen in the weekly and fortnightly records from the network. The diurnal fluctuations caused by transpiration show up well, and it has been possible to analyse a large number of these fluctuations for both wells. Response to individual rain events has been used to derive estimates of the specific yield of the peat, and these have been used in turn in the estimation of evaporation rates.

3 Analysis of results

In the interpretation of the water level record, it would be difficult to better Godwin's scheme of dividing the analysis into the effects of rainfall, diurnal fluctuations and seasonal drift. A fourth aspect, considered inferentially by Godwin (1931), and in more detail by Godwin and Bharucha (1932), is the form of the water table surface, which is of great importance in management. The seasonal fluctuations in level and gradient can be seen in the weekly readings: in the main the record for each borehole shows a decline in the summer, between the end of June and the beginning of September, a rise, initially rapid, from then to the beginning of November, and relatively stable levels during the winter. The variation in Lode and dyke levels is much less evident.

3.1 The form of the water table

Godwin and Bharucha (1932) used records from a series of pits near Drainer's Dyke that the water table in the fen changed its form between winter and summer. During winter the water table was convex, and by inference drained towards the Dyke: during summer the shape was reversed, and there was a steep gradient from the Dyke, becoming gentler with distance from the open water. Assuming that this behaviour extended to other areas of the Fen bordered by dykes, Godwin went on to show that this water table form provided a certain amount of recharge from the dykes, to limit the fall in water level beneath fen vegetation near the dykes. Records from the present borehole transects show a similar behaviour, but the greater extent of the network and the length of record increases the confidence with which this simple model can be advanced.

Notwithstanding the imperfections in the initial topographic survey, the records from the borehole network can also be used to show the variation of the water table over almost the whole of Wicken Fen. The interpretation is based on the assumption that the model of control by dyke level and summer transpiration is correct, but serves to show in broad outline the significance of the drainage network and the land surface elevation in controlling the depth to water, which Godwin showed to be one of the most important factors defining the constitution of the plant community.

At the eastern end of the reserve, a general fall in land surface from the Lode towards Spinney Bank gives rise to a fall in winter maximum levels from about 2.1 m OD near the Lode to about 1.95 m OD at the Bank. Summer minima are also lower towards the northern edge of the reserve, about 1.0 m rather than 1.3 m, but this may be caused by distance from open water bodies, and the absence of lateral replenishment. Towards the western end of the reserve, near New Dyke, land levels at the northern boundary are lower, and the winter maximum, which is defined by the ground surface, falls to about 1.6 m OD. Summer levels are still sustained by lateral flow from New Dyke, and have a minimum of about 1.2 m OD. New Dyke levels vary between 1.5 and 1.6 m OD, where the Lode and its associated dykes vary between 1.7 and 1.8 m OD.

3.2 Continuous measurements

3.2.1 Response to rainfall

The immediate effect of rainfall on the fen is a rapid rise in the groundwater level, followed by a slower decline. The rise in groundwater level is caused by the filling of unfilled pores in the peat, and a consequent rise in the phreatic surface, represented by the water level in an open borehole. The phreatic surface lies some distance below the interface between saturated and unsaturated peat, and the change in water stored can only take place by a movement of this interface. Between the phreatic surface and the interface between saturated and unsaturated zones lies a 'capillary fringe' in which soil water under tension fills the pores.

The ratio between the input of water to the groundwater body and the rise in water table, normally expressed as a percentage, is the specific yield or effective porosity. The specific yield of peat, which varies with compaction and hence with depth, is a fundamental parameter which determines the quantity of water stored in the peat, and the rate of lowering of the water table over drought periods.

Godwin (1931) noted that when the water table was in the upper 20 cm of the peat, the rise in water level was between 7 and 12 times the amount of rainfall, indicating an effective porosity of 10%. Gowing (1977), working with more recent data gathered at Godwin's recorder site, derived a range of values for the effective porosity, varying from 10% to 33%, and concluded that the figure of 10% should be revised to 15%.

The records from the continuous recorders mounted on boreholes 19 and 20 have been analysed in relation to the rainfall figures available to date. The most consistent set of data, which was available on the IH computer, comprises measurements from Ely, but local measurements taken at the Reserve Centre would be preferred, especially for convective rainfall in summer.

