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Ditch water levels managed for environmental aims: effects on field soil water regimes

Adrian Armstrong[1] and Stephen Rose

ADAS Hydrology, Gleadthorpe Research Centre, Meden Vale, Mansfield, Notts, NG20 9PF, UK
Tel: 01623 844 331; Fax: 01623 844 472

[1] Corresponding author: Email: Adrian.Armstrong@adas.co.uk

Abstract

The effects of ditch water management regimes on water tables are examined for two test sites in England, Halvergate in the Broads and Southlake Moor in the Somerset Levels and Moors Environmentally Sensitive Areas. It is observed that in some fields the effects of water management are only poorly transferred from the ditch to the field centre, especially where the hydraulic conductivity of the subsoil is small. Where there are large variations in the ditch water levels, reflecting the influence of major ditches subject to pump drainage, field soil water regimes differ significantly. Nevertheless, the effects of even quite small changes in the ditch regime can be noticeable. Simple modelling studies show that much greater effects can be achieved by increasing the frequency of ditches within wetlands.

Introduction

Greater public awareness of the environment and in particular of the value of wetlands (Maltby, 1986) has resulted in measures both to protect wetland ecosystems and to restore existing wetland areas, together with the creation of new wetland areas in suitable locations. A major component of the prescriptions for achieving those ends has been the control of the water levels in the ditches adjacent to target wetland areas. However, it is by no means certain that by simply holding ditch levels high, the target wetland benefits will be created. Restoring wetland habitats requires appropriate management of hydrological conditions and agricultural operations (Armstrong *et al.*, 1995). Practical management therefore needs to be able to evaluate the effects of ditch water management options.

This paper reports observations from long term management studies of the effect of managing ditch water regimes in two areas within the Environmentally Sensitive Areas (ESA) schemes (MAFF, 1989) in the UK. Parallel work on the effect of the water management regimes on the ecological status has been undertaken by Treweek *et al.* (1998). These study sites offer a long term record of wetland hydrology, suitable for modelling studies, and so the paper also uses a simplified model of wetland hydrology to examine the impacts of the various ditch water level options on the hydrology of managed wetlands.

Site 1: Halvergate, The Broads ESA

The Broads ESA consists of a series of low-lying river valleys, marshes and fens, in Norfolk and North Suffolk in Eastern England. The whole area of river valley, broad, fen and marsh, forming an inter-connected wetland system, is unique in Europe, and contains the largest area of lowland grazing marsh in eastern England (MAFF, 1991a). The Broads ESA was designated in March 1987 and, since January 1988, farmers have been able to enter into agreements with MAFF to maintain traditional grassland management (payment tier 1), and may also raise water levels in ditches to a more ecologically sympathetic height in the spring (tier 2). In 1992, a third tier (tier 3) was introduced which required the participating farmers to flood land in spring and hopefully further improve the ecological value of the land

The Halvergate area in the centre of the Broads ESA was chosen as the site for detailed monitoring studies. The wide expanse of flood plain centred on Halvergate marshes, which was traditionally summer grazing pasture, forms an area of considerable ornithological interest. Since 1989, water levels in six fields, Fig.1, have been monitored to identify the effectiveness of the management regimes imposed in response to the ESA scheme. Four fields were within one block of land that was subject to a water

