The use of fertilizer-free buffer strips to protect dyke flora from nitrate pollution, on Walland Marsh S.S.S.I.

NRA

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Dr H Moorby and Dr H F Cook
Environment Section,
Agriculture, Horticulture and Environment Dept.,
Wye College, University of London.
Wye, Ashford, Kent. TN25 5AH

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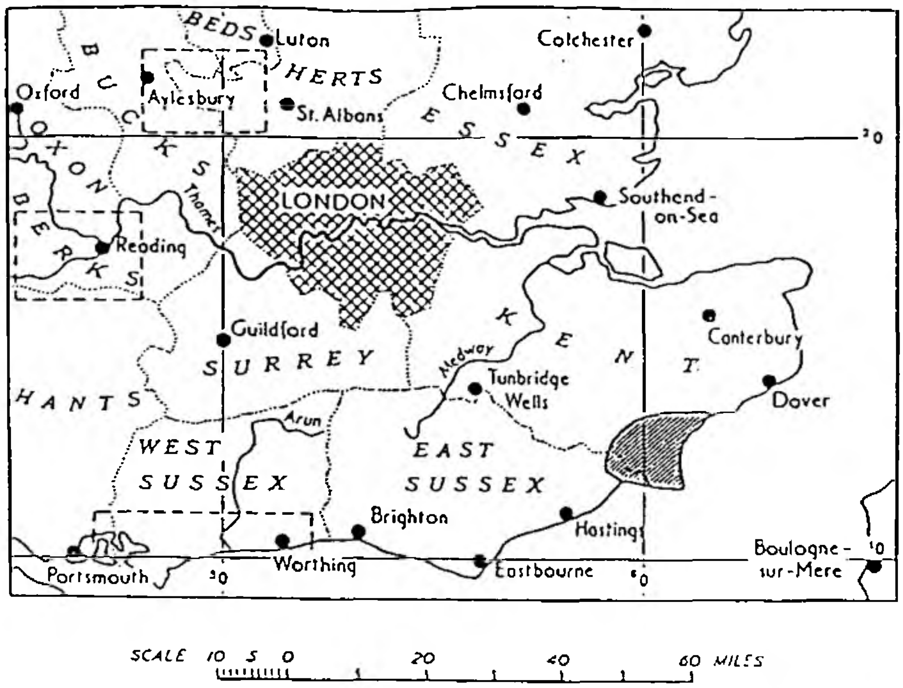
Funding for this project ran from 1st April 1990 to 31st March 1993. Fieldwork on the project started in July 1990.

INTRODUCTION

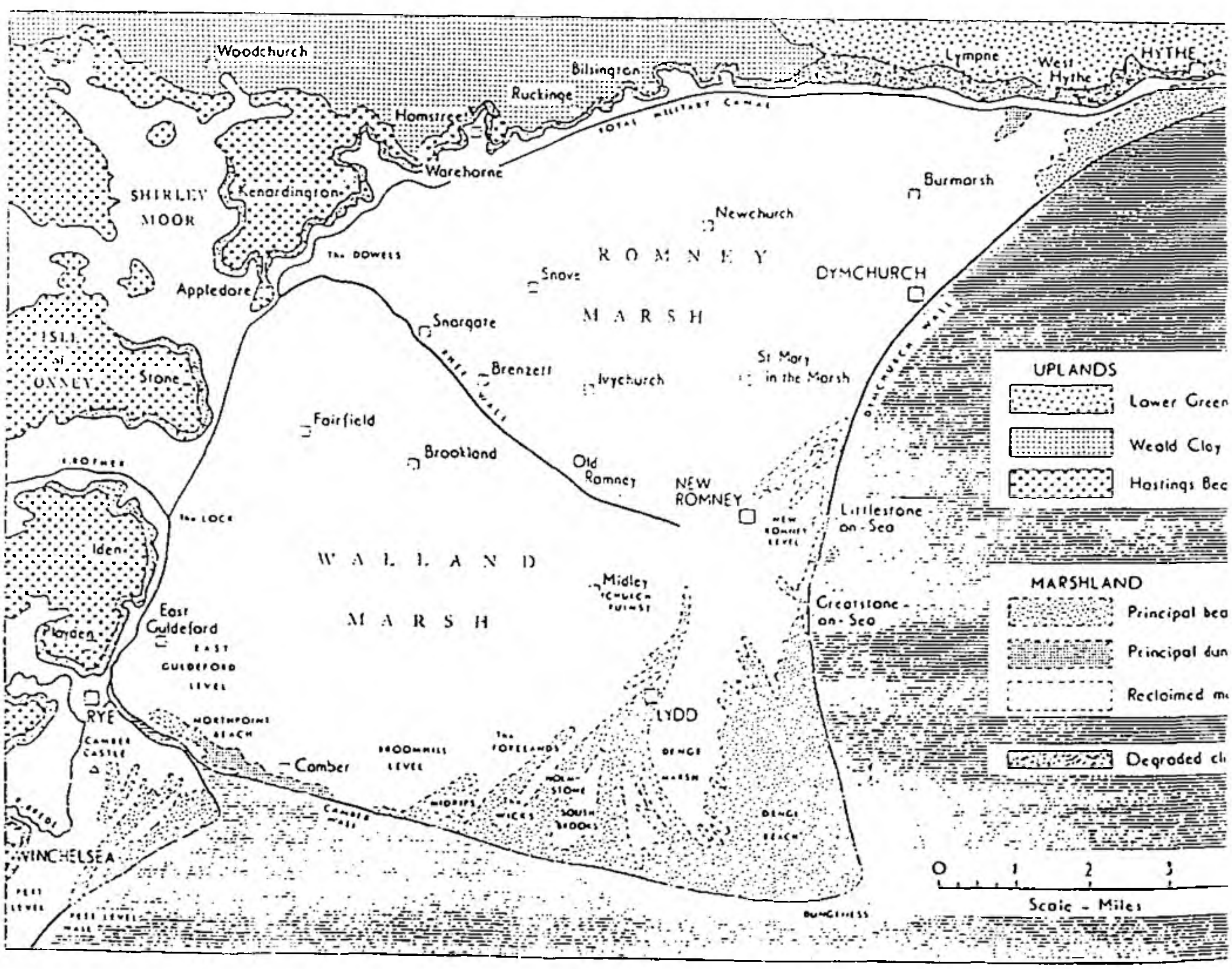
Romney Marsh is an area of 150 sq.km of reclaimed coastal marshlands and beaches. The landscape is very flat with an intricate pattern of dykes, some following the natural drainage pattern ,others man made. The land has been used for agriculture since the Middle Ages and has a strong tradition of raising sheep. Since the Second World War much of the grazing marsh has been ploughed and deep drained for arable cropping. there has been a reduction of the grazed area from 90% of the total land area before the war to 32% by the mid 1980's. As a consequent of this reduction most of the scientific interest in terms of the flora and fauna now resides in the dykes. To try to protect the dyke water from fertilizer runoff and leaching a series of management agreements have been set up by English Nature in the Walland Marsh SSSI. Map 1 shows the location of the Walland Marsh area and Map 2 shows the boundaries of the SSSI.

The Management policy concerns both the remaining permanent pasture or grazing marsh and the arable-ley rotation. In both cases the fertilizer application rates are restricted and no fertilizer may be applied within 5m of any dyke or water course.
The cutting and stocking rates of the permanent pasture and the leys are strictly controlled, while on the arable areas a grass headland of 5m must be left adjacent to any dyke or watercourse. The maintenance of the dykes and the water levels is also strictly controlled.

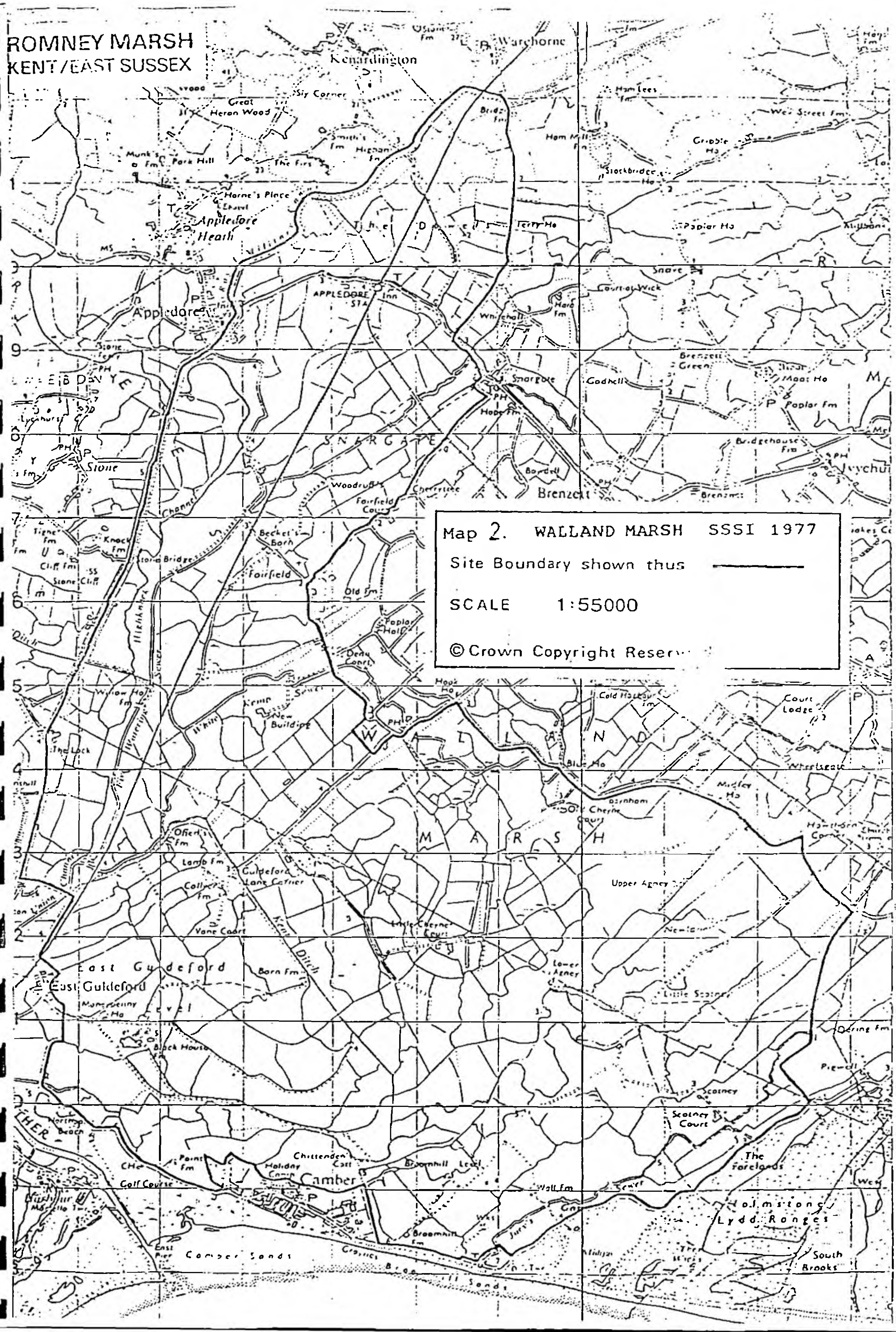
The 3 year project reported here aimed to evaluate these management practices. In addition an experiment was done to quantify the effectiveness of 5m fertilizer free strips in protecting the dyke water from nitrate leaching. Four contrasting farming practices were evaluated: permanent pasture, restored pasture from arable, permanent arable with 5m buffer zone and permanent pasture without a buffer zone. During the 1990-91 and 1991-92 leaching seasons, water movement and nitrate leaching were measured on these four sites. During the 1992-93 season work was concentrated on the arable site with 5m fertilizer free strips. An experiment was set up in which nitrate was applied to the land in November, leaving differing widths of fertilizer free grassland between the dyke and the crop. The aim of this experiment was to measure the downward movement of the nitrate into the saturated zone and its consequent movement through the saturated zone into the dyke.



Map 1. Location of Romney Marsh (south-east England)



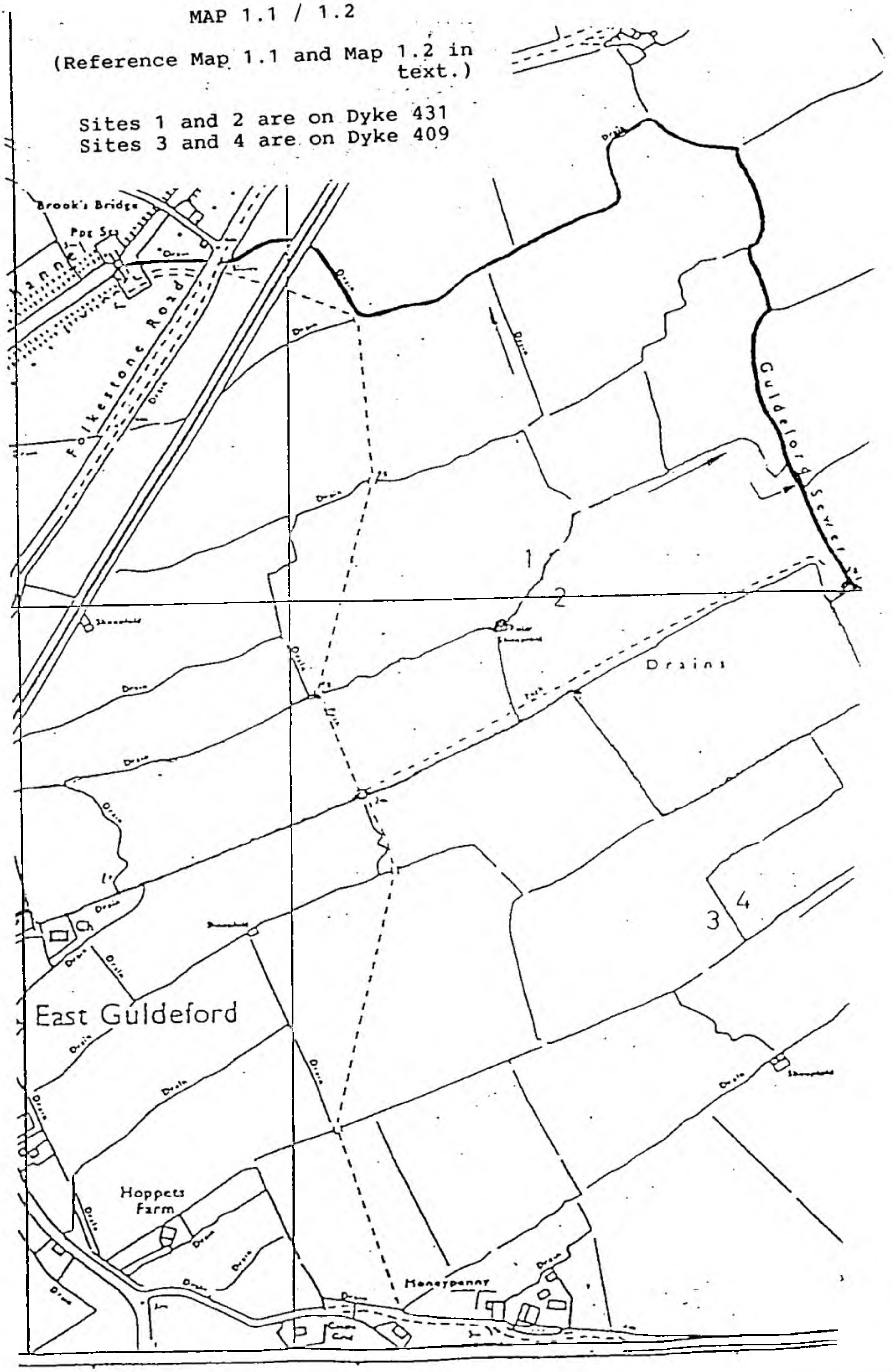
The different Marshlands


ROMNEY MARSH
KENT/EAST SUSSEX
Map 2. WALLAND MARSH SSSI 1977
Site Boundary shown thus
SCALE 1:55000
© Crown Copyright Reser...
Warehorne
Kenardington
Great Heron Wood
Appledore Heath
Appledore
APPLEDORE STA
Snargate
SNARGATE
Brenzett
Fairfield
Brenzett Green
Snave
East Guldeford
Camber
Camber Sands
Lydd Ranges
South Brooks
The Forelands
W A L L A N D
M A R S H

MAP 1.1 / 1.2

(Reference Map 1.1 and Map 1.2 in text.)

Sites 1 and 2 are on Dyke 431
Sites 3 and 4 are on Dyke 409



CHAPTER 1

BACKGROUND INFORMATION

Reclamation and Drainage.

The area of Walland Marsh where the experiments were located (Map 1.1) shows an orthogonal pattern of dykes and which is based upon the former creek pattern (Green, 1968). It is probable that this pattern derives from the drainage of mud flats and saltmarshes deposited between about 1280 and 1500 AD, after which the area was reclaimed. It is *possible* that settlement had occurred in the area prior to this period, however serious flooding inundated the area during the later part of the Thirteenth Century; a new outlet for the River Rother having most probably been established near to Rye, East Sussex, during the Twelfth Century (Tatton-Brown, 1988). This resulted from the breaching of a former longshore shingle bar on the west side of Walland Marsh. Prior to this, the River flowed further east to the sea (Lewis, 1932).

Here original marshland drainage channels converted to dykes, have a very low sinuosity (between 1.00 and 1.01) and typically trend ENE-WSW. Sinuosities rise to around 1.2 where creeks, originally second order streams receiving water from the former, are fed by these straighter and near parallel former first order streams. Otherwise artificially dug cross-dykes are perfectly straight; typically trending NW-SE. The modern, post-reclamation drainage density west of the Guildford sewer is 8.12 km/km^2 which compares with drainage densities quoted elsewhere (Cook and Moorby, 1983) of between 6 and 9 km/km^2 for reclaimed alluvial secondary marshlands in the East of England, where effective rainfall is comparatively low.

The modern drainage in the locality is internal, essentially north-westwards via the Guldeford sewer into the White Kemp Sewer (Robinson, 1988).