When those rises in groundwater level that could be attributed directly to rainfall events were examined, it was found, as in Gowing's study, that a wide range of effective porosity figures was obtained. The highest values were found when the water table was at its highest, as could be expected, the effective porosity of litter and loosely compacted plant material approaching 100%, but this is not the full explanation.

The method of comparison of rainfall and groundwater rise necessarily assumes that all rainfall is available to top up the groundwater store, where in fact the processes of interception on vegetation and uptake of water into the unsaturated zone to satisfy any soil moisture deficit account for a significant proportion of the rainfall, particularly in light showers and summer storms. The actual input to the groundwater store is thus rather less than the rainfall, and the value obtained for the effective porosity will tend to be an overestimate. Values computed from high rainfall events should tend to be lower, and approach a 'true' value.

3.3 Diurnal fluctuations

A persistent feature of continuous records of mire groundwater levels is the presence of diurnal fluctuations. The general form of the fluctuations is a decline during late morning and afternoon, followed by a full or partial recovery or a constant level during the night. Godwin correctly identified these variations, recorded at Wicken, as indications of evaporative loss from the groundwater body. At the recorder site now included in the IH network as Bh 18, a recovery during the night was attributed to recharge from Drainer's Dyke 50 m away, and Godwin hypothesised that water levels far from a dyke would remain constant during the night. This was confirmed at his pit 6a, close to the IH continuous recorder sites.

An experiment with a lysimeter or 'insert phytometer' confirmed that a soil mass isolated from lateral replenishment did indeed show little change in level during the night. Provided allowance was made for replenishment, and that a reliable estimate of effective porosity were available, the fluctuations in the fen water level could be used to determine the evaporative loss.

Close examination of diurnal fluctuations on the records obtained from boreholes 19 and 20, discernible usually between mid-June and late September, shows that the variations take three distinct forms. During June and the first part of July, a high evaporative demand produces fluctuations of large amplitude, characterised by a rise in the latter part of the morning. This rise could perhaps be interpreted as a redistribution of soil water after a high daytime demand from roots penetrating below the water table. As the water table declines, and transpiration demand lessens, the constant night-time portion of the curve becomes more evident. At the lowest groundwater levels, the fluctuations become ripples on a continuous decline. This could be interpreted as a dispersion of the diurnal wave of water demand, the processes of redistribution of soil water requiring more time as the unsaturated zone becomes deeper. Thus the demand on the groundwater body is spread throughout the day, and diurnal fluctuations become less obvious.

4 Evaporation

4.1 Estimation of evaporation from diurnal fluctuations

The diurnal fluctuation is the resultant of two effects: the daily drawdown of the water table by transpiration and the overnight recovery caused by lateral flow. At a site distant from an open water body which might provide the lateral flow, the overnight recovery is absent. At bh 19 this is the case after the early summer: some fluctuations in the early part of the summer are affected, and their magnitude had to be corrected for the purposes of this study, but later fluctuations are unaffected by recovery.

To use the magnitude of the diurnal fluctuations for the estimation of transpiration, it is necessary to know the specific yield of the peat. The most appropriate method is the use of the response of the water table to rainfall. The recorder charts for bh 19 were examined for obvious rises caused by rainfall. 68 suitable events were found during 1984-7, with rises in groundwater level ranging from 20 mm to 240 mm. The specific yield was estimated using the equation:

$$S = 100\frac{\Delta h}{P}$$

where Δh is the rise in water level corresponding to rainfall P, and S is quoted as a percentage.

Specific yields found varied between 5.2% and 64.7%, the higher values being found when the water table was near the ground surface. Near the surface the specific yield could be expected to be large, owing to the open structure of the unhumified peat. There is also the possibility that lateral flow off the fen could dissipate the effect of the rainfall. There are few reasons for obtaining very low values of specific yield, as this would imply too great a response to a rainfall event: on the other hand, the effects of interception by vegetation and storage of water in the unsaturated zone could produce high values.

The distribution of the results suggests a value for S in the region of 10 - 20%: 47 out of 68 results lie in this range. The mean of all the values under 30 was 15.1%. However, bearing in mind the tendency of specific yield determinations by this method to over-estimate, it might be wiser to choose a lower value than 15%. For these reasons, a value of 12% was chosen for water levels below 1.8 mOD, and to take account of the real increase in porosity near the surface the specific yield was supposed to rise linearly to 20% at the ground surface, i.e. 1.95 mOD.

Well-defined fluctuations throughout the summers of 1984 to 1986 have been used to provide estimates of daily evaporation, using the specific yield distribution suggested above. The results are plotted in figure 32.