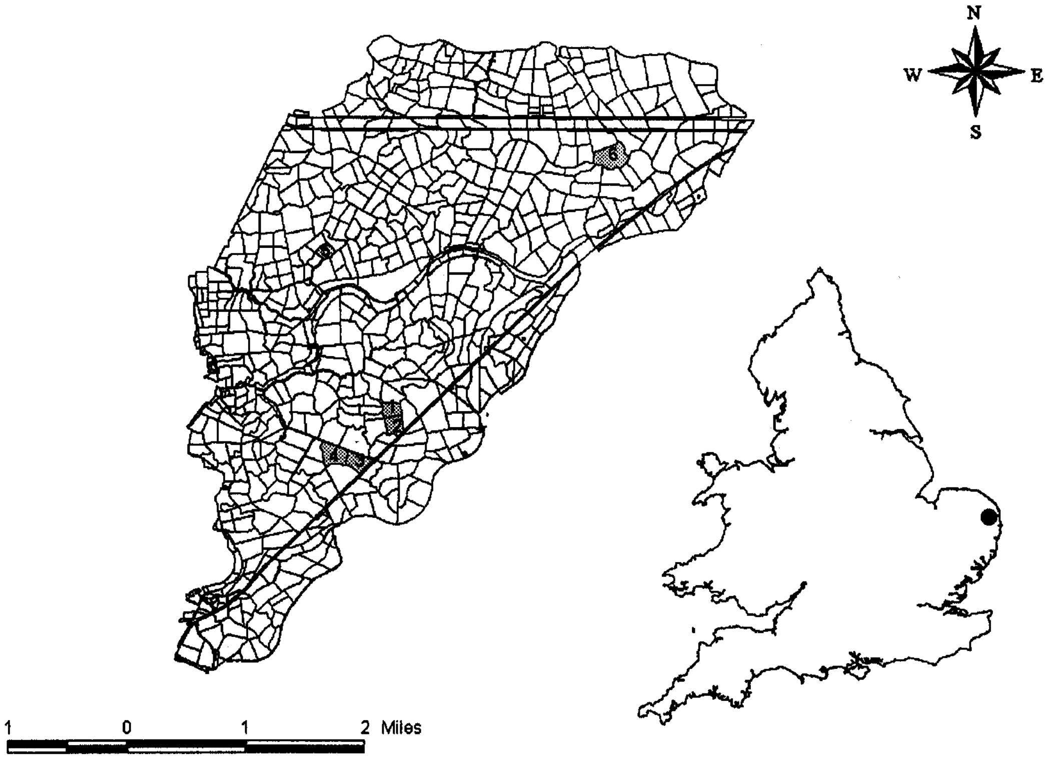

Fig. 1. *Halvergate: location of the sites studies*

management scheme for the retention of spring and summer water levels (ESA Tier 2). Within this sample, two fields (Fields 1 and 2) were subject to the enhanced level of management (ESA Tier 3) from January 1994. Two reference fields (Fields 5 and 6) outside this area, which had the normal summer water levels (ESA Tier 1), were also identified and monitored.

In these fields, water tables have been monitored by a combination of open auger holes, 'dipwells' (Armstrong, 1983), and continuous recording water level meters (Talman, 1980, 1983). The dipwells formed a transect from ditch to ditch, and so recorded the shape of the water table; they were read on average every 3 to 4 weeks. Continuous records of the water levels were maintained in the field centres and in the ditches.

Meteorological data were obtained for the synoptic station at Hemsby, about 10 km to the North. Some local rainfall information, gathered by RSPB staff at their Berney Arms site on the SE edge of Halvergate, showed that there was little systematic difference between the two sets, and it was considered that the Hemsby data could be used as a good estimate of the conditions at Halvergate. Estimates of potential evapotranspiration for the site were provided using these data and the MORECS system (Thompson *et al.*, 1981).

The soils of the area are alluvial clays of the Newchurch series (Clayden & Hollis, 1984). These soils are very well structured in the topsoil, where they are rich in organic matter, but rapidly become structureless with depth, and at 2 m depth are 'buttery' and anaerobic. The hydraulic conductivity of the soil reflects this structural development, and varies between values in excess of 100 m/day close to the surface, to values less than 0.1 m/day at depths below 1 m.

Monitoring results:

Results from the long term monitoring locations in Fields 1 and 6 (Fig. 2) show the contrast between the water regimes observed in raised ditch levels (ESA Tier 2) in Field 1 and the unaltered 'normal' regime in Field 6.

In Field 1, in an area with normally high water levels, the ditch water levels remain high, and the field water table levels remain close to the surface for all except the driest summer months. From 1989, these fields were subject to an ESA Tier 2 agreement, in which the water levels in the ditch were maintained within 0.5m of the ground surface. In the summer of 1991, severe water shortage prevented the maintenance of high water levels in the ditches, and the field water table level fell accordingly. In each summer, the water table level in the field centres falls below that of the ditch, indicating that recharge of water from the ditch to the field (sub-irrigation) was not sufficient to meet the evaporative demand from the vegetation.