Soils

Soils in the area are mapped as either Romney-Agney Complex or Newchurch-Walland Complex by Green, (1968). The former belong to 'mounds' associated with former creeks, are texturally coarser (loam, clay loam or sandy loam) and consequently better drained. The intervening land is the heavier, and less well drained Newchurch and Walland series (silty clay, clay loam, silty clay loam, and silt loam). Suitable instrumented sites were checked, then selected to be Newchurch-Walland Complex (C.P. Burnham, *pers comm.*) being virtually all silty clays or silty clay loams between 0 and 1.0m. Sandy layers were encountered at times in the subsoil between 1.0 and 2.5m, in otherwise unripe fine-textured subsoils. A combination of pronounced horizontal stratification (Childs *et al*, 1957) and unripe fine-textured subsoils below about 1.5m under arable soils would work to prevent the deep percolation of drainage waters from the field to the dyke by effectively presenting an impermeable 'floor' constraining flow to the near-horizontal (c.f. Nwa and Twocock, 1969).

Climate

Rainfall

The Walland Marsh area has low rainfall by British Standards, with relatively high potential evapotranspiration (ET).

For the period January 1990 to April 1993 which includes the experiment and the immediately preceding period, rainfall figures are presented in Table 1.1

TABLE 1.1: MONTHLY RAINFALL FIGURES DURING THE EXPERIMENT.

	1990 mm	1991 mm	1992 mm	1993 mm
January	101.1	94.5	11.9	83.2
February	102.4	30.3	24.6	6.4
March	5.4	42.6	51.0	16.5
April	52.0	50.6	65.1	68.8
May	10.3	19.8	32.7	
June	57.4	131.3	8.9	
July	8.3	80.9	72.8	
August	30.3	1.8	91.7	
September	17.6	32.2	57.0	
October	120.9	36.7	96.2	
November	74.2	118.8	146.3	
December	59.9	19.6	63.1	
Ann. Tot.	639.8	659.1	658.2	

The long-term rainfall average at the site for the period 1916-50 was 699mm (Green, 1968), and Smith and Trafford (1976) give a figure of 683mm for the 'agro-climatic' region of the Marsh.

Analysis of rainfall data for the period 1960-1992 at Scots Float yields an annual average figure of 729.8mm. Table 1.2 shows probability of exceedance and recurrence interval for the whole years (January to December) and for the winter during which substantial leaching of nitrate was found to occur - the 'leaching period' from November to March.

TABLE 1.2: PROBABILITY OF EXCEEDANCE (P), RECURRENCE INTERVAL (R) AND RAINFALL (RF) DATA DURING THE COURSE OF THE EXPERIMENT:

calender year				Nov. To March			
	P(%)	R	RF		P(%)	R	RF
1990	88.2	1.13	639.8	1990-1	63.6	1.57	301.5
1991	70.6	1.42	659.1	1991-2	87.9	1.14	225.9
1992	73.5	1.36	658.2	1992-3	62.5	1.60	315.5
				with 65mm irrigation, March:	40.0	2.50	380.5

Rainfall figures from Scots Float (1.5km to the NW of the sites) showed total rainfall between 1990 and 1992 to be below long-term averages. These years were respectively the thirtieth, twenty-fourth and twenty- fifth driest in thirty-three in terms of rainfall alone. The early part of 1992 was abnormally dry; 11.9mm (only 15.7% of the 1960 to 1992 average for that month fell during January; in February 24.6mm or 50.8% of the average fell.

For both the whole years 1990-2 and the periods November to March 1990-3, the probability of exceedance of rainfall, omitting irrigation was at least 62% reflecting the lower than average rainfalls. For this reason, in an attempt to encourage the leaching of nitrates, the experiment established on site 3 was irrigated with 25, 20 and 20mm rainfall equivalent being added on the 4,11 and 18 March 1993.

Evapotranspiration and Drainage

The long-term average (1941-1970) annual potential evapotranspiration for the agroclimatic region including the site is 563mm Smith and Trafford (1976) which due to the extreme south-eastern location of the area. This figure is relatively high by British standards.

Figures for actual evapotranspiration from a short green crop are available from the MORECS model, and are presented in Table 1.3. Actual evapotranspiration figures are lower than potential for most of the year, although winter figures are frequently the same or very close. In 1991 and 1992 the MORECS 'actual evapotranspiration (real land use)' figures were 512 and 491mm respectively.

TABLE 1.3: MORECS ACTUAL EVAPOTRANSPIRATION (AET), RAINFALL (RF) AND DRAINAGE (DR) DURING THE WINTER PERIODS AT SITES 1/2 AND 3/4 DURING THE EXPERIMENT (mm).

	AET	RF(1/2)	DR(1/2)	RF(3/4)	DR(3/4)
Nov 90-Mar 91	95	306	211	302	207
Nov 91-Mar 92	88	230	142	226	138
Nov 92-Mar 93	81	-	-		
No irrigation		-	-	(315)	(234)
With irrigation		-	-	380	299

In Table 1.3 the drainage term 'DR' is an effective rainfall figure calculated as the difference between AET and RF. It represents the excess of rainfall over evapotranspiration, that is water available for drainage and leaching of chemical substances out of the soil profile. The amount was appreciably lower for the 1991-2 season reflecting the extremely low winter rainfall figures (see also Table 1.1). It should be noted that there was a very uneven distribution of rainfall during both the winters of 1991-2 and 1992-3, meaning that December 1991, January 1992, February 1992, February 1993 and March 1993 (without irrigation) all had differences between AET and RF which were within 12mm, and in the latter two cases AET actually exceeded RF, a situation more usual in the summer.

METHODOLOGY

The Study Area.

Map 1.2 shows the exact location of the four study sites within the SSSI. The sites were chosen with similar soil type and properties. The soil belongs to the Newchurch series defined and described by Green (1968) . It is a calcarious soil on Marine Alluvium.
The sites, shown on the map, were as follows.

1. Ancient sheep pasture which has not been treated with fertilizers.
2. Arable land which in autumn 1989 was returned to permanent pasture, with 5m wide fertilizer free strips (established in 1987) along the edges of dykes.
3. Arable land with 5m wide fertilizer free grass strips (established in 1884) along the edges of the dykes.
4. Arable land without 5m wide fertilizer free strips.
5. In 1991-92 a fifth site was set up on the arable land being restored to permanent pasture. This site was set up because it became clear that the water on site 2 predominantly drained away from the dyke. Site 5 was on the opposite side of the field where the water did drain into the dyke.

Fertilizer application.

Sites 1, 2 and 5 did not receive any fertilizers. Site 3 received fertilizers at rates of 439 kg/ha of 20:10:10 compound fertilizer and 50 kg/ha of Nitram per annum. Site 4 received 250 kg/ha of 15:15:15 compound fertilizer and 500 kg/ha of nitram per annum.

Instrumentation

Sites for instrumentation were chosen as close as possible to the end of dykes to simplify the drainage conditions to the dykes selected. Site 1 (ancient pasture) and site 2 (arable reverting to pasture with 5m fertilizer free strips) were on opposite sides of ditch No 431(see map 1.2). Site 3 (arable with 5m fertilizer free strips) and site 4 (arable without 5m fertilizer free strips) were opposite to each other on dyke No.409 (See map 1.2). Site 5 drained into dyke

No 425 (see map 1.2). The dykes are numbered according to the numbering given to them by English Nature in their floral surveys.

On each site, 2 instrument areas were set up, about 10m from each other. Each set of instruments comprised :- 1 dipwell to 2m, 1 neutron probe access tube, to 1.8m , and 1 set of porus ceramic cups each set having tubes to 30,60,and 90cms depth. 6 sets were installed on each of sites 2 and 3. One set at the dyke edge, one at the 5m strip/field interface and one 10m into the field. On sites 1 and 4 four sets were installed on each site, one at the dyke edge and one 5m into the field. A total of 20 sets of instruments. In addition, a bank of tensiometers (at 0.3,0.6,0.9 and 1.2 m) was set up on each site. Readings at 0.1m and 0.2m were taken with a portable tensiometer. One raingauge was also placed on each site. Poles permanently installed in the dykes recorded the dyke levels.

Sampling

1990-1991

In the first year of the project the instruments were in place by the end of September 1990, however due to the dry summer no samples could be taken from the ceramic cups or dip wells until the 2nd of November 1990. A similar situation occurred in the summer of 1991 and no samples could be taken until early December 1991. Samples were collected weekly, unless the soil profile was too dry for the ceramic cups to function. Tensiometer readings also could not be taken until the soil had completely re-wetted in late November 1990 and early December 1991. Dyke 409 was completely dry during August and September 1990 and the vegetation eaten by sheep, once water returned to the dyke the dyke flora rapidly began to regrow. Dyke 431 contained a small quantity of water throughout the summer and the dyke flora did not suffer.

The first measurable rain fell on the 19th October 1990, the soil took several weeks to wet up, soil water samples for nitrate measurements were taken from the 30cm ceramic cups on 2 November, from the 60cm cups on 21st November and from the 90cm cups on 28th November.

1991-1992

Similar, though not so severe, drought conditions occurred in the summer 1991. All dykes retained some water throughout. Although small quantities of rain fell during September and October it was not until 31st October that sufficient rain fell to begin recharging the soil. The first samples were collected from the ceramic cups on 21 November 1991

CHAPTER 2

HYDROLOGICAL DATA 1990-1992

Introduction

Neutron probe data

Neutron probe soundings at 0.2, 0.3, 0.4, 0.6, 0.9, 1.2, 1.5 and 1.8m were taken in access tube networks established across each site. Soil water contents were then used to calculate soil water deficits (SWDs) using published calibration curves, and assuming there was a 'field capacity' condition after several days free drainage in the virtual absence of evapotranspiration. These conditions were met frequently during the winter months. SWD was then used together with climatic data in the calculation of fertiliser leaching rates. SWDs were established from neutron probe soundings for 0 and 0.6m and between 0 and 0.9m below the surface. Because SWD is implicitly a negative quantity (ie the difference between profile water content at field capacity and that in the soil at the time of sounding), a negative sign for a quoted SWD figure implies a wet soil. In other words, the profile contains more water than the soil water profile at field capacity, a situation favouring drainage. Transpiration during the spring and summer favours large 'positive' SWDs.

Vertical movement of water

Tensiometer data at the sites were used to indicate vertical movement of water. Total potential profiles indicated that 'field capacity' conditions were reached at all sites between 22 and 29 November 1990. At all sites the profiles drained until reaching field capacity between 28 March and 3 April 1991. Field capacity was again reached by 14 November 1991; drainage was then the dominant process until 2 April 1992. By 9 April 1991 soil-water was moving upwards at all sites.

Watertable fluctuations

Dipwells set at the dyke edge and at five and at ten metres into the field enabled depth below surface of groundwater to be monitored.

Lateral movement of water

Levelling of the dipwells permitted the height in metres *Ordnance Datum* (mOD) of the ground watertable to be measured at each dipwell. In this way, the groundwater gradients (and hence direction of flow with respect to the ditch) were found. Times when subsoil water moved towards the dyke (the usual winter situation) or when water moved from the dyke to the field subsoil could then be established. However, due to the entirely artificial nature of drainage systems in reclaimed land, care has to be taken about such generalisations. For example, water levels are deliberately maintained high in times of drought either to preserve the 'wet-fence' function of the ditches or 'sub-irrigate' the fields in order to maintain grass growth, especially in old pasture.

Hydrology of the sites

Representative examples only of depth below surface, watertable heights and SWDs are given.

Site 1

This is a permanent pasture site which had not been ploughed for at least 25 years, and was continuously grazed by sheep throughout 1990-92.

1990-1

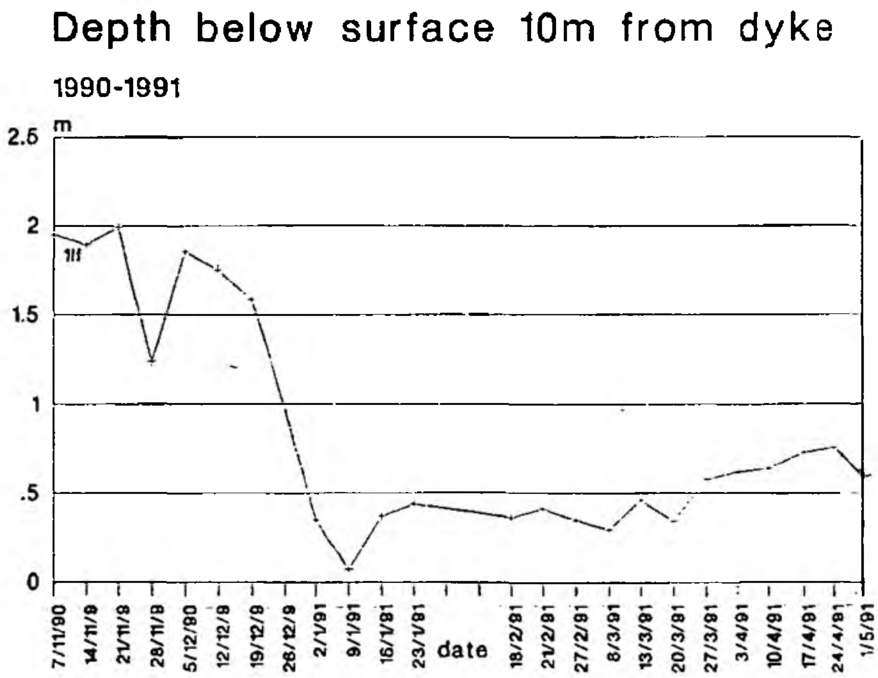


Figure 2.1

Figure 2.1 shows the depth below surface 10m from the dyke at one dipwell. The late autumn situation was one of low watertable (between 1.5 and 2.0m deep) following the dry summer of 1990, with flooding of the pasture in January 1991 bringing the watertable almost to the surface. The 'typical' winter depth would appear to be between 0.3 and 0.5m held between mid-January and late March, these values are consistent with a lack of underdrainage at the site.

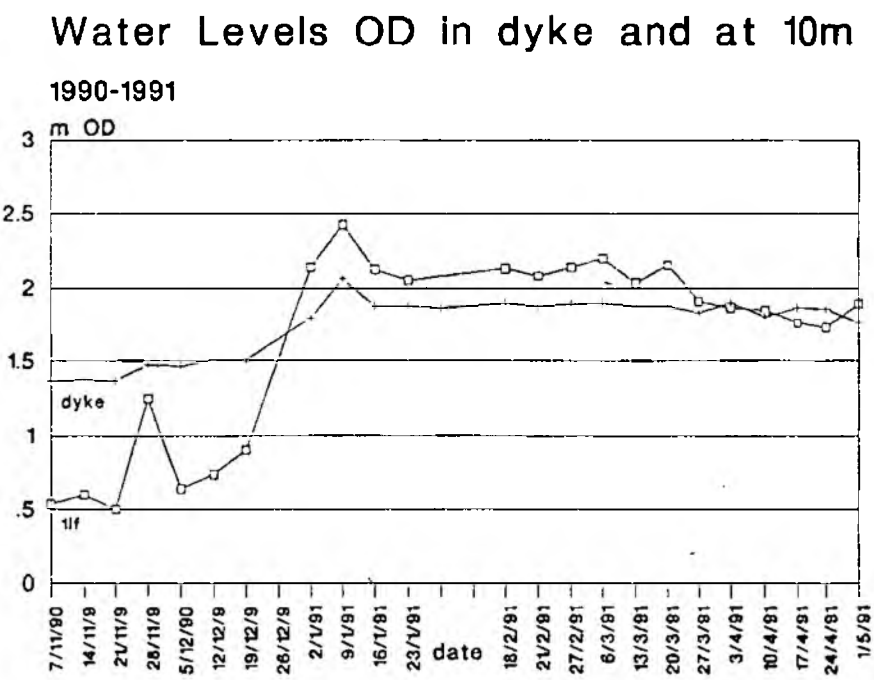


Figure 2.2 shows the heights in m OD of water in the same dipwell ('1lf') as Figure 2.1 and in the dyke. What is significant here is that from late December/early January to late March water levels 10m from the dyke were higher than in the ditch. Flow from the field to the dyke may be inferred from these observations during this time. The reverse situation occurred before and after this period.

Figure 2.3 shows the SWD at the site between November 1990 and October 1991. Deficits to two depths are shown, 0.6 ('1lf60') and 0.9m ('1lf90'). The large 'negative deficit' between late December 1990 and May 1991 is interpreted as the effect of a shallow watertable (c.f. Figure 2.1). During this time, the values for 0-0.9m are lower than for 0-0.6m, supporting this view because the depth 0.6 to 0.9m would be saturated throughout this period. In reality shallow watertable influences make the establishment of a SWD difficult for this site. SWDs in excess of 50mm were measured from August 1991, with close agreement between the two depths to which SWD was calculated.