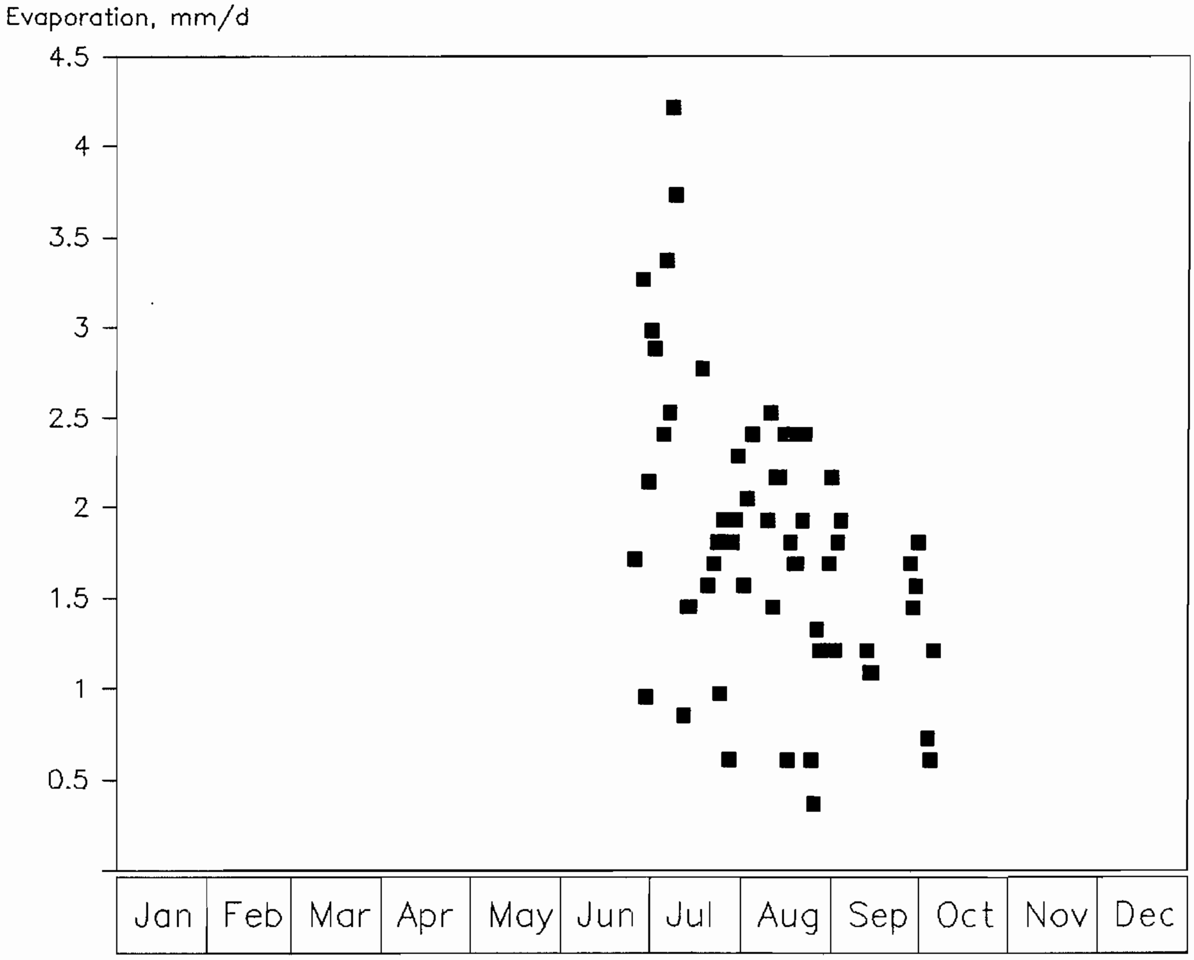

Figure 29 Actual evaporation from litter, 1984

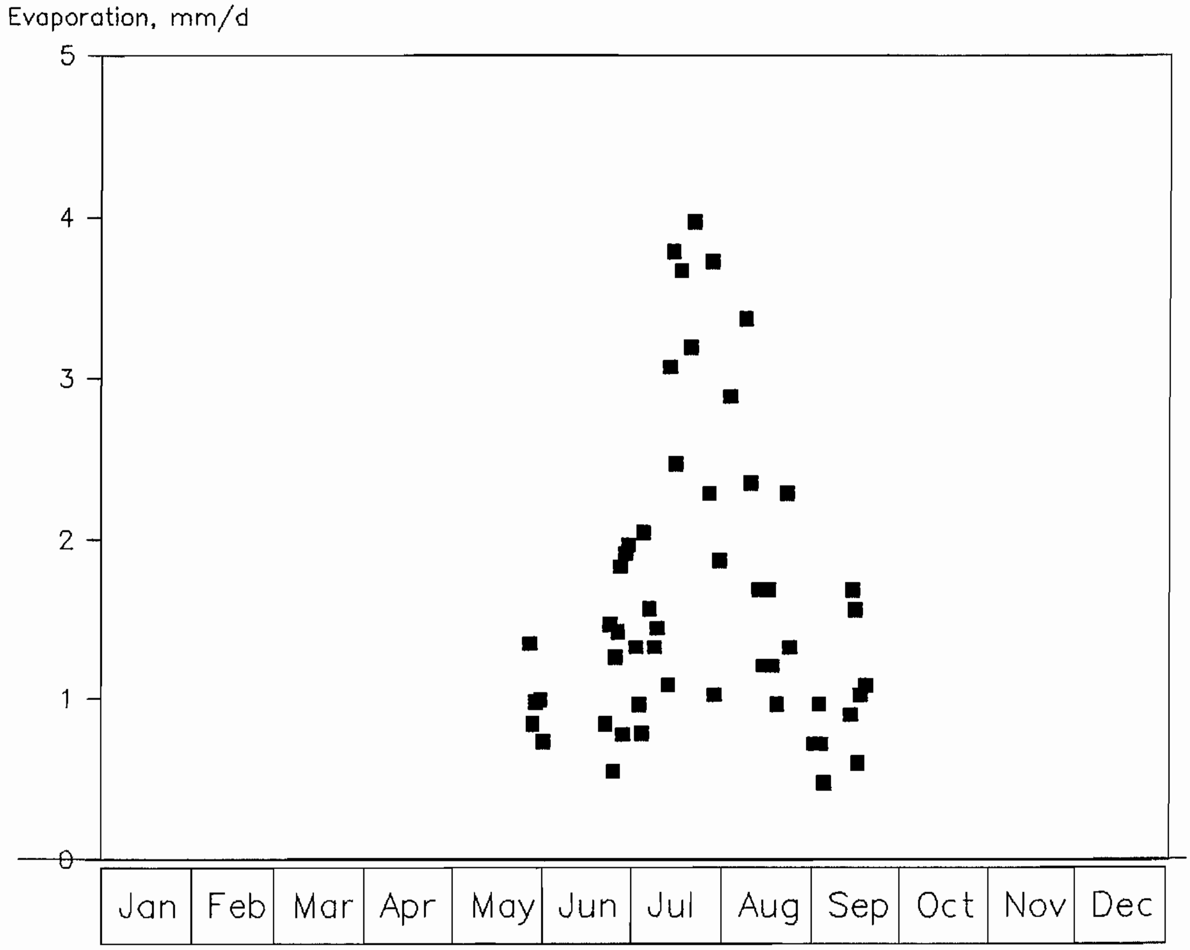

Figure 30 Actual evaporation from litter, 1985

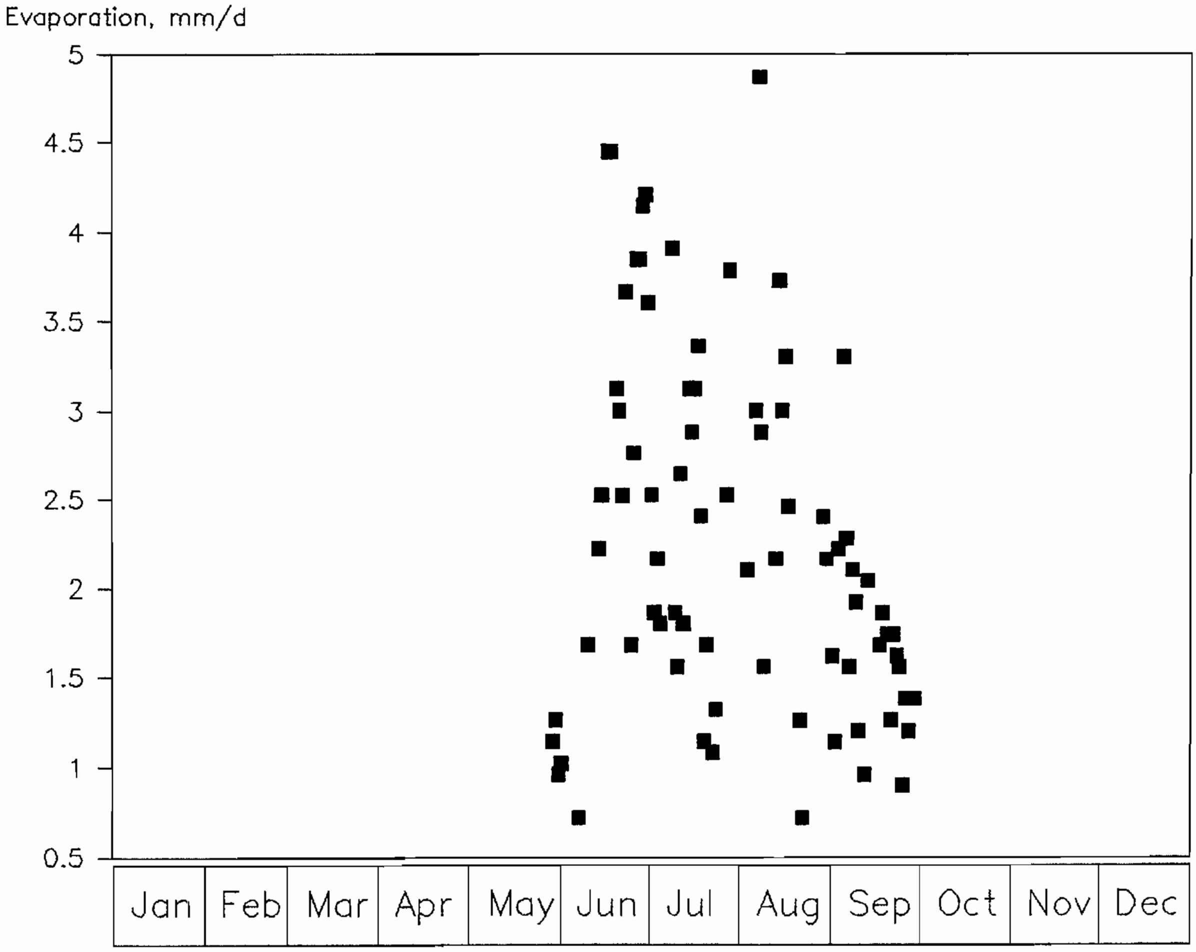

Figure 31 Actual evaporation from litter, 1986

The daily values of daily transpiration obtained by this method are within the expected range, and fit in well with the figures quoted by Godwin: to make a comparison with published figures for potential evaporation from grass, similar values were filled in for days without diurnal fluctuation calculations, and the weekly totals compared with the MORECS estimate produced by the Meteorological Office. The totals for the summers of 1984, 1985 and 1986 came to 64.4%, 65.5% and 79.7% of the potential evaporation estimate. For an unknown reason, the effects of cutting in 1985 did not cause any obvious reduction in evaporation rates until late in August.

With some refinement of the method for determining effective porosity, the diurnal fluctuation method is a promising means for estimating actual evaporation from mire communities. The technique is being developed by IH Plynlimon for use with lysimetric methods, and a lysimeter is being installed in a litter community at Wicken as part of an experiment that will apply the methods to several wetland sites in the UK.

4.2 Estimation of evaporation from decline in water table

By examining the decline in the water table at selected sites in the Fen, it is possible to make an estimate of the relative transpiration rates of the various communities. For this purpose, periods without significant rainfall were chosen during the summers of 1984, 1985 and 1986, and the rates of decline were calculated for boreholes 1, 11, 17, 18, 19, 21 and 24. The results are presented in Tables 6 to 8.