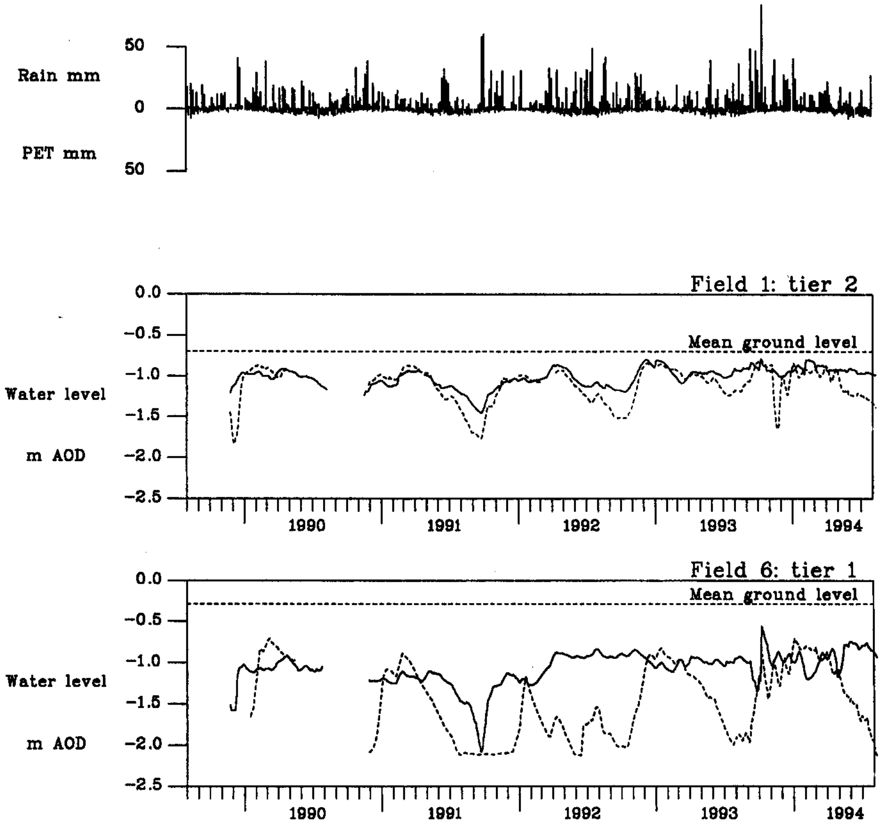

Fig. 2. *Halvergate monitoring sites: Rainfall and calculated soil moisture deficits (SMD); Observed ditch water levels (solid lines) and water table levels (dotted lines) for Fields 1 (raised ditch water levels) and 6 (normal ditch water levels). Water levels are shown relative to mean sea level (AOD, Above Ordnance Datum).*

The water regimes in Field 6 are dramatically different. This is an area in which the ditch water levels are maintained at a low level to facilitate agricultural production. The ditch that controls the water level in this field is a major channel and is controlled by the pump that drains the whole of the area. The water level is generally between 1.2 m and 1.5 m AOD and falls even lower in the summer. However, the soil of this field has the same low conductivity as field 1, and so the water table in the field can rise in the middle of the field in response to the incident rainfall. The result is that the water table in the field is much less closely coupled to the ditch water regime than that for Field 1. Although the winter period is dominated by drainage, in the summer there is only limited recharge. Because the land levels are higher than for Field 1, the water table is further from the surface in the summer, and the site is thus drier.

The shape of the water tables in early summer throughout the area is illustrated by Fig. 3 for the same two fields and for the other monitored fields. These demonstrate that the water table in most fields is very nearly flat, and is close to the ditch water level for all except Field 6 in which there is the classic domed water table. All the fields exhibit the 'bowl shaped' topography that is characteristic of grazing marshes, produced by the repeated excavation and clearance of ditches leading to the deposition of material round the field margins. This variation in field level imposes a variation in water table depth, so that the water table is further from the surface at the margins, but close to the surface near the field centre. This result demonstrates the major importance of topography in defining the water table conditions at any point. It also shows that, even where the water table can be controlled accurately, there will be variation in the hydrological regime within a field due to the topographic variation. The corollary is that within-field topographic variations lead to the development of a mosaic of different wetness conditions, with the attendant variation of vegetation.