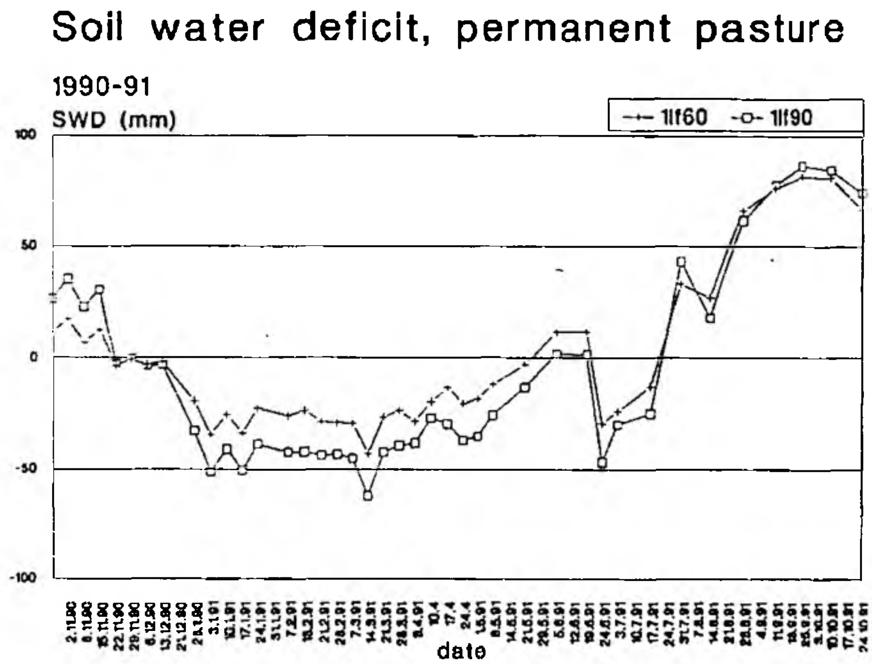


Figure 2.3

1991-2

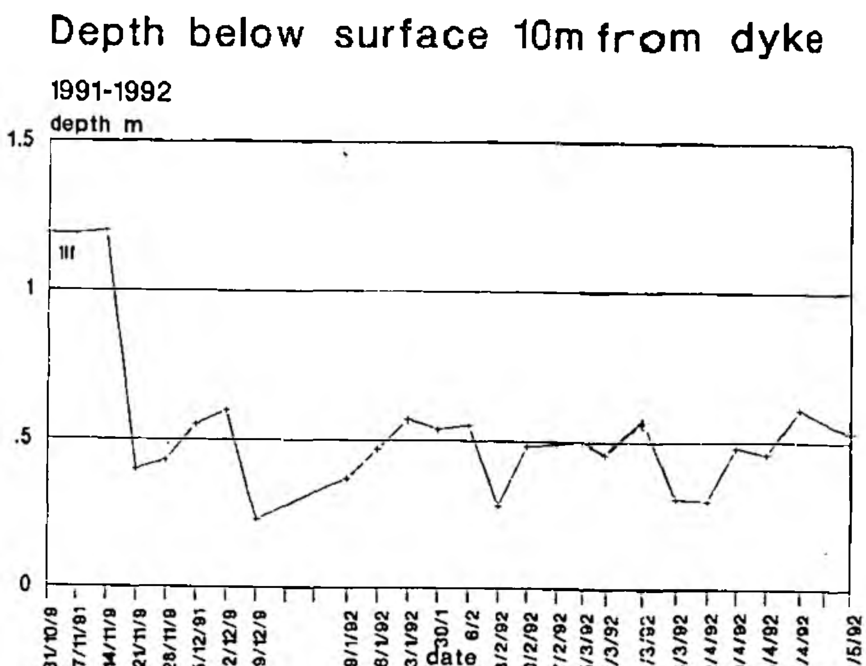


Figure 2.4 shows the depth below surface for the same dipwell as Figure 2.1. Following the wet November 1991 the watertable height increased, but from January 1992 onwards during the dry winter period, watertable levels stayed around 0.5m until late March, generally lower than during the previous year

(c.f. Figure 2.1).

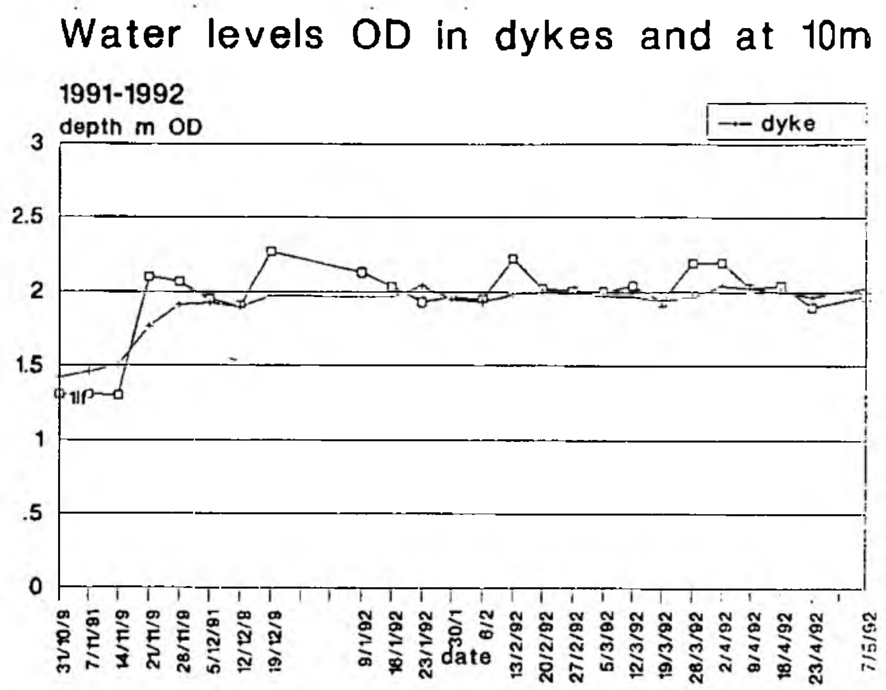


Figure 2.5 shows a less dramatic separation of the heights OD, in the dyke and at 10m ('11f'), than for the preceding year (c.f. Figure 2.2). This is to be expected during a drier winter, however the pattern of peaks show drainage towards the dyke dominated the drainage pattern between late November 1991 and the end of March 1992.

The drier winter (and consequent lower watertables) lead to higher soil water deficits between December 1991 and May 1992 than for the previous year (c.f. Figure 2.3). After this time the effects of transpiration show as SWDs (for 0–0.9m) above 50mm between mid-June and late August.

Site 2

This site was in arable for five years prior to Autumn 1988 when it was sown with grass, a fertiliser free grass strip being established in 1987. Underdrainage was put in place during the 1960s and hence is near the end of its useful life.

1990–91

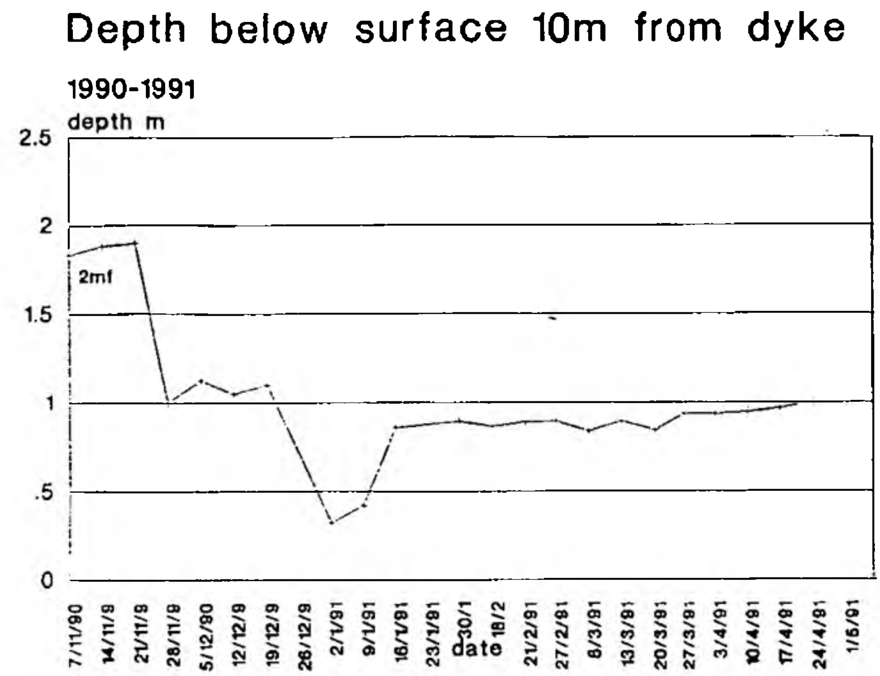


Figure 2.6 shows depth below surface of the watertable 10m from the dyke during the winter of 1990-91. comparison with Figure 2.1 shows the effect of underdrainage, maintaining a deeper watertable at between 0.8 and 1.0m throughout the period January 1990 to May 1991.

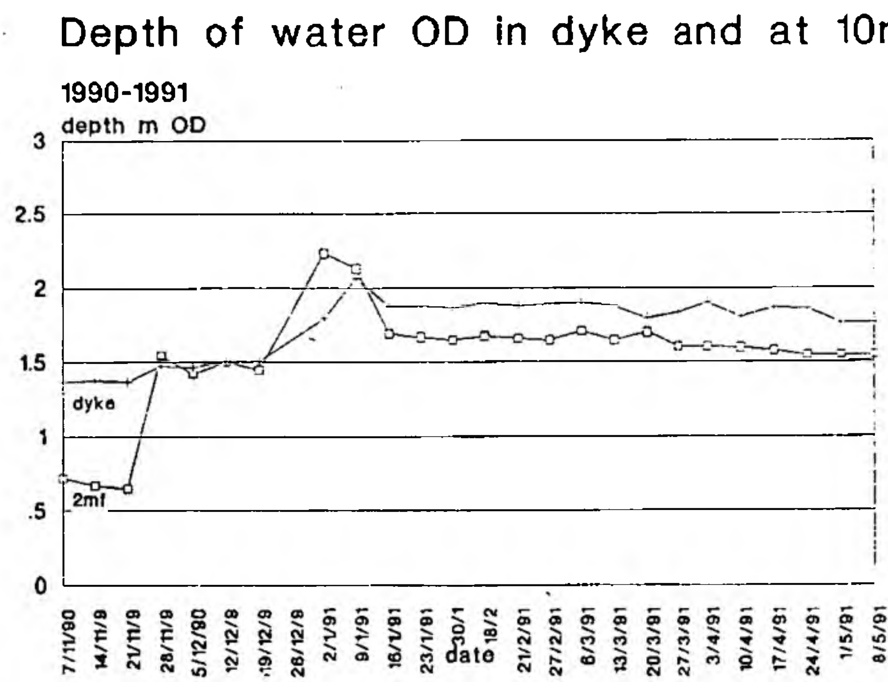


Figure 2.7 shows heights in mOD in the dyke and at 10m into the field ('2mf'). This site displayed water flowing from the dyke to the field from mid-January onwards, a consequence of an over-deepened dyke on the far side of the field to the instrumented site, probably assisted by the operation of the old tile

drainage system. Scrutiny of the levels in mOD at both 5 and 10m from the dyke indicates there was movement of water from beneath the strip to the dyke only during the period 28.11.90 to 9.1.91.

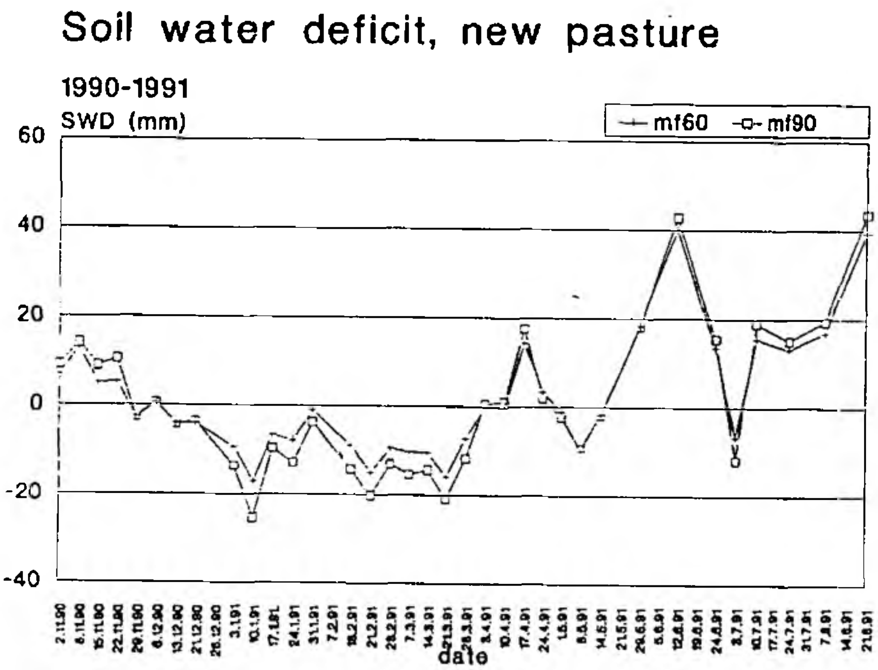


Figure 2.8 shows SWDs did not exceed 45mm between November 1990 and August 1991. The deeper watertables than Site 1 (c.f. Figure 2.3) mean overall winter SWDs are higher, with lower values being recorded for 0-0.9m. Maximum SWDs recorded during the summer of 1991 are lower than for Site 1. No significant conclusions may be drawn from this comparison due to the exaggerated effects of shallow watertables already noted at Site 1.

1991-2

The depth below surface 10m from the dyke showed watertable depths are maintained between 0.8 and 1.0m throughout much of the (dry) winter and into Spring 1992. These values are comparable for the previous year (c.f. Figure 2.6).

Heights in mOD in the dyke and at 10m Showed only one observation (21.11.91) with the water moving from the field to the dyke. This is for a shorter period than the previous year (c.f. Figure 2.7).

The 1991-92 SWDs showed that winter deficits are of a similar to the preceding year, with summer deficits to 0.9m reaching around 90mm, more than the preceding year (c.f. Figure 2.8).

Site 3

This site consisted of a five metre strip emplaced in 1984 around a field converted to arable in 1980. Underdrainage was between 20 and 22m away from the dyke edge with the system dating from the 1960s. Instrumentation was set along the dyke edge away from the underdrainage lines.

1990-91

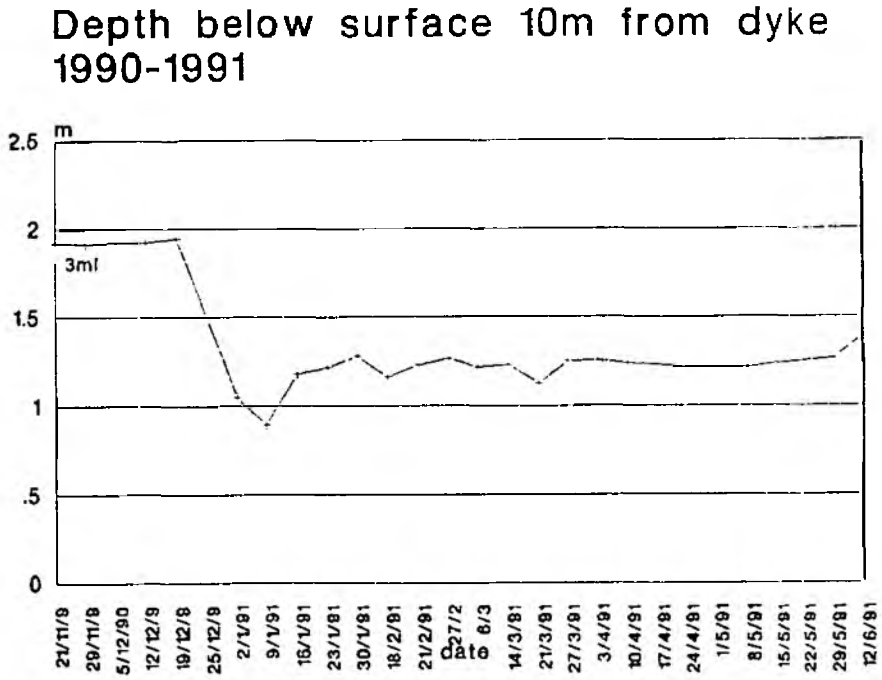


Figure 2.9 shows that the watertable was below 1.0m throughout the period mid-January to May 1991.

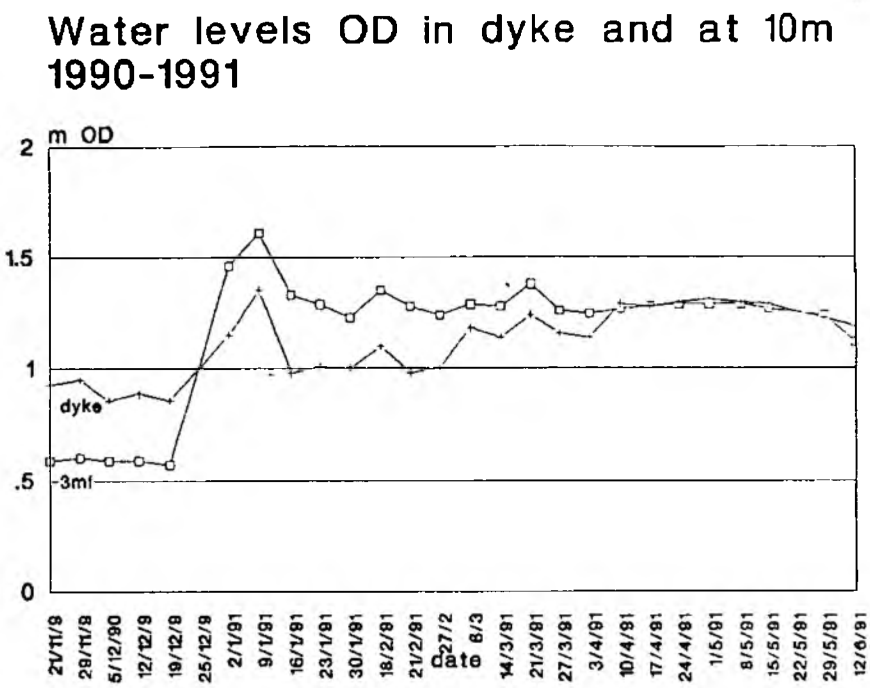


Figure 2.10 shows that the watertable heights 10m from the dyke edge ('3mf') were higher than in the dyke during the period from late December 1990 to mid-April 1991. After that time the watertable and dyke level was similar, indicating a flat watertable with little movement to or from the dyke.