Dates	bh 1	bh 11	bh 17	bh 18	bh 19	bh 21	bh 24
	litter	sedge	litter	carr	litter	carr	carr
26/06/84 - 03/07/84	0.09	0.09	0.09	0.09	0.10	0.10	0.11
3/07/84 - 10/07/84	0.12	0.12	0.10	0.10	0.15	0.12	0.10
19/07/84 - 25/07/84	0.06	0.08	0.06	0.06	0.06	0.08	0.18
25/07/84 - 30/07/84	0.06	0.06	0.05	0.04	0.07	0.06	0.07
13/08/84 - 22/08/84	0.14		0.12		0.15	0.14	0.16
22/08/84 - 28/08/84	0.06		0.04		0.08	0.08	0.08
28/08/84 - 03/09/84	0.06	0.06	0.05	0.04	0.09	0.09	0.07
08/10/84 - 15/10/84	0.04	0.03	0.04	0.07	0.04	0.03	0.03

Table 6 Rates of fall of water table in selected boreholes, 1984

Dates	bh 1	bh 11	bh 17	bh 18	bh 19	bh 21	bh 24
	litter	sedge	litter	carr	litter	carr	carr
1/07/85 - 8/07/85	0.14	0.10	0.12	0.14	0.07	0.10	0.13
8/07/85 - 14/07/85	0.07	0.07	0.08	0.08	0.09	0.10	0.10
6/08/85 - 12/08/85	0.09	0.07	0.06	0.08	0.11	0.08	0.07
25/08/85 - 1/09/85	0.10	0.07	0.07	0.08	0.08	0.09	0.08
15/09/85 - 21/09/85	0.04	0.04	0.04	0.03		0.05	0.06
21/09/85 - 29/09/85	0.06	0.04	0.03			0.06	0.07
29/09/85 - 05/10/85	0.04	0.04	0.03	0.08		0.06	0.05
13/10/85 - 20/10/85	0.03	0.04	0.03	0.01	0.04	0.04	0.04
20/10/85 - 27/10/85	0.03	0.03	0.01		0.03	0.02	
27/10/85 - 03/11/85	0.01	0.02			0.02	0.02	

Table 7 Rates of fall of water table in selected boreholes, 1985

Dates	bh 1	bh 11	bh 17	bh 18	bh 19	bh 21	bh 24
	litter	sedge	litter	carr	litter	carr	carr
21/05/86 - 26/05/86	0.09	0.08	0.03	0.07	0.01	0.03	0.06
7/06/86 - 14/06/86	0.09	0.10	0.07	0.11	0.08	0.19	0.15
14/06/86 - 21/06/86	0.02			0.02	0.04		
13/07/86 - 19/07/86	0.11	0.16	0.11	0.11	0.14		0.07
30/08/86 - 10/09/86	0.07	0.09	0.09	0.11		0.12	0.13
18/09/86 - 27/09/86	0.08	0.09	0.08	0.10	0.11	0.11	0.09
27/09/86 - 4/10/86	0.04	0.03	0.03	0.04	0.04	0.05	0.06
4/10/86 - 13/10/86	0.03	0.02	0.03	0.03		0.04	0.07

Table 8 Rates of fall of water table in selected boreholes, 1986

For bh 19, these rates of decline were converted into estimates of daily transpiration, using a value of 12% for the specific capacity. For 1984, the range of daily rates was between 1.6 and 2.6 mm/day for most of the summer, falling to 0.7 mm/day in early October. In 1985 rates between 1.2 and 2.2 mm/day were maintained in July and early August, but the rate of transpiration was not measurable in late August and September, reaching low values between 0.3 and 0.7 mm/day in October. This decrease in transpiration correlates well with the cutting of this field, which took place on 8 July. In 1986 rates of transpiration were low, between 0.2 and 1.4 mm/day, in May and June, but rose to 2.8 mm/day in July, when the vegetation was presumably fully recovered from cutting.

The values of the water level decline for each borehole were subjected to linear regression on those for bh 19, to investigate the relationship if any between rate of decline and vegetation community. It was found that the declines were:

bh 1	litter	66% ± 29% of bh 19
bh 11	sedge	69% ± 29% " "
bh 17	litter	65% ± 24% " "
bh 18	carr	50% ± 40% " "
bh 21	carr	84% ± 35% " "
bh 24	carr	37% ± 49% " "

While the relationships are not precise, it appears that most communities have a water level that declines less rapidly than bh 19 in the absence of rain. Particularly striking are the results from bh 18 and bh 24: Godwin's assertion that carr transpires less than fen is supported by this evidence. However, it remains to explain the apparent steep fall in summer levels in the Sedge Fen Drove and Spinney Bank boreholes. If the level in the absence of rain declines at a lower rate than in bh 19, the answer must be that the levels are not raised to the same extent by summer rain. An examination of the plots of annual variation in level shows just that: for instance the moderately heavy rain of 1-6 August 1984, a total of 37.6 mm over 6 days and the first significant fall for 18 days, caused a rise of 30 mm in bh 19 between 30 July and 13 August, where over the same period the level in bh 21 was unchanged. The level in bh 24 fell by 10 mm.