Modelling the effects of management options

Extension of the observations to examine the consequences of differing management options has been undertaken by the use of the DITCH model (Armstrong, 1993). This model basic drainage theory examines the interaction between ditch and field centre, by modelling the height of

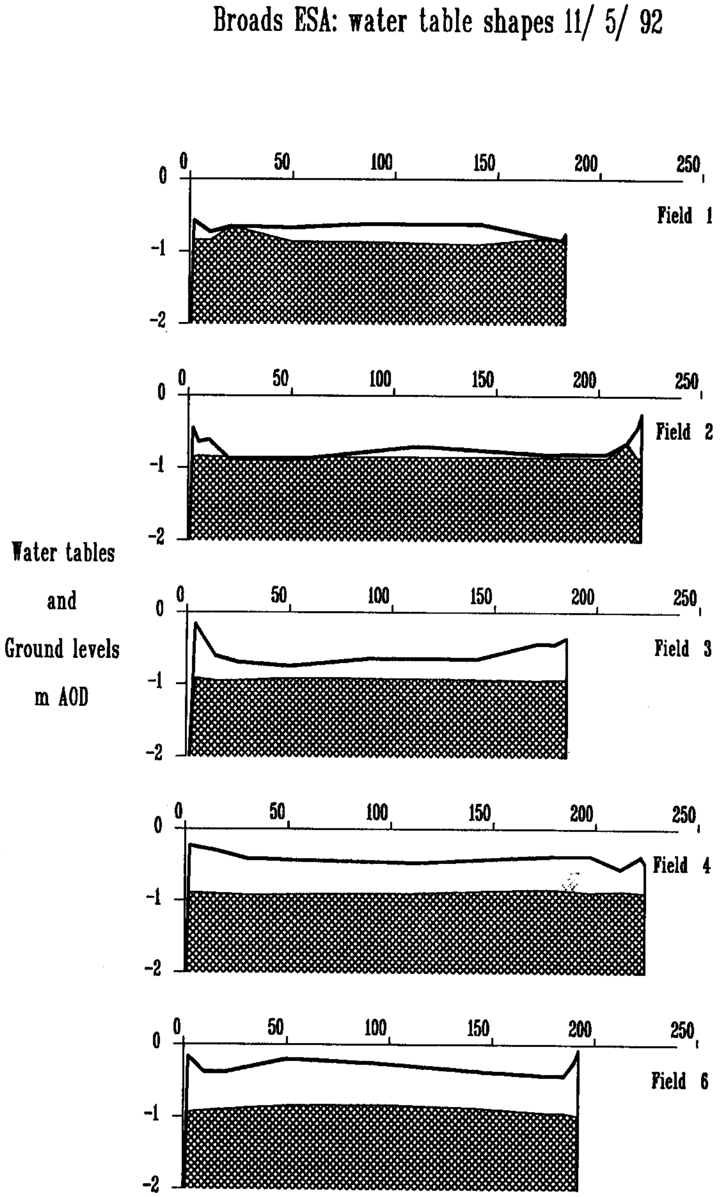

Fig. 3. *Halvergate. Example water table and ground level profiles. May 1992.*

the water table at the centre of the field. It simulates the fluxes of water moving between the soil and the peripheral ditches (both recharge and drainage), and so estimates the position of the water table in the field. The model is generally similar though not identical to that described by Youngs *et al.* (1989).

For simple situations, water levels in a field can be calculated from a consideration of the water balance:

$$M_t = M_{t-1} + (R - E_t - Q_d) / f \qquad (1)$$

in which the water elevation in the field on day t is M_t, R is the rainfall, E_t is evapotranspiration, Q_d is the discharge through the drainage systems and f is the relevant soil porosity. For a soil drained by parallel ditches, the drainage can be calculated from one of the well-known drainage equations (e.g. Ritzema, 1994). Strictly, drainage equations should be applied only to parallel ditches, and for field situations, the three-dimensional analyses of Childs & Youngs (1961) and Youngs (1992) should be used. However, for long narrow fields, the error involved in estimating the field centre is small, and the use of the much simpler drainage equations is adopted as an efficient simplification.