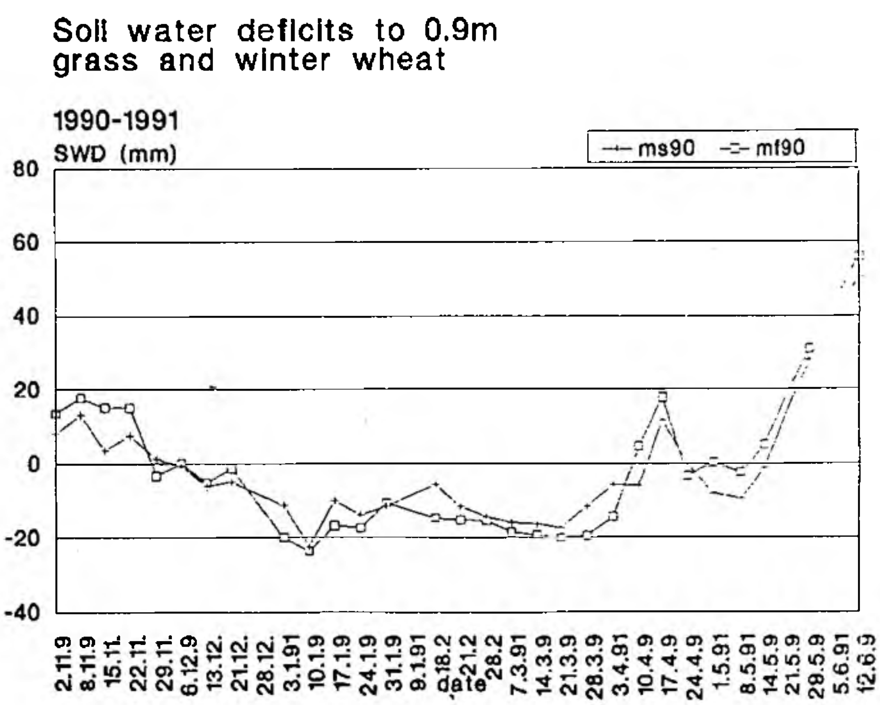


Figure 2.11 shows SWDs for the grass strip ('ms90') and field with a winter wheat crop ('mf90'). The SWD values are negative throughout much of the winter and early spring indicating drainage was favoured, with the two crops showing very close agreement throughout.

1991-92

The depth below surface of the watertable 10m from the dyke edge shows levels maintained below 1.0m over much of the period November 1991 to April 1992, a situation comparable with the previous year (c.f.Figure 2.9).

Watertable levels 10m from the dyke were higher than in the dyke from 21 November 1991 to 12 March 1992, indicating drainage from field to dyke during this period. At the replicate site, the period was longer, 14 November 1991 to 26 March 1992.

SWDs for both grass and winter wheat were at or below zero between mid-November 1991 and April 1992, after which time both show a rapidly increasing SWD.

Site 4

Site 4 was in arable throughout the experimental period and was located opposite Site 3. No fertiliser-free strip was present, crops were oilseed rape in 1990-91 and winter wheat 1991-1992.

1990-91

Watertable depth 10m from the dyke edge was maintained at around 1.0m over much of the period December 1990 to April 1991.

Watertable height 10m into the field was greater than in the dyke from late November 1990 to mid-May 1991 at two sites, being late December to mid-May at the third.

SWDs to 0.6m and 0.9m during the period November 1990 to June 1991 were negative occur during the winter months, with transpiration increasing the deficit after March 1991 reaching around 55mm (calculated to 0.9m) and 30mm (calculated to 0.6m) in early Summer.

1991-92

Watertable depth 10m from the dyke edge was maintained at or below 1.0m throughout most of the period December 1991 to May 1992.

Watertable height 10m into the field was greater than in the dyke from mid-November 1991 to 12 March 1992.

SWDs during the period Early November 1991 to mid-April 1992 were negative for much of the period, however positive peaks occur during the dry winter. After mid-April they rapidly increased.

Site 5

An extra grassland site established on the opposite of the 'new pasture' field to Site 2. Instruments were located during the winter of 1991-92 between underdrainage outfalls and 10m from each. Flow was towards the dyke between early-December 1991 and early-April 1992.

CHAPTER 3

NITRATE CONCENTRATIONS AND LEACHING

Site 1

1990-91 leaching period

Dipwell measurements showed that the water table at this undrained site remained high during the winter, at times flooding occurred. The movement of water was at all times towards the dyke. The only nitrate input to this site for many years has been from clover, rain and animal urine. The nitrate contents of the soil water samples from the ceramic cups were negligible for most of the leaching season. The highest concentration measured being 1.16mg/l at 30cms depth in the field on 3rd April '91.
Concentrations in the dipwells were measurable but were very low, ranging from 0 to 0.5 mg/l, there was no difference in concentration in the field and at the dyke edge. It was concluded therefore that the contribution of nitrate to the dyke water by leaching from site 1 was negligible.

1991-92 leaching period

Site 1 was sampled once a month during the 91-92 season. As in the previous season the nitrate levels were consistently very low, ranging from 0-3.0 mg/l. Nitrate levels in the dyke (431), which were measured weekly, ranged from 0-0.76 mg/l.

Site 2

As explained earlier in this report, predominant water movement at this site was from the dyke into the field and hence little contribution to nitrate in the dyke could have come from the field.

1990-1991 leaching period

This site was arable with 5m strips until 1989 when it was returned to pasture. It has received considerable nitrate in the past, none was applied in 1991. Sheep were not grazed over winter and the field was cut for hay. Virtually no nitrate was recovered from the dyke edge or the strip/field interface but large quantities were recovered from the field, particularly at 60 and 90 cm depth (Fig 3.1.).

Please note that all data for ceramic cups and dipwells given on graphs is the mean of the two replicates converted into a rolling average. This was done to smooth out the fluctuations in values which occurred from week to week. It was felt that the rolling average represented more accurate picture of the peaks and troughs of nitrate concentration as they moved through the soil.

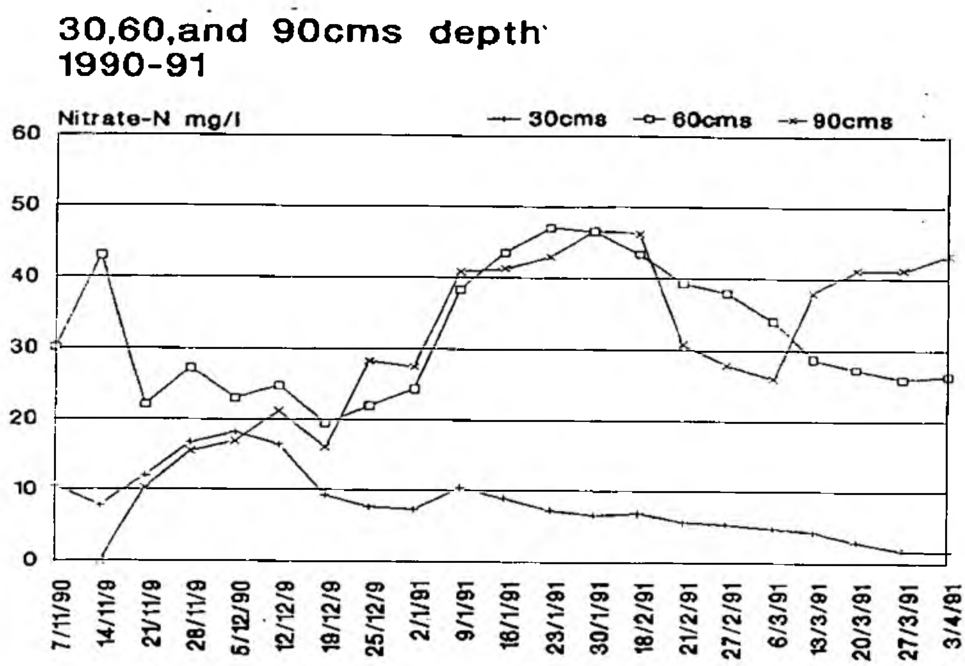


Fig.3.1 Nitrate N concentration in ceramic cups site 2,field,1990-91

This nitrate presumably represented residual nitrate from the arable crops. It was available to the hay crop and much would have been removed from the site with the hay. This was confirmed during the 91-92 season when the concentration of nitrate recovered from both the dipwells and the ceramic cups was very low.

1990-1991

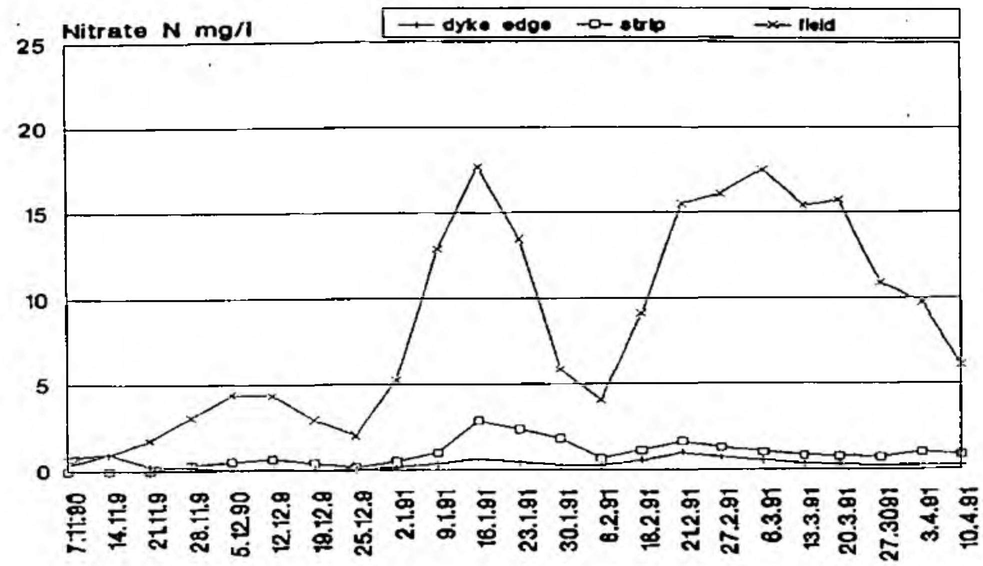


Fig.3.2 nitrate concentration in the dipwells on site 2

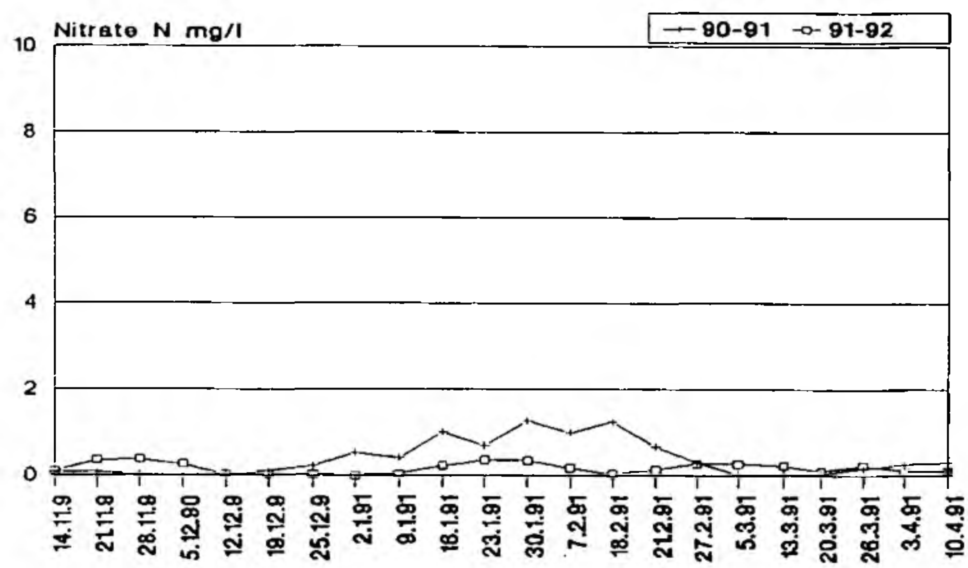


Fig.3.3 nitrate concentrations in the dyke between sites 1 and 2 for both seasons.

The only water contributing to the dyke was from the permanent pasture. Similarly nitrate concentrations recovered from the new site 5 in the same field were very low at all depths and sample sites.

Site 3

1990-1991 leaching period

At site 3, a peak of nitrate concentration occurred in ceramic cup samples from 60cm depth, 10m into the field, during December and from then on the concentration fell steadily (Fig.3.4).

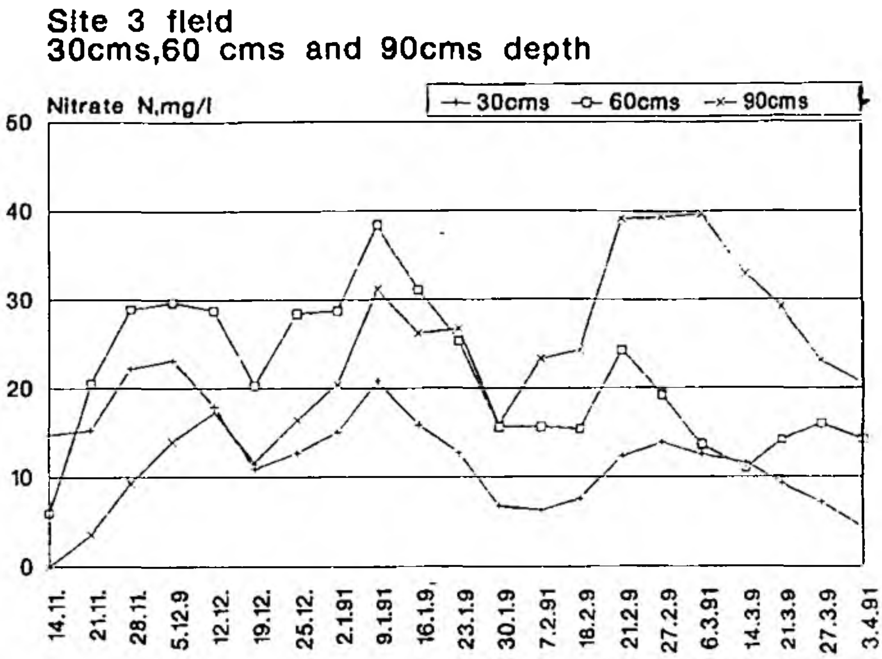


Fig.3.4

At 90 cm, however nitrate concentration gradually built up to a peak at the end of February and it fell sharply from this point. At the dyke edge, nitrate concentrations were always very low, at 30 cm they ranged from 0-2.5 mg/l while at 60 and 90 cm the concentrations were negligible. (Fig.3.5)

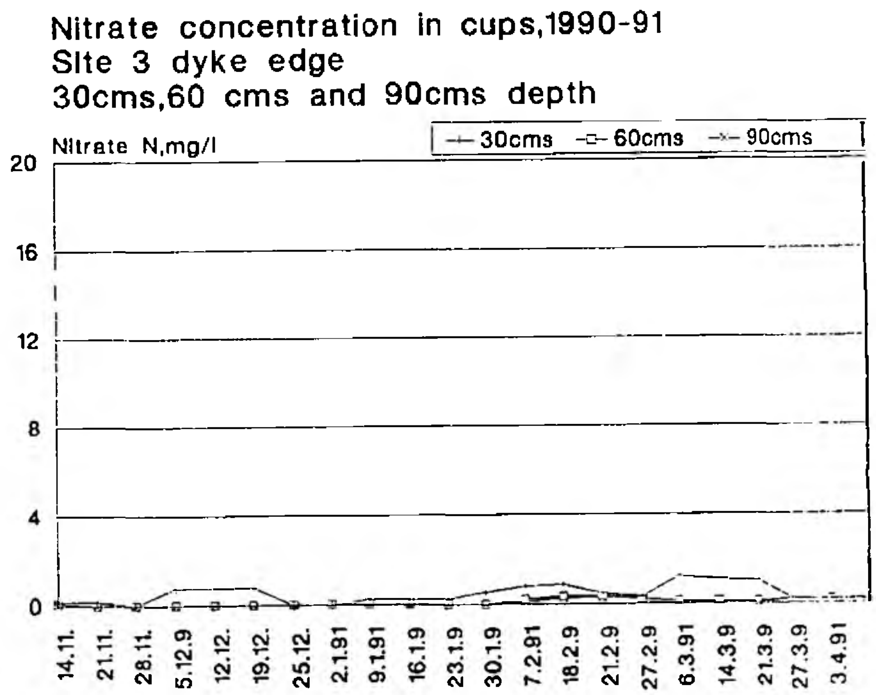


Fig.3.5

Dipwell samples showed that as the water moved towards the dyke from the field the nitrate concentration fell, until at the dyke edge, it was negligible (Fig.3.6)

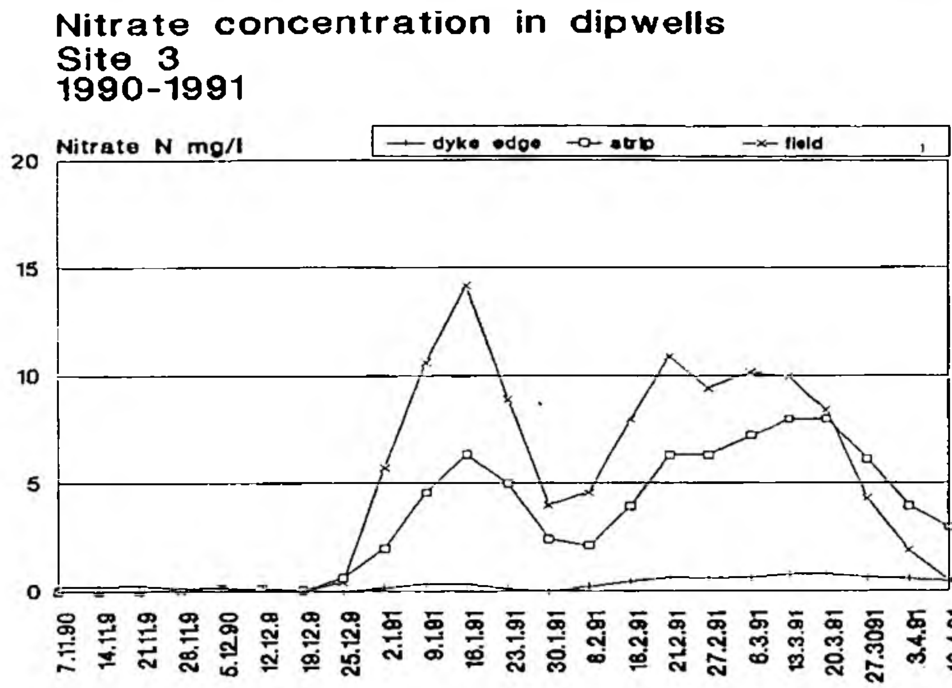


Fig.3.6

Concentration peaks indicate that on site 3 it took 3- 5 weeks for nitrate from the top of the soil profile to reach the saturated zone and concentrations in the dipwells were never as high as in the ceramic cups.