The weekly data is unsuited to this type of analysis, as peak levels could have been missed between visits, but it appears that the key to the large decline in carr water levels during the summer is the inhibition of the effects of summer rainfall, which causes a partial recovery in levels under fen vegetation. The interception of slight to moderate rainfall by the carr canopy is a very likely mechanism.

5 Conclusions and future work

The measurement network at Wicken Fen has provided a means of assessing the behaviour of the fen water table over three seasonal cycles. The spread of stations across the Fen gives confidence that the various parts of the Fen have been sampled effectively, and with the use of continuous water level recorders it has proved possible to obtain results relating to transpiration rates from the litter community and the specific capacity of the peat.

The Fen behaves in much the same way as it did in Godwin's time, though Gowing's results suggest that dyke levels are lower, and the incidence of winter flooding is less frequent. The fen expanse, where the summer water table is controlled by transpiration rates, is little influenced by dyke levels, though a high water level in the dykes helps to prevent peat wastage in the marginal area. The response of the water table to rainfall and evaporative demand is well understood, and this study has confirmed many of Godwin's findings. However, one interesting difference of opinion has emerged. Godwin concluded from his measurements of low transpiration rates for carr that water levels under carr would be higher in summer. This does not appear to be the case, and it is concluded here that this is due to the interception of summer rainfall by the carr canopy.

This report has shown the use of the records in describing hydrological behaviour and estimating parameters. A closer examination of the data would clarify the effects of cropping, and permit more detailed modelling work aimed at predicting the effects of management of dyke levels.

Gowing (1977) alluded to the difficulties of deducing long-term changes from the discontinuous information available. A more extensive base of historical climatic and hydrological data, and information relating to sluice operation, awaits collection from the Anglian Water Authority, and effort must be directed towards setting the current study in a long-term context, and making fuller use of comparisons between recent work and the studies of Godwin and his colleagues. In particular, the question of changing retention levels in the Lode, and its significance for dyke and fen levels, must be addressed.

Little attention has been given in this study to the problem of water quality, which may ultimately prove to be more important than dyke water level in maintaining the character of Wicken Fen. Gowing (1977) gave a number of possible remedies for the surface acidification of the Fen, none of which was simple or inexpensive, and it is clear that the adoption of any expensive schemes must depend on more definite knowledge of its consequences. There is a need for more detailed information on the variation of acidity throughout the peat profile, and it may be that an approach through measurements of calcium concentrations rather than pH would be a better indication of leaching of bases. A programme of sampling peat at the surface and at depth could help to indicate the significance of leaching processes in producing acid conditions at the surface. The hypothesis that surface flooding has been an important factor in the past could be tested by comparisons between eastern and western parts of the Fen.

6 Acknowledgments

I acknowledge with gratitude the assistance and guidance of Tim Bennett in the setting up of the data collection network and in ensuring its smooth running.

Though a visitor to Wicken in summer would find it difficult to imagine, Cambridgeshire in the wild wintry days has little to recommend it. Thanks are therefore due to the observers, M Bentley and R Fisher and others, who have managed to get around the network in all weathers and conditions, and to return data of a high standard of consistency. They should also have my apologies for making it such a long walk!

7 Log of management practices likely to have affected water levels

7.1 1984

28/09/84	Litter field around bh 20 cut

7.2 1985

31/01/85	Farmer pumping water into Drainer's Dyke
24/06/85	Litter field around bh 1 - bh 5 cut
08/07/85	Litter field around bh 19 cut
21/07/85	Culvert installed to drain farmland near Howe's Bank
06/08/85	Vegetation around bh 19 beginning to shoot Vegetation around bh 20 now at about 1 metre tall
25/08/85	Sedge field cut around bh 9 - bh 11
01/09/85	Sedge field cut around bh 9 - bh 7
25/09/85	New dam constructed on New Dyke - old dam not removed
03/12/85	Vegetation around bh 1 - bh 5 now about 0.6 m tall

7.3 1986

08/01/86	Farmer pumping water into Drainer's Dyke
20/05/86	Litter field around bh 20 cut