For the Broads area, the soils show a decrease in conductivity with depth (Fig. 4). If the relationship between

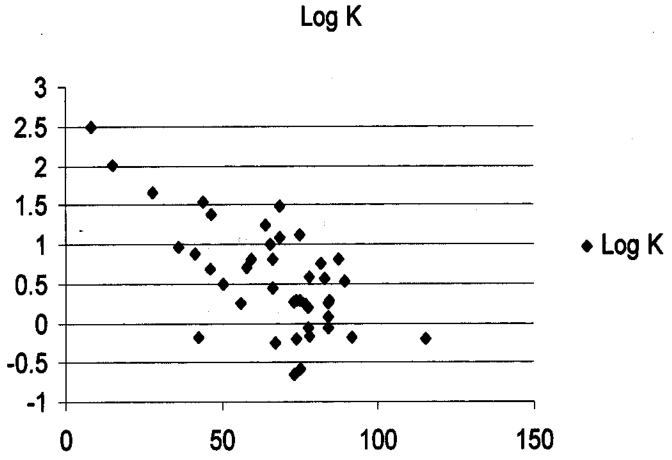

Fig. 4. *Halvergate: variation of hydraulic conductivity with depth below the soil surface.*

soil conductivity and height above the base of the profile is given in exponential form:

$$K(z) = K_0 e^{\beta z} \qquad (2)$$

where K_0 is the hydraulic conductivity of the saturated soil at $z = 0$ and β is a constant, then Youngs (1965) shows that for non-empty ditches spaced D apart, in which the level of the water in the ditches, H_w, and that in the field centre is H_m , then

$$Q = 2K_0[e^{\beta H_m} - e^{\beta H_w} - \beta H_w] / \beta^2 D^2 \qquad (3)$$

which gives the drainage flux, Q, which can easily be included in Eqn. (1). Data shown in Fig. 4 give values of $K_z = 1.97$ and $B = -0.02$ with a correlation coefficient of 0.67, where K_z is the value at the surface, and the hydraulic conductivity is measured in m/d.

The meteorological data and the observed daily ditch water levels for Field 1 were used to model the water tables in the centre of the same field. A validation check using the data from January 1990 to December 1994 inclusive was undertaken by comparing the modelled and observed water tables (Fig. 5). Visually, the results show reasonable agreement between the model and the observation. The correlation coefficient between the modelled water tables and the mean water table position when read manually (70 data points) was 0.847, which was considered to be an excellent confirmation of the model. The Model Efficiency criterion (Loague & Green, 1991) gave a value of 0.683, which indicates an acceptable level of model performance.

The model was then used to examine the effectiveness of the various tiers of management on the water regimes of the Halvergate soils. The model was run for a 16 year period from 1979 to 1994 and adopting three water regimes representative of the three tiers of management relating to the ESA prescriptions:

- Tier 1. Ditch water levels at 1.5 m below ground level from 1 January to 30 March, at 1.0 m below ground level from 1 April to 30 October, and at 1.5 m below ground level from 1 November to 31 December.
- Tier 2. Ditch water levels at 1.2 m below ground level from 1 January to 1 March (i.e. with 0.3 m more water in the ditches than the comparable tier 1 levels) , rising to 0.45 m below field level by 1 April, remaining at 0.45 m below ground level until 30 October, and thereafter at 1.2 m below field level.
- Tier 3. Ditch water levels are held at mean field level from 1 January to 30 April; at 0.45 m below field level from 1 May to 30 October, then rising to mean field level by 1 December, and remaining at that level until the end of the year.

The mean water tables for these three options (Fig. 6) show the dramatic effect on in-field water regimes that are created by the different tiers of management. In particular, the adoption of high water levels in the tier 3 levels results in the water table fluctuating only in the upper, conductive, layers of the soil, so that the field and ditch water levels are closely tied together. By contrast, where the ditch levels fall in summer, water movement becomes concentrated in the lower impermeable layers. The soil is then unable to transmit sufficient water from the ditches