Site 4

1990-1991 leaching period

The rape crop on this site probably took up more of the available nitrate throughout the winter than the cereal crop in Site 3. A recent paper by Goss et al (1993), found that the root system of rape was able to intercept 31kgN/ha more than cereals supplied with the same amount of autumn fertilizer. There was a sharp rise in concentration in the dipwells in both the field and at the dyke edge in late February when nitrate was applied (Fig.3.7). The nitrate concentration remained high until April.

Fig.3.8 shows the nitrate N at depths 30,60 and 90 cms on site 4, at the dyke edge. There was considerable nitrate at 30 cm early in the leaching period, this contrasts with the situation on Site 3 at the dyke edge(Fig.3.5), where there was a fertiliser free strip. As the season progressed the nitrate concentrations fell at all depths and did not even show a rise when nitrate was applied to the crop in early February. The cups were situated very close to the dyke edge, it is possible that fertiliser was not applied to this area.

Nitrate concentration in dipwells
Site 4
1990-1991

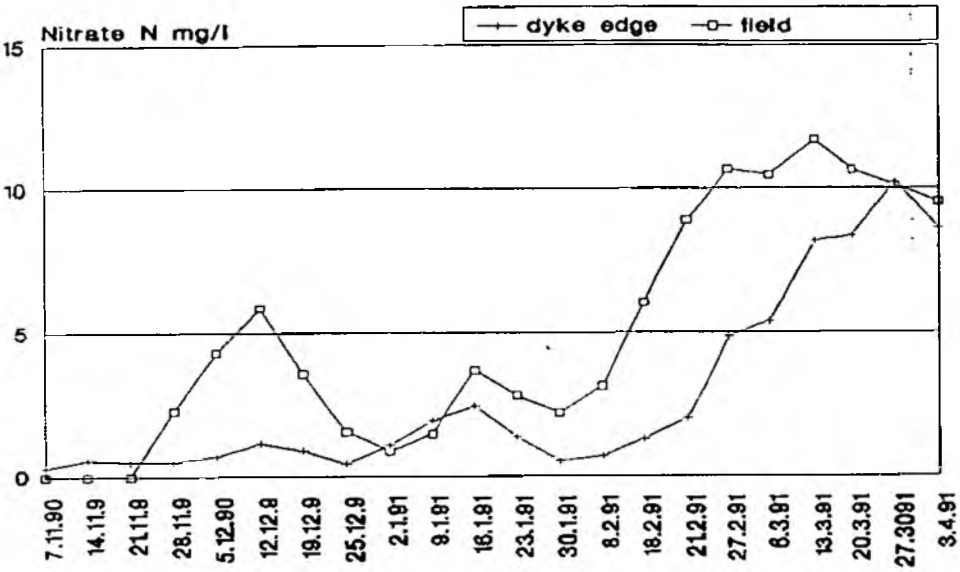


Fig.3.7

Nitrate concentration in cups,1990-91
Site 4,field

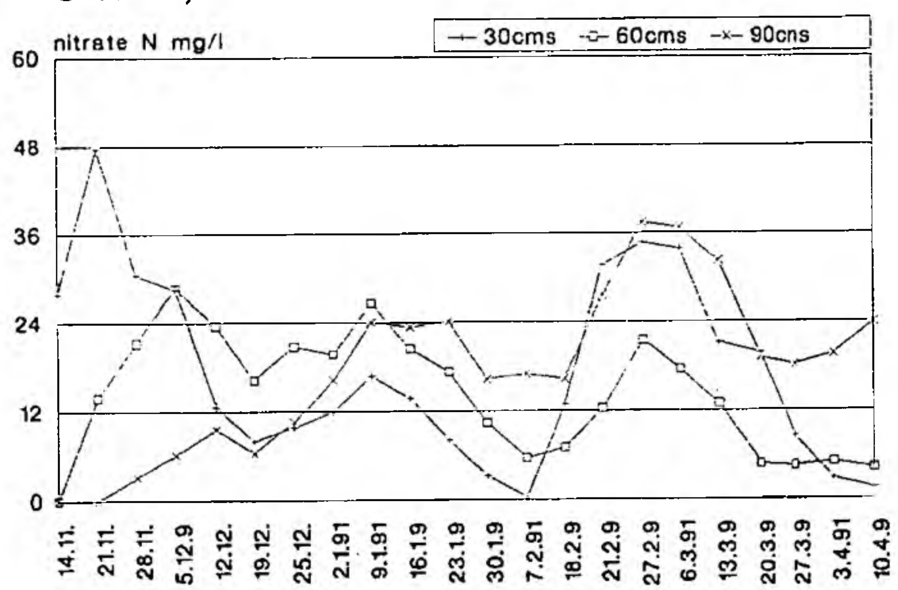


Fig.3.8

Comparing the 1990-91 data sets from sites 3 and 4 it can be seen that the concentration of nitrate in the unsaturated zone in the field, where nitrogen was applied, is similar on both sites. However, the pattern of nitrate concentration in the saturated zone is very different. On Site 4, where there is no fertiliser free strip, nitrate levels in the field and at the dyke edge are similar and high, particularly after nitrate has been applied in late February. On Site 3, where there is a fertiliser free grass strip, the levels of nitrate in the saturated zone in the field and at the dyke edge are very different, with virtually no nitrate at the dyke edge. The fertiliser free strip may prevent nitrate reaching the dyke water in two ways. Firstly because there is no input of nitrate as the water moves through the soil towards the dyke there is time for plant uptake and soil organisms to remove nitrate from the soil water as it travels towards the dyke. Secondly, any nitrate which might reach the dyke by run off can also be taken up by the grass before it enters the soil water.

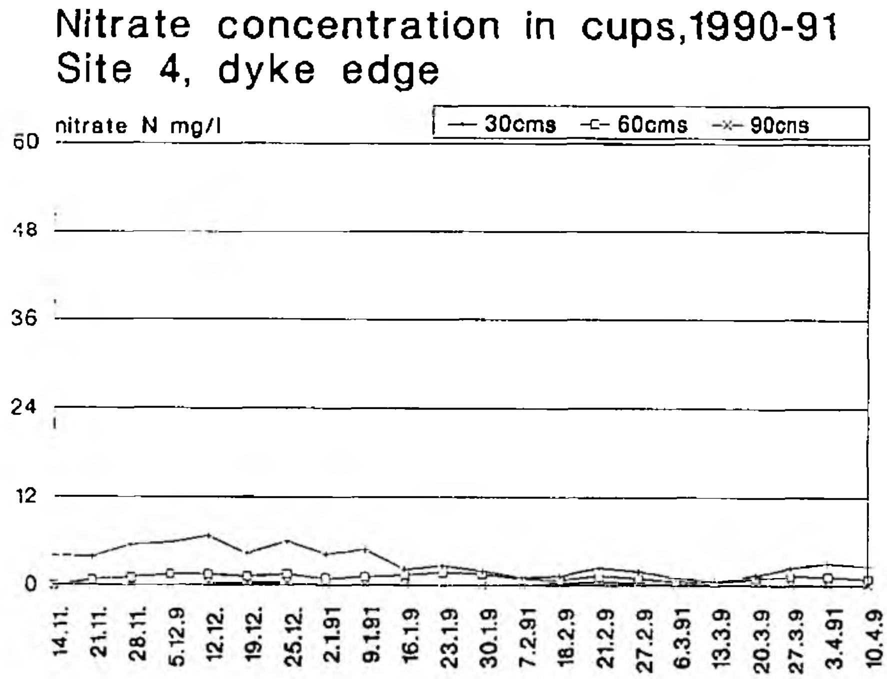


Fig.3.9

Nitrate in dyke 3/4,1990-91 and 1991-92

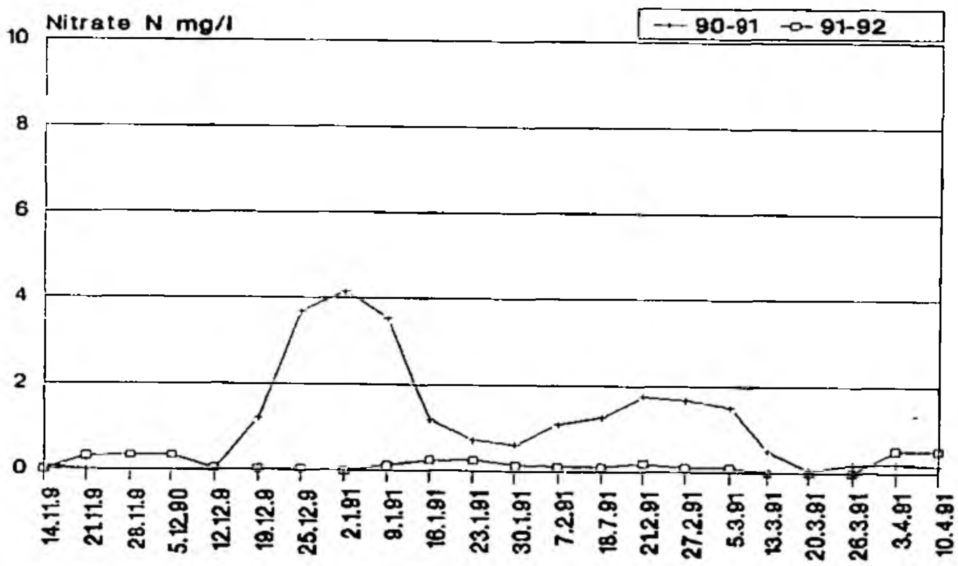


Fig.3.10

Figure 3.10 shows the nitrate concentrations in the dyke at sites 3/4 for the

Figure 3.10 shows the nitrate concentrations in the dyke at sites 3/4 for the 2 seasons. In 1990-91 there was a large increase in nitrate concentration in late December and early January with another in the week of the 6th March, the latter peak corresponds to similar peaks found in the dipwell data for site 4 (Fig.3.6) . These peaks all followed the application of nitrate to the rape crop in late February. Nitrate concentrations in dyke 3/4 were 2-3 times higher than those in dyke 1/2. Nitrate concentrations were consistently low throughout the 1991-92 season.

Total amounts of nitrate leached.

Calculation of quantities lost.

The amount of nitrate lost though leaching was calculated using the method given in Barraclough et al (1992), given in Chapter 3. The concentration of nitrate in the 90cm depth sampler was assumed to be that in the draining water. The flux of water was calculated from the following equation:

$$Loss= (R-Et-SMD).concentration/100$$

R = rainfall measured on site during the 7 days before the sample was taken
Et = evapotranspiration from data from Scots Float, only a quarter of a mile from the site, SMD calculated from neutron probe data collected on site on the same sampling date. Concentration = that in cups at 90cms depth.
If R,Et and SMD are in mm and concentration is in mg N per litre then loss is in kg N per hectare.

Table 3.1 shows the mean quantities of nitrate N leached from all sites in 1990-91 and 1991-2. In general much more nitrate was leached in 1990-91 than in 1991-92, this was a reflection of the rainfall, 1990-91 being a wet winter 1991-92 being a very dry winter.

Table 3.1 Mean quantities of nitrate-N leached, kg/ha

	Site 1		Site 2			Site 3			Site 4	
	dyke edge	field	dyke edge	strip	field	dyke edge	strip	field	dyke edge	field
1990-91	0.01	0.42	18.4	0.69	136.9	0.2	56.3	91	0.56	81.6
1991-92	0.15	0.73	0.23	0.18	0.05	0.3	2.63	31.5	0.1	3.3

Site 1 ,unfertilized pasture, lost very little nitrate in either year. Site 2, arable reverting to pasture, lost large quantities in 1990-91 both at the dyke edge and in the field. The field data in 1990-91 may have been due to a urine patch, sheep having grazed in the field for a short while. Ryden, Ball and Garwood(1984) showed that very large amounts of nitrate could be leached from urine patches. The nitrate could also have been residual nitrate left from fertilizer applied in earlier years when the site was arable, it was mainly found at 60 and 90cms depth (cf.fig 3.1). The very low quantities in 1991-92 reflect the fact that hay was taken from the field in the summer of 1991.
Sites 3 and 4, both arable, lost large quantities from the field in 1990-91, the amounts were considerably reduced in 1991-92, showing the effects of rainfall on nitrate leaching.

Phosphate

Dyke samples were also analyzed for phosphate. Phosphate concentration was always very low,< 0.01 mmol/l, in both dykes, this data is not given.

Conductivity

The conductivity in dyke 431 varied between 280 and 1000 umhos while that in dyke 409 varied between 2200 and 3500 umhos. These figures suggest that the water in dyke 409, the arable site, is slightly brackish.

Conclusions

The contrasting nitrate concentrations in the dipwells at the dyke edge on sites 3 and 4 in 1990-91 show the effect that a fertilizer free strip can have, on nitrate concentrations reaching the ground water and thus entering the dyke. The dry winter in 1991-92 prevented us from repeating this data.
The data from site 2, also in 1990-91, shows how much residual nitrate can be retained in the soil several years after an arable site has been returned to pasture.

CHAPTER 4

EXPERIMENT ON SITE 3 1992-1993

The 1992-3 experiment was located along the same dyke edge as Site 3 (arable with a 5m fertilizer free strip) in the preceding two years. The aim was to follow the movement of nitrate from the field to the dyke. Extra nitrate was applied in the form of potassium nitrate to 2m wide strips at right angles to the dyke, at various distances across the strip and into the field. The nitrate was applied at the rate of 200kg/ha, in one application on 17th November 1992.

Treatments

3 treatments were applied.

1) controls with no extra nitrate, replicates 1.1 and 2.1
2) nitrate, at concentration of 200kg/ha, from 10m into field to the edge of the 5m strip, replicates 1.2 and 2.2
3) nitrate, at concentration of 200kg/ha, from 10m into field to 2.5m of the dyke edge, replicates 1.3 and 2.3
4) nitrate, at concentration of 200kg/ha, from 10m into the field to 0.5m from dyke edge, replicates 1.4 and 2.4

Each 2m strip was separated by a 10m fertilizer free area and each treatment was replicated twice. The treatments were in two randomised blocks. as set out below. The blocks were separated by 20m.

Layout of experiment. The site of each treatment was separated by 10m.

	Block 1				Block 2			
Treatment	1.3	1.1	1.4	1.2	2.2	2.3	2.4	2.1
10m	\\\\		\\\\	\\\\	\\\\	\\\\	\\\\	
5m	\\\\		\\\\	\\\\	\\\\	\\\\	\\\\	
5m	\\\\		\\\\			\\\\	\\\\	
0.5m			\\\\				\\\\	
dyke								

\\\\ denotes nitrate applied.

Instrumentation

At each site a piezometer to 175cms depth was placed at the dyke edge, to measure nitrate in the deep saturated zone which might pass into the dyke. Further piezometers to 150cms depth were placed at 0.5m, 2.5m, 5m and 10m from the dyke edge. These piezometers were to measure nitrate in the upper saturated zone and allow sideways movement of nitrate to be measured. Alongside each 150cms piezometer were placed one ceramic cup at 60cms depth and one ceramic cup at 90cms depth. These cups measured the passage of nitrate through the unsaturated zone , where only downwards movement was considered likely. Neutron access probe tubes were put along side each set of piezometer and ceramic cups, these measured the quantity of water in the soil, which in turn was used to measure the quantity of nitrate leached from each site. Banks of tensiometers located in the strip and field (four banks in all at depths 0.3, 0.6. 0.9 and 1.2m) provided information on the vertical movement of soil-water. Dyke water samples were taken at each treatment site. All sites were sampled taken once a week throughout the leaching season (November to April).

Rainfall was measured on site and analyzed for nitrate. Evapotranspiration was obtained from MORECS data from Scots Float provided by the NRA Canterbury office.

Results.

Hydrological datasets collected were the same as for the field sites during the period October 1990 to September 1992; that is watertable depth below surface, heights of watertable in m OD, SWDs and total potential profiles.

Field capacity was reached by 28 October 1992 after which time the predominant movement of water was downward drainage to the watertable. Field capacity was reached again by around 7 April 1993, after which the predominant movement of soil-water was upward due to the transpiration stream. Lateral drainage, as shown by the relative heights of water in the dyke and dipwells at 10m into the field, was from the field to the dyke throughout the experimental period, 28 October 1992 to 7 April 1993..

Figure 4.1 shows the relative heights of the water table in the dyke, dyke edge and 10m into the field. This establishes that water moved towards the dyke from the field throughout the experiment. Also shown are the heights OD of the ceramic cups at 60 and 90 cms below ground. This data shows that both were in the water table in November and early December. However this time does not coincide with the time of highest nitrate concentration in mid December. By this date the water table had fallen well below 90cms and, except briefly in the field, remained there. The period of drought in February shows clearly on the graph as does the increased height of the water table in response to irrigation.

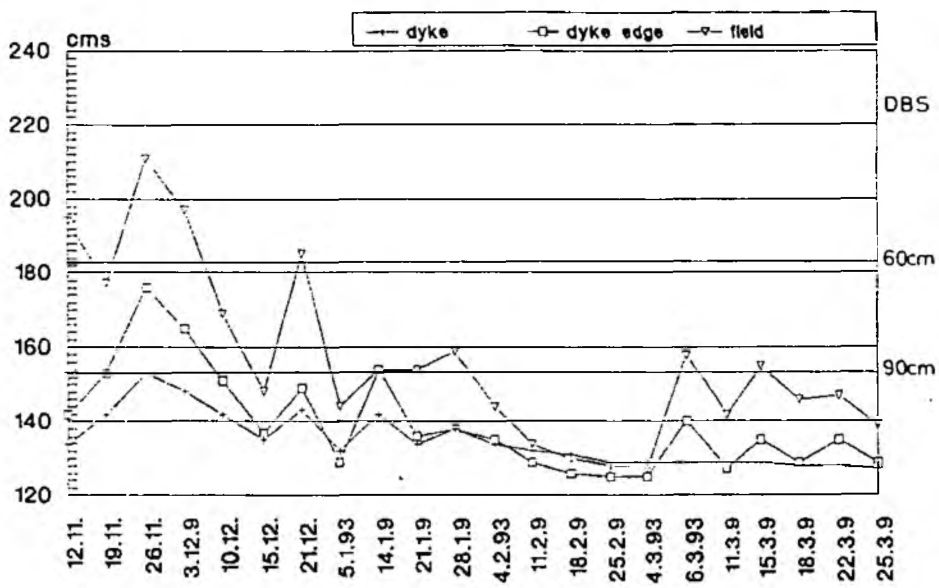


Fig.4.1 Height OD of water table on block 1 and depth below surface of 60 and 90cms depth ceramic cups.

Nitrate concentration in the dyke and saturated zone at 175cms depth.

Figure 4.2 shows the mean concentration of nitrate in the dyke for the 4 treatments. The rise in concentration from 12th November to the 26th November began before nitrate had been added to the treatment sites. The most probable source of this nitrate was from the arable field (which does not have 5m fertilizer free strips) on the opposite bank. This field was ploughed in mid October and nitrate would have been released by ploughing.

During the rest of the experiment nitrate concentration in the dyke was very low, no increase as a result of our experiment could be detected.

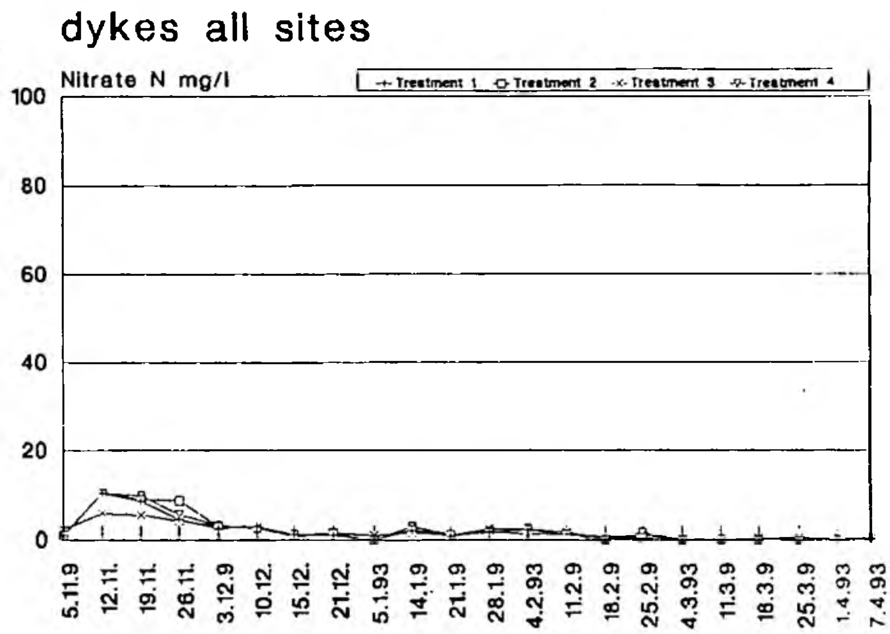


Fig.4.2 Nitrate concentration in the dyke.

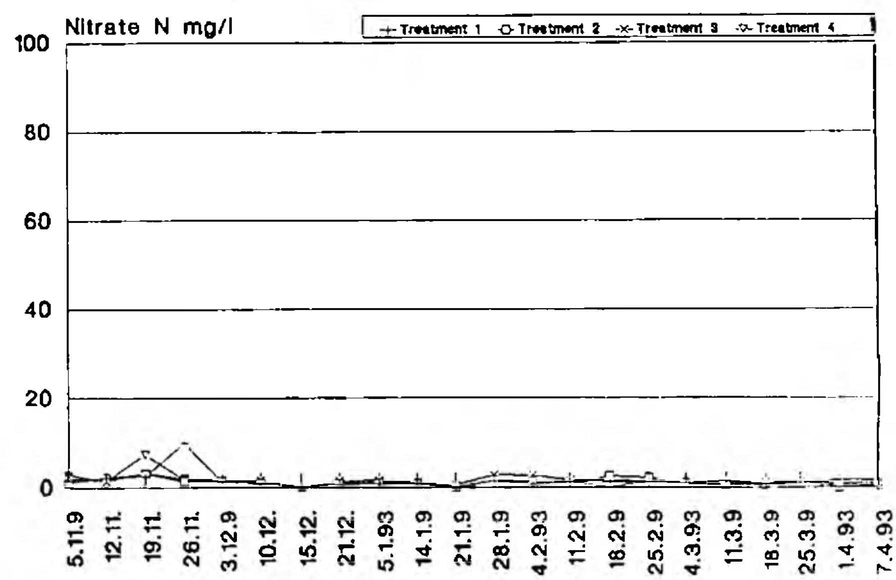


Fig.4.3 Nitrate concentration in piezometers at 175cms depth, 0.5m from the dyke edge. Mean for each treatment.

As in the dyke water, nitrate concentration in the deep saturated zone remained very low and no evidence could be found that nitrate from our experiment had entered this zone .

Nitrate concentration in the unsaturated zone.

Figs. 4.4–4.7 show the movement of nitrate down the soil profile in each of the treatments.

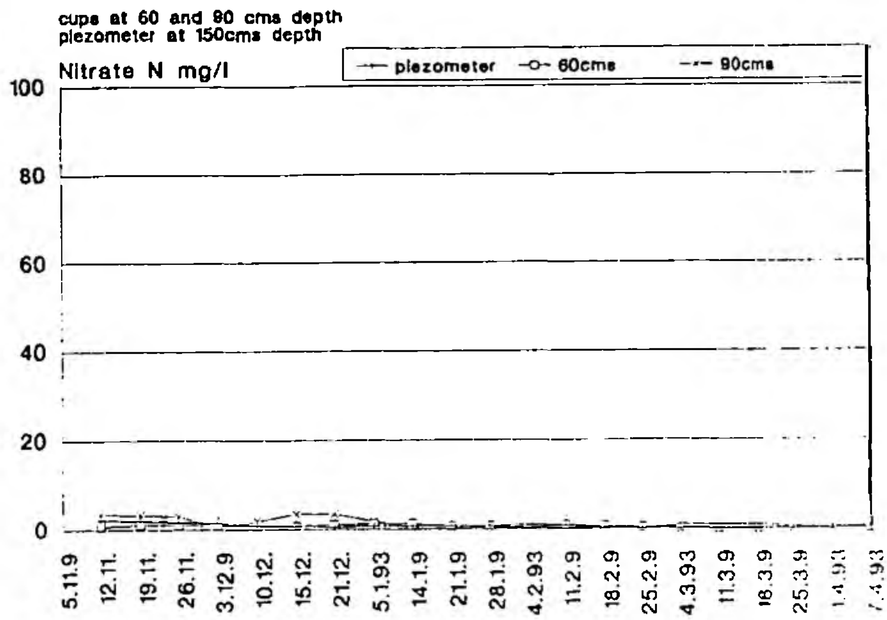


Fig.4.4a. 0.5m from dyke edge

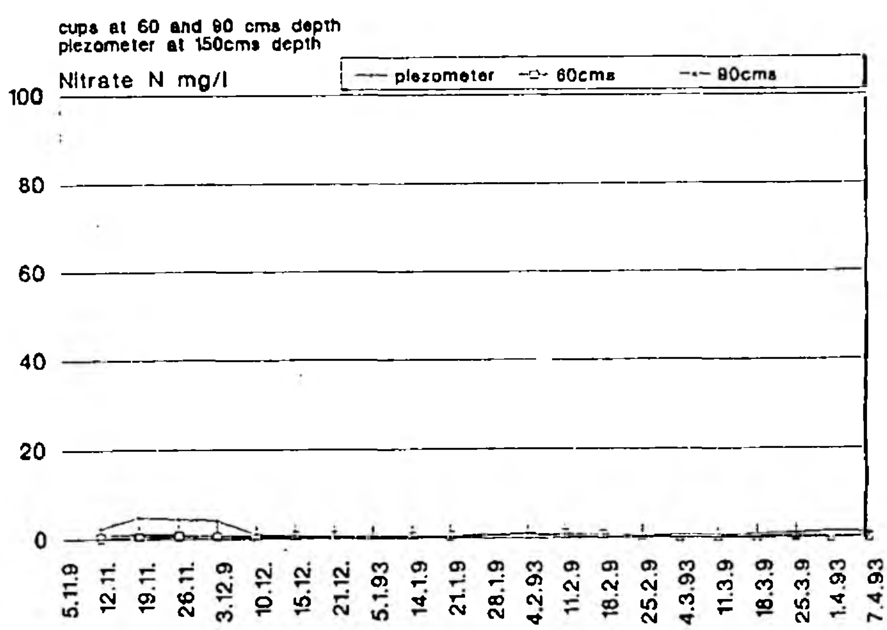


Fig.4.4b. 2.5m from dyke edge.

Figs 4.4. a-d.Nitrate concentrations on the control sites (1.1 and 2.1), no nitrate added.

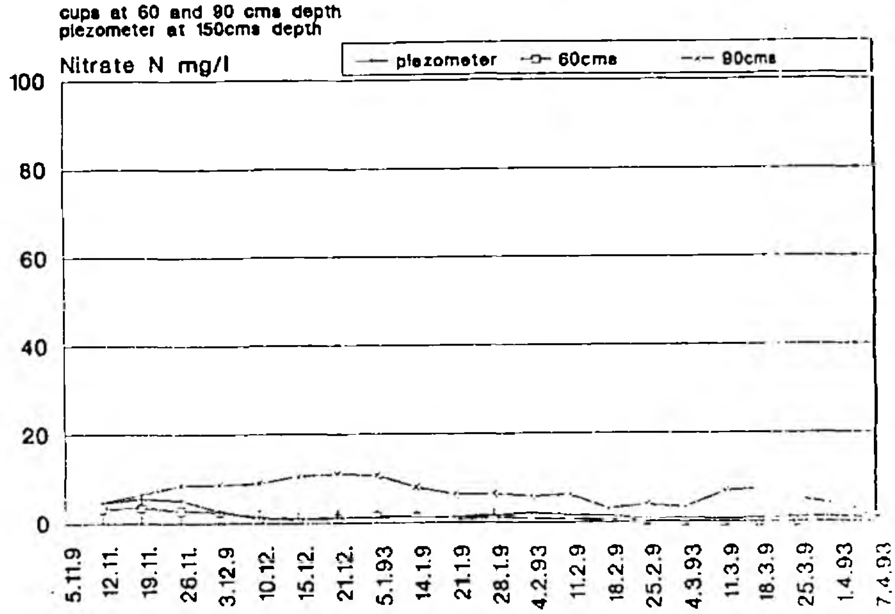


Fig.4.4 c. 5m from dyke edge.

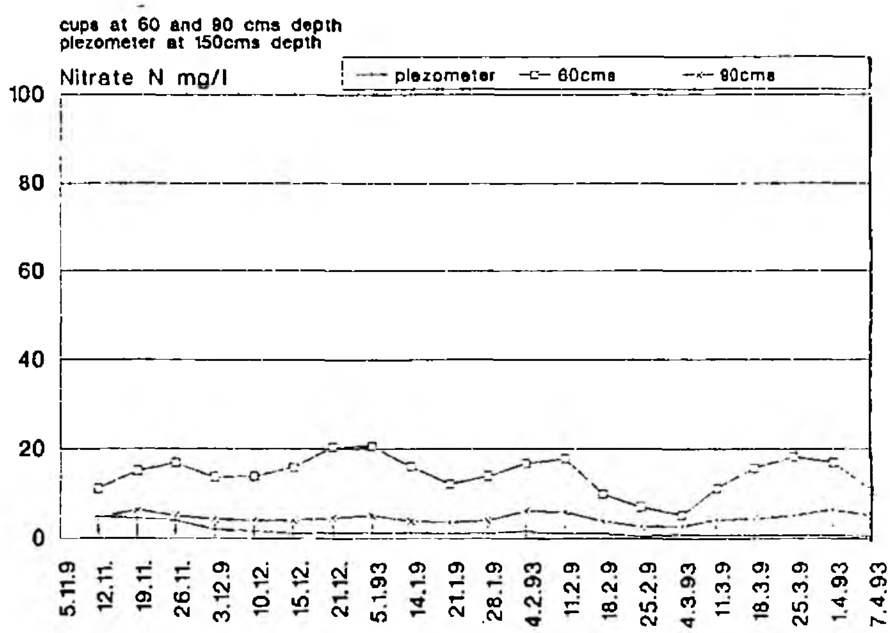


Fig.4.4d. 10m from dyke edge.

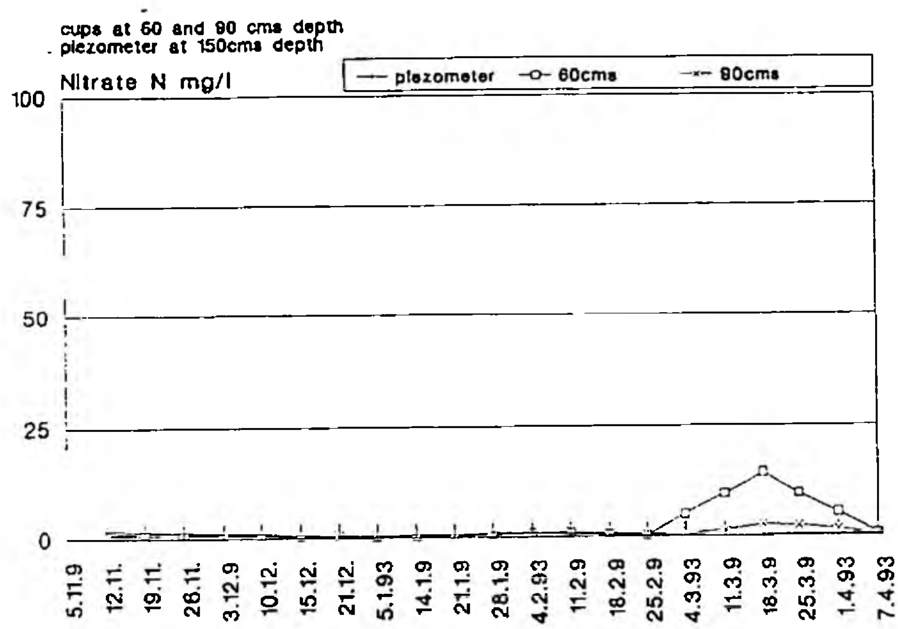


Fig.4.5a.0.5m from dyke edge

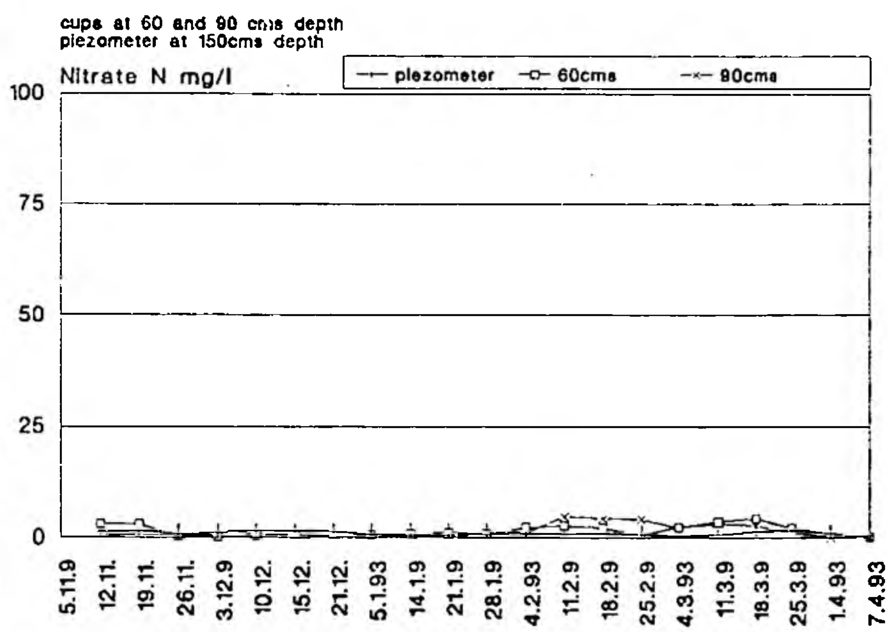


Fig.4.5b.2.5m from dyke edge.

Figs 4.5. a-d.Nitrate concentrations on sites 1.2 and 2.2, nitrate added on arable area 5 to 10m from the dyke.

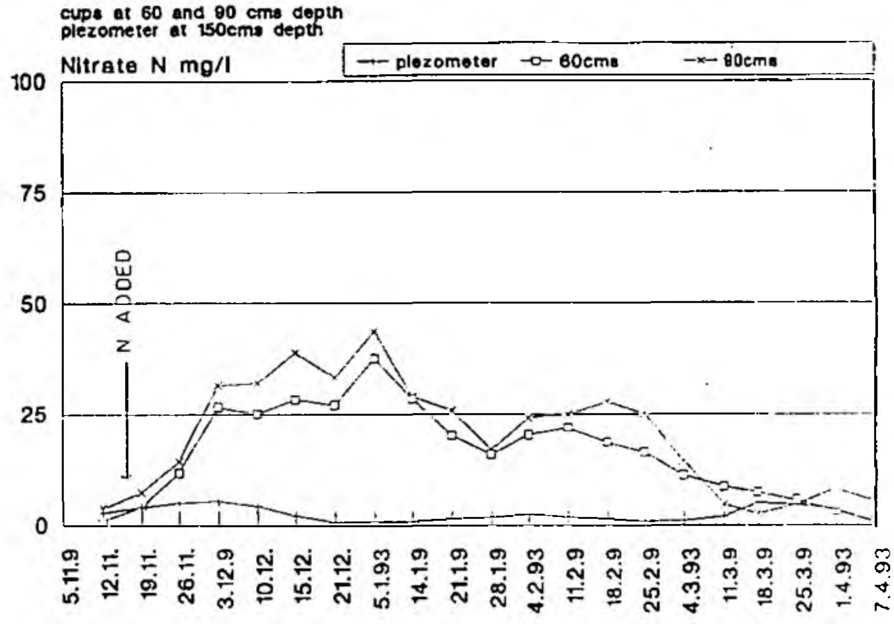


Fig.4.5c. 5m from dyke edge

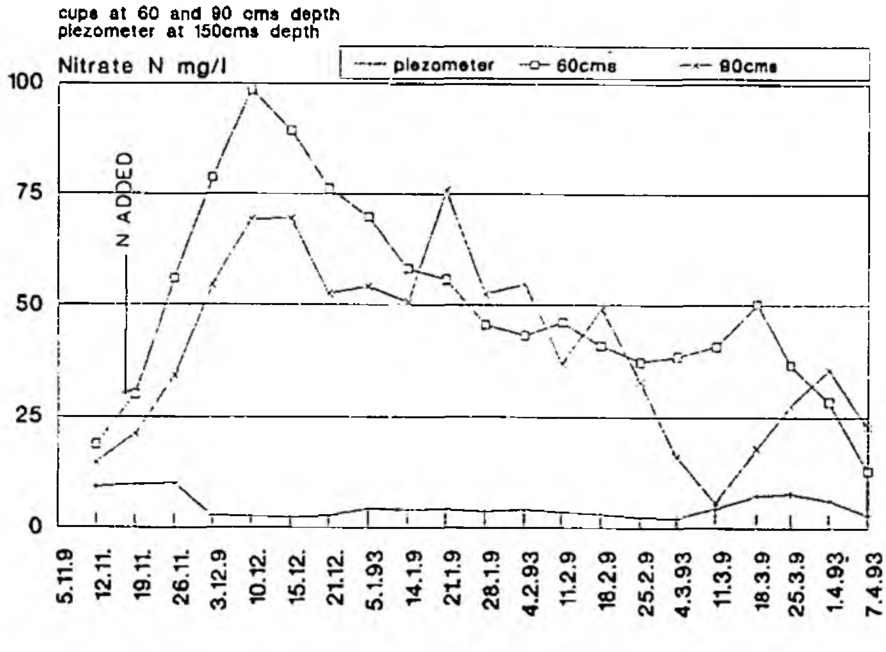


Fig.4.5d. 10m from dyke edge.

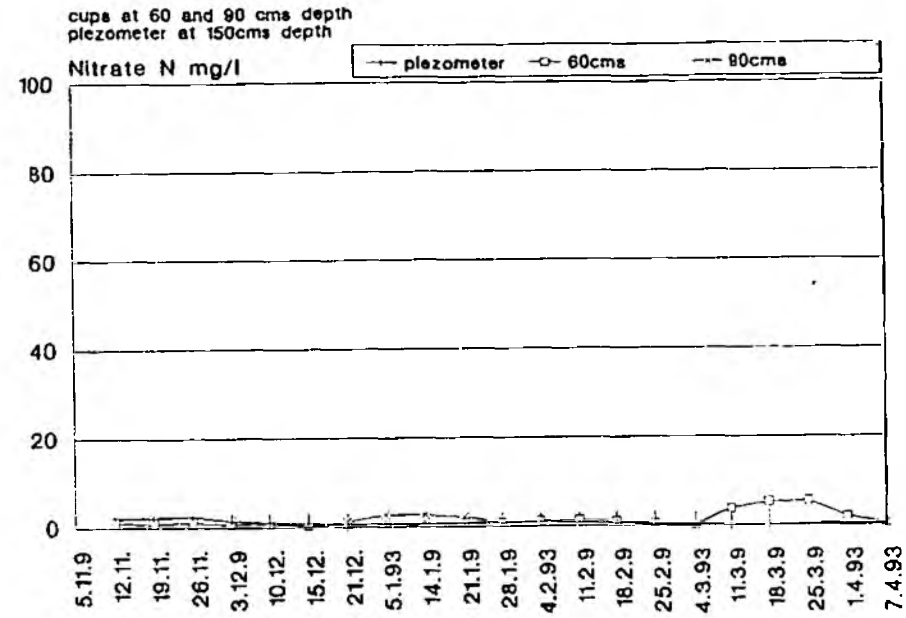


Fig.4.6a. 0.5m from dyke edge.

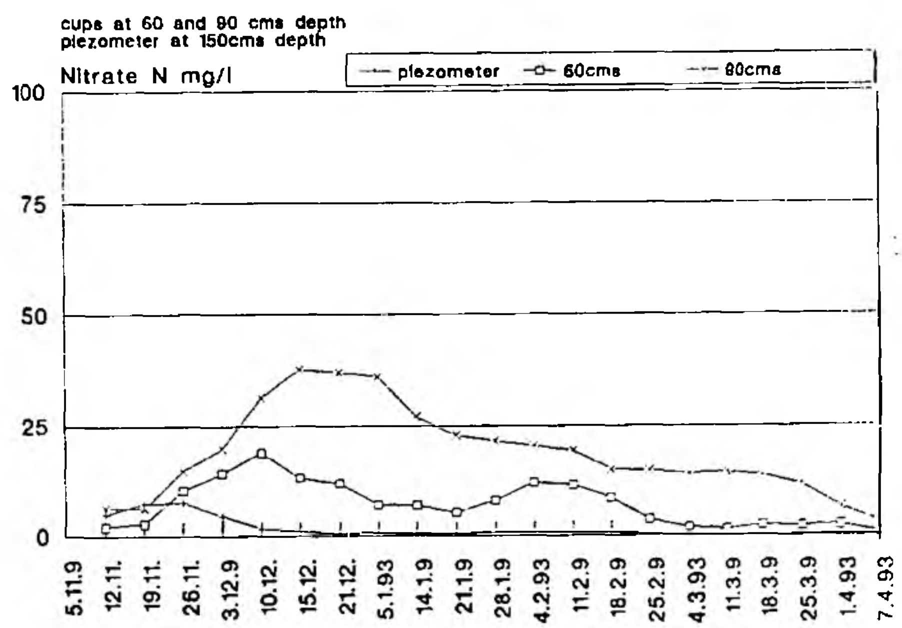


Fig.4.6b. 2.5m from dyke edge.

Figs 4.6. a-d.Nitrate concentrations on sites 1.3 and 2.3, nitrate added on arable area 5 to 10m from the dyke, and grass strip 2.5-5m from dyke.

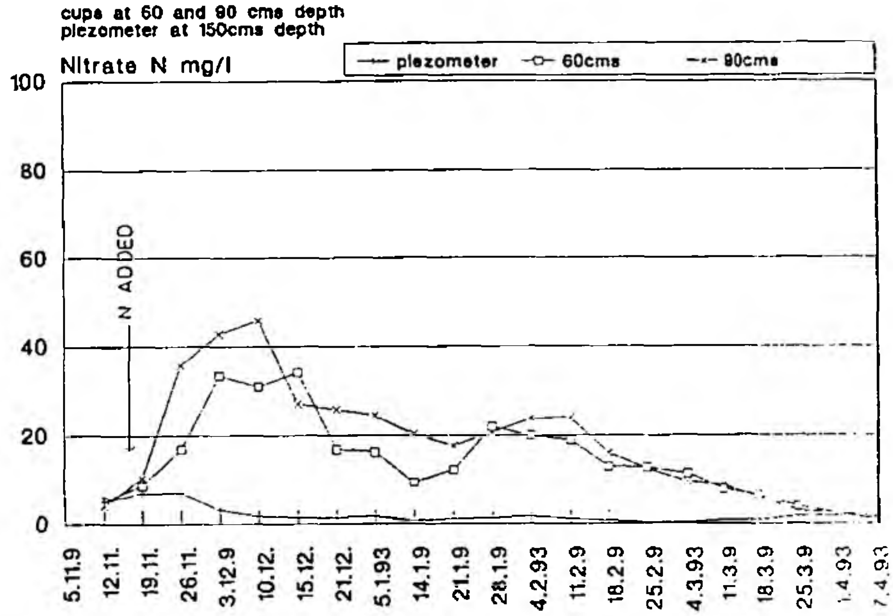


Fig.4.6c. 5m from dyke edge.

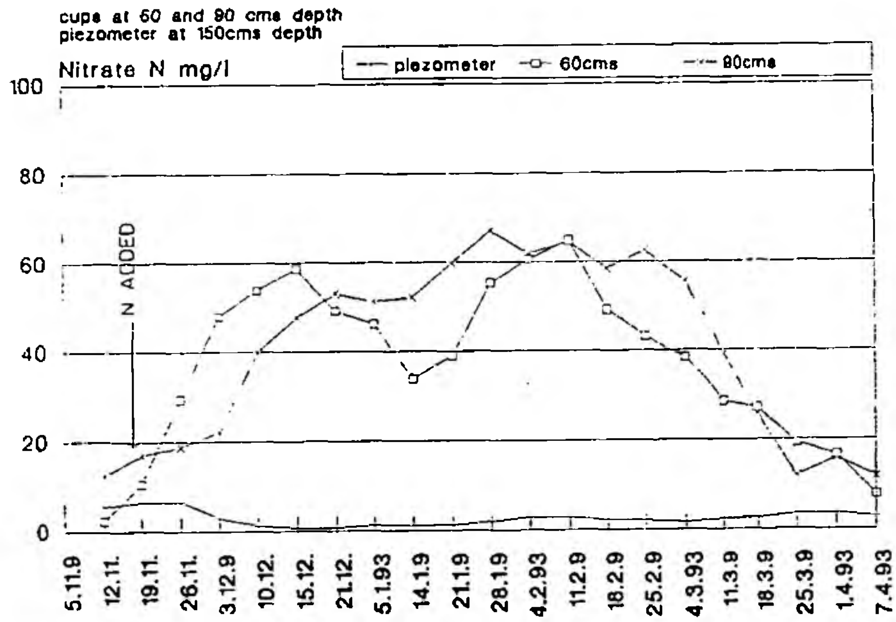


Fig.4.6d. 10m from dyke edge.

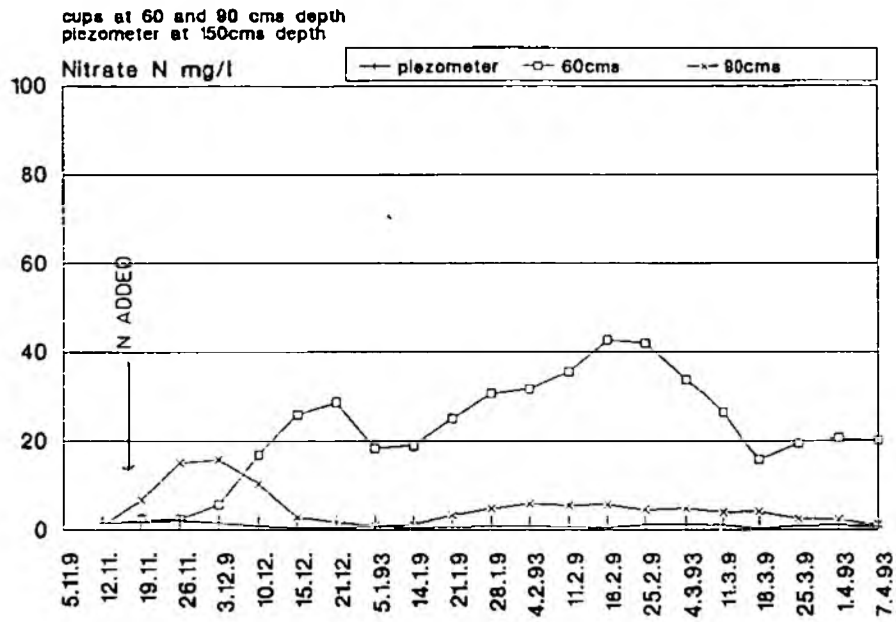


Fig.4.7a. 0.5m from dyke edge.

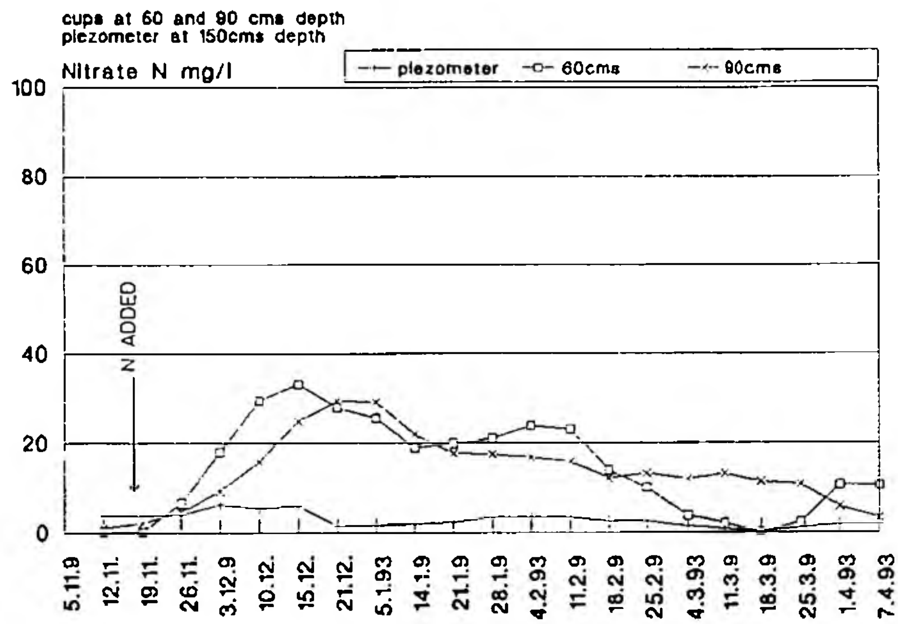


Fig.4.7b. 2.5m from dyke edge.

Figs 4.7. a-d.Nitrate concentrations on sites 1.4 and 2.4, nitrate added on arable area 5 to 10m from the dyke, and grass strip 0.5-5m from dyke.

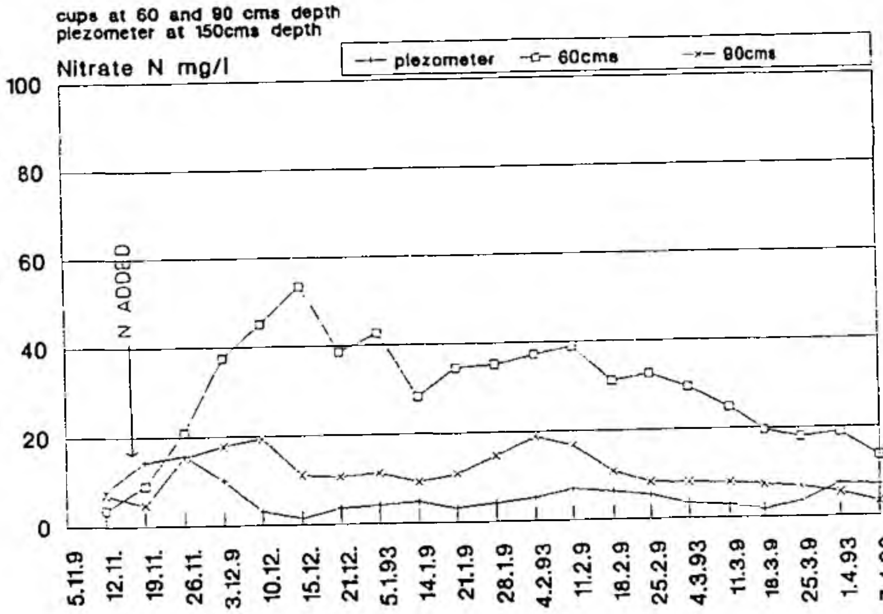


Fig.4.7c. 5m from dyke edge.

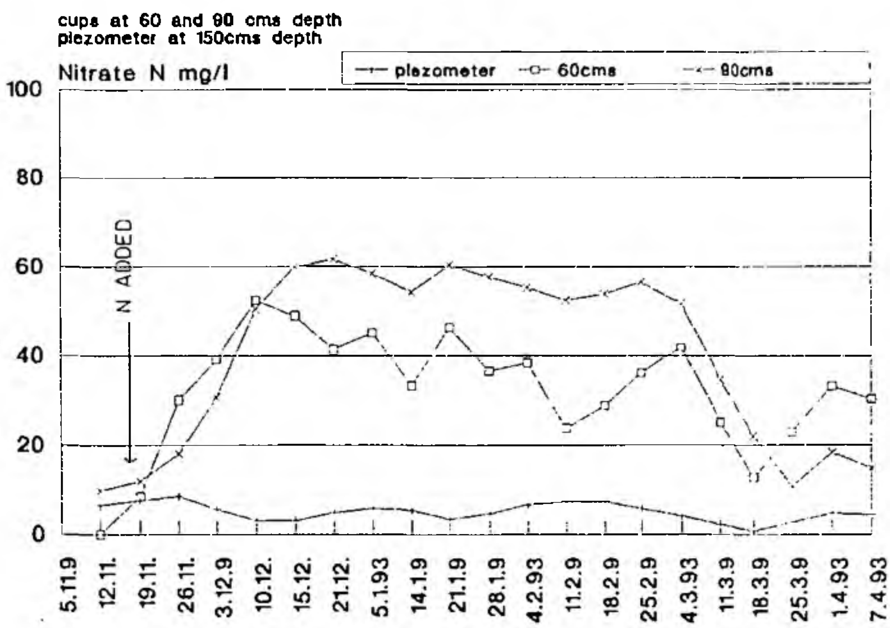


Fig.4.7d. 10m from dyke edge.

These figures show that on the control sites (1.1,2.1) very little nitrate was found except at 60cms depth 5m and 10m into the field. This was expected because residual nitrate from previous fertiliser applications and nitrate released from the crop roots when ploughed in, would be available. However little reached 90cms depth and virtually none the saturated zone at 150cms depth. Nitrate was applied to the experimental plots on 17th November 1992. In every case there was a rapid transference of nitrate down the profile to 60cms and in some cases to 90cms. This transfer had started by the 26th November, 9 days after nitrate was applied. Concentrations reached a peak during December and then at 60cms began to decline. Values continued to rise for a while at 90cms but ,with the exception of sites 1.4 and 2.4 at 5m and 10m into the field, no nitrate continued down the profile to the saturated zone at 150cms depth. there was no evidence of sideways movement of nitrate higher up the profile. Areas which did not receive nitrate, (sites 1.2 and 2.2, 0.5m and 2.5m, sites 1.3 and 2.3, 0.5m,) showed no increase in nitrate at any depth. Further evidence that sideways movement did not occur came from the grass in the strips. The grass showed considerable increase in growth and was a deeper green colour where the nitrate was applied, but no increase in growth or colour was seen even a foot away from the areas where nitrate was applied. The early downward movement of the nitrate occurred during a period of high rainfall.(see Chap.1) However during February no rain fell, and downward movement of the nitrate stopped. No nitrate reached 150cms depth. Although the sites were irrigated during March no further movement of nitrate down the profile could be detected. By March soil temperature had risen and both the wheat crop and the grass began to grow and take up the nitrate, the leaching season had finished.

Amounts of nitrate leached.

Calculation of losses.

The amount of nitrate lost though leaching was calculated using the method given in Barraclough et al (1992)(see Chap.3). The concentration of nitrate in the 90cm depth sampler was assumed to be that in the draining water.

Results

Table 4.1 summarizes the total amounts leached from each experimental site during the leaching season, November 1992 - April 1993

Table 4.1 Nitrate leached,kg/ha, November 19th 1992-April 1st 1993

Site	0.5m	2.5m	5m	10m
1.1	4.3	1.6	8.6	15.0
2.1	1.9	1.5	4.1	42.8
1.2	3.9	3.9	104.4	169.2
2.2	2.5	1.8	43.56	101.46
1.3	3.67	65.1	43.65	131.72
2.3	11.5	23.67	111.1	92.5
1.4	13.73	10.1	32.0	143.45
2.4	24.4	14.3	33.1	86.3

These results show that where nitrate has been applied to the soil extra nitrate has leached down to 90cms but when it is considered that nitrate was added at 200kg/ha very little has been recovered at this depth. The data from 10m from the dyke for treatments 2, 3 and 4 can be considered as replicates, as can the figures for 5m from the dyke for the same treatments. When the control quantities have been subtracted from the figures for 10m from the dyke an average of 97.2kg/ha were recovered. This is nearly 50% recovery. These cups were in the arable area where a winter wheat crop was sown, the plants were still small and would not be capable of take up much nitrate. The cups at 5m from the dyke however, were just in the grass strip, at these sites an average of 55.6kg/ha were recovered, 27.8% of the total. This suggests that the grass was able to absorb nitrate more effectively than the crop. At 2.5m into the strip, treatments 3 and 4 were replicates, here an average of 28.7kg/ha were recovered, only 14% of the total. At the dyke edge in treatment 4, 15.3kg/ha were recovered 7.5% of the total. While there is wide variation between samples there does seem that permanent grass is more efficient in capturing nitrate than a young crop. Grass at the field edge of the strip would always have had access to nitrate applied to the crop and would therefore not be deficient. Grass in the strip had been deprived of nitrate since the strip was set up 8 years ago, and would by this time be nitrate deficient and consequently take up large amounts of nitrate.

Due to complete lack of rainfall leaching did not occur during February. This suggests that nitrate losses would have been much higher if normal amounts of rain had fallen, but it is likely that the trend would have been the same.

Data from the earlier in the season (November 12th -26th) suggests also that nitrate would have reached the saturated zone at 150cms depth if sufficient rain had fallen. Data from 1990-91 on this site,(Chap.3 Fig.3.6) suggests that it would not have reached the dyke where a buffer strip was in operation.

CHAPTER 5

FLORAL SURVEY

The flora of the dykes was surveyed on a monthly basis in 1991 starting in April and finishing in August. This work was the basis of a 1st degree thesis entitled "The effect of land management and aspect on dyke flora on Wallend Marsh" by Mlle E Morin from the Ecole Nationale Superieure Agromique De Toulouse, Mlle Morin was an ERASMUS student at Wye College for 6 months. A copy of her thesis was sent to the NRA. Surveys were also done in June and September 1992 by Dr Moorby.

Survey methods

The dykes and banks were surveyed using the methods adopted by English Nature so that our results would be comparable with theirs. For each site a length of dyke 20m long was measured and pegged. Repeat surveys were done on the same stretch of dyke. The floating, emergent and bank species were recorded according to their abundance in the length of dyke.
The standard DAFOR notation was used i.e. D = dominant, A = abundant, F= frequent, O = occasional, R = rare.
Table 5.1 shows the total number of species found in the two sites on the bank and both floating and emergent species in the dyke.

Table 5.1

	1991 aquatic & emergent	1991 bank side	1992 aquatic & emergant	1992 bank side
Dyke, site 1/2	37	21	34	16
Dyke, site 3/4	23	24	17	20

Table 5.1 shows that the pasture site had more floating and emergent species than the arable. The situation is reversed where the bank species are concerned, the absence of grazing on the arable site allowed a greater number of species to flourish.

Tables 5.2 and 5.3 give the names of the species found and their relative abundance.

Table 5.2
Aquatic and emergent species

	Pasture		Arable	
name	1991	1992	1991	1992
Agrostis stolonifera	F	F	A	A
Alisma plantago-aquatica	O	O	O	O
Apium nodiflorum	O*	O		
Azolla filiculoides	R*	R		
Callitriche obtusangula	O*	O	F	F
Carex distans	R	R	O	O
Carex otrubae	O*	O	O*	O
Ceratophyllum submersum	F	F		A
Chara vulgaris	A	A	A	
Eleocharis palustris	F	F	F	F
Enteromorpha sps	R	R	F	D
Galium palustre	O	O	O*	O
Glyceria fluitans	O	O	O	O
Hydocharis morsus-ranae	A	D		
Juncus acutifloris	O	O		
Juncus gerardii	O*	O	O*	O
J.inflexus	O	O	R	R
Lemna minor	F	F		
L.trisulca	A*	A	O	O
Myosotis caespitosa	R*	R	R*	
Myriophyllum spicatum	F*	F	F*	
Oenanthe fistulosa	F	F	F	F
Potomageton crispus		R		
P.natans	R*	R	R*	
P.pectinatus			F*	F
P.pusillus	F	F		
Ranunculus baudotii	A*	D	O*	O
R.peltatus	F	F	O	
R.trichophyllus	F	F	F	F
Rorippa nasturtium-aquaticum	A	A	F	F
Samolus valerandi	R			
Scirpus lacustris tabernaemontani	R*	R	F*	F
S.maritimus	F*	F	A	A
Sparganium emersum	R			
S. erectum	F	F		
Typha angustifolium	A	A		
Urticularia vulgaris	R*	R		
Vaucheria	F	F		
Veronica catenata	R*	R	R*	
Total	37	34	25	18

Table 5.3 BANK SPECIES

Name	Pasture 1991	Pasture 1992	Arable 1991	Arable 1992
Agropyron repens	F	F	F	F
Agrostis Stonifera	O	O	O	O
Alth.officinalis			R	O
Arrhenatherum elatius	R			
Bellis perennis	O	O	O	O
Bromus mollis	A	A	F	F
Cirsuim arvense	O	R	R	R
Cirsium vulgare			R	
Cynosurus cristatus	F	F	R	R
Dactylis glomerata	F	F	O	O
Eplilobium hirsutum	R			
Festuca arundinacea	O	O	F	F
Festuca rubra	A	A	F	F
Galuim aparine	O			
Geranuim columbinum			O*	O
Holcus lanatus	O	O	O	O
Hordium secalinum	F	F	A	A
Leontodon taraxacoides	R*			
Lolium perenne	F	F	R	R
Lotus corniculatus			R*	R
Phleum bertolonii	R*	R	O*	O
Picris echioides			F*	F
Poa trivialis	A	A	F	F
Pulicaria dysenterica			O*	O
Ranunculus acris			R	R
R.repens	O	O	O	O
Senecio jacobea			R	
Sonchus asper	O	O	R	
Trisetum flavescens	A	A	F	F
Total	21	16	25	22

An extensive survey of the dyke flora was done in 1980 by William Latimer. Species marked with an asterisk on the above lists were not noted as being in these dykes at that time. There appears therefore to have been an increase of 16 species at the pasture site and an increase at the arable site of 14 species. This increase may be real but it could also be due to the increased number of surveys which we did. The 1980 study was of the entire Romney and Walland Marsh area and invitebly less time was spent on each site. Nevertheless, it confirms that the flora in the area we studied is stable and not declining, exactly how much is due to the new managment regimes cannot be said with certainty. It can be said however, that the regime is not harming the dyke flora and most probably is enhancing it.

Pasture site

From our monthly surveys in 1991 it became evident that differant species dominated the floating population at different seasons. For example, Water Crowfoot was dominant in the spring in the pasture dyke, while Frogbit was dominant in the late summer and early autumn. The increase in amount of Frogbit from "frequent" to "Dominant" is very satisfactory because this species is decreasing in many areas. In addition this species is very sensitive to small increases in nutrient concentrations, its presence in such high numbers in this dyke indicates that the water is pollution free. Frogbit is the first species to disappear when pasture is converted to arable and it is a useful indicator species of the occurance of pollution. Ceratophyllum submersum was also much more abundant in the late summer/early Autumn. It was not found until May in the pasture site in either year and did not become abundant until July/August. It was not detected at all in the arable site in 1991 but by September 1992 it had become the dominant floating species at that site.

Arable site

The arable dyke dried out completely in the summer of 1990 and was grazed by sheep. However from the number of species found in the dyke the following summer little harm seems to have arisen from this treatment. During the late winter and until late summer of 1991-92 the surface of the dyke was completely covered by Enteromorpha. This had a dramatic effect on the floating plants . They were completely shaded out and in August when the Enteromorpha died back none of the floating plants present the previous year, could be seen. The removal of competition allowed Ceratophyllum submersum to flourish and it became the dominant floating species.

PLANT COMPOSITION

A single plant digest and analysis for total nitrogen and phosphate content was done on plant samples collected on the 10th July 1991, Table 5.2 shows these results.

Table 5.4

Site	Name	%N d.wt	%Pi d.wt
1,strip	Grass	2	0.48
2,strip	Grass	2.6	0.47
1/2 dyke	Lemma sp.	1.9	0.53
1/2 dyke	Hydrocharis	1.7	0.76
1, dyke edge	Sparganium	2.4	0.54
3, dyke edge	Oenanthe	1.7	0.65
3, dyke edge	Fleabane	1.2	0.43
3, dyke edge	Eleocharis	1.3	0.28

The total nitrogen concentrations in all the plants regardless of site are low while the phosphate concentrations are relatively high. Crop plants usually contain 4-5% total nitrogen.

CHAPTER 6

SOIL POROSITY AND AGGREGATE STABILITY

The soils of the instrumented sites belong to the Newchurch-Walland Complex of Green (1968), being texturally silty clay, clay loam, silty clay loam, or silt loam. Topsoils were found to be silty clays or silty clays loams. Such soils are representative of reclaimed alluvial marshlands in eastern England (Cook and Moorby, 1983).

That the soil physical condition is affected *inter alia* by land use; specifically by whether management has been long-term grass or arable, has long been understood (Low, 1972). Old pasture soils would be expected to possess higher porosity (and consequently a higher available water holding capacity) and display higher aggregate stability. These have important implications for such properties as water retention, drainage and physical strength of the soils.

Table 1 shows a summary of porosity data for topsoils (depth 0-0.1m) at four sites. Site 1 was ancient sheep pasture, site 2 which was reverted from arable to grass in autumn 1988 following some five years of arable cropping, a sample from the strip around the edge of that field (established in 1987), and Sites 3 and 4, which were permanent arable fields. Site 3 had been ploughed in 1980 with the strip established in 1984. Matric potentials were set in the laboratory on cores of volume 425cm^3 to determine water contents between 0 and -100kPa, and on small samples in pressure plate apparatus set at -1500kPa. Sampling was taken on 15 November 1990; data presented being the means of three samples, except for Site 2 (field) where six were taken.

TABLE 1: WATER RETENTION OF FIVE NEWCHURCH-WALLAND COMPLEX TOPSOILS, VOLUME PERCENTAGE:

site	A.W.C.	AIR CAP.	SATURATION	CHANGE 10-50kPa
1 field	26.3	7.9	61.7	8.0
2 strip	16.3	7.5	53.4	3.8
2 field	17.6	9.1	55.5	2.8
3 field	15.6	15.1	57.2	4.0
4 field	17.4	14.6	59.7	3.6

Available Water Capacity (AWC) is defined as volume percentage water retained between -5 and -1500 kPa; typically 26 to 30 percentage retained at -1500 kPa reflecting the heavier texture of these soils. Table 1 shows comparable AWCs for all Soils, excepting the permanent pasture at Site 1. The analysis showed this sample to possess between two and three times the porosity for water retained in the range -10 to -50 kPa ('change 10-50 kPa', the larger end of the 'mesopore' range); water thus retained is easily available for plants. The Site 1 soil also displays the highest water content at saturation, although it is the arable topsoils which show the highest air capacities (water emptied from pores between 0 and -5kPa). These pores are important in the free drainage of soil water. Their presence in large percentage volume probably reflects regular tillage of arable soils; whereas their lower AWC contrasts with the high mesopore space of the old pasture. Site 2 soils reverted to pasture in the preceding two or three years display lower AWCs and low mesopore space.

The reversion of arable soils to pasture should, given time, lead to the recovery of a pore size distribution typical of an ancient pasture. The water retention as measured using pressure apparatus in the laboratory of soils at Site 2 was monitored between November 1990 and October 1992.
Data are shown in Table 2, being the means of six samples.

TABLE 2: WATER RETENTION, PERCENTAGE VOLUME, OF SOILS AT SITE 2, FOLLOWING THE ESTABLISHMENT OF PASTURE

sample date:	water retained at matric potentials of:						
	0	1	5	20	50	100	-kPa:
	%	%	%	%	%	%	
15 Nov 1990	55.5	51.9	46.5	43.6	42.2	41.1	
28 Mar 1991	56.3	51.1	48.5	46.1	44.7	42.6	
2 Nov 1991	56.2	51.6	48.0	45.9	44.1	42.4	
13 Mar 1992	54.8	51.0	47.7	44.9	43.7	42.3	
28 Oct 1992	55.4	51.4	46.6	43.7	41.8	39.5	

Analysis of variance showed that water retained at the matric potentials -20 and -50 kPa were significantly different between sampling times ($P < 0.05$). At other matric potentials, and at saturation, the differences were not significant. However, because no trends over time are evident from these data so no inferences can realistically be drawn from the results.

Aggregate stability was undertaken using a wet sieving technique (MAFF, 1982) on three replicates with the average displayed. The data shown in Table 3a and 3b shows differences between sites, and at Site 2:

TABLE 3: TOPSOIL AGGREGATE STABILITY DATA:

3a) Aggregate stability at four sites sampled 15.11.1990:

site:	1	2	3	4
index:	246.3	208.1	133.1	178.3

3b) Aggregate stability at site 2 over time:

date:	15.11.90	28.3.90	2.11.91	13.3.92	28.10.92
index:	208.1	157.6	243.6	191.2	216.7

The highest aggregate stability is displayed by topsoils at Site 1, followed overall at Site 2. This may display a return in aggregate stability upon reversion to grass which was not echoed in the porosity data (Table 2). Table 3b shows no clear trend in aggregate stability data, although samples taken in March 1990 and 1991 display lower aggregate stability than those collected in the autumn.

It is concluded from these data that, whereas soil management has affected soil physical properties, there is no substantive sign of recovery of the physical properties of old pasture soils in topsoils up to four years after the establishment of grass. Clearly the desirable features of old pasture topsoils - stability of peds and higher AWC values - take a longer time to establish.

RECOMMENDATIONS FOR THE PROTECTION OF RECLAIMED ALLUVIAL GRAZING MARSHES AND DYKE FLORA.

1) The results of our experiments indicate that fertiliser-free nitrate protection strips as narrow as 2.5 metres may be effective in reducing nitrate in groundwater feeding dykes during the autumn, winter and spring months.

2) The protection strips must be in the form of vegetation strips, usually grass, bare earth or winter sown crop would not function satisfactorily.

3) Grass strips have a further purpose in that they encourage insect and other animal life. They also allow the establishment of a more diverse bankside flora

4) Where tile drains pass under the strip to outfall into the dyke, the strip is rendered ineffectual.

5) Where the hydrogeological gradients are predominantly from the dykes to the fields, perhaps due to different levels of outfall ditches on either side of a field, strips are unnecessary. However for administrative convenience and because of the work necessary to determine the direction of water flow in a field it is probably wise to continue the practice of setting up strips wherever arable abuts a dyke.

6) On this site, four years after the reversion of arable to grass, under a zero fertilizer regime and regular hay cropping, leaching of nitrates became negligible and close to that from the adjacent ancient unfertilized pasture.

7) In drier years or where the distribution of rainfall is uneven throughout the period November to March, thereby leaving drought periods, nitrate may not reach the groundwater even in the arable area. In which case the nitrate remains available for the crop when it begins to grow.

8) It appears that very small increases in nitrate concentration can have a profound effect on the dyke flora, e.g. the complete disappearance of Frogbit from dykes in arable areas. Therefore the protection of the dyke water from nitrate pollution is vital if rare plant species, which require a low nitrate

environment, are to survive.

9) The present practice in Rotational Setaside, in which summer ploughing is recommended, cannot be endorsed. The higher temperatures combined with wet weather will encourage the mineralisation of organic material to nitrate. The absence of plant cover to absorb this nitrate will allow it to be washed into the deeper layers of the soil. This will put it out of reach of autumn sown crops and add to the amounts available for leaching in the autumn.

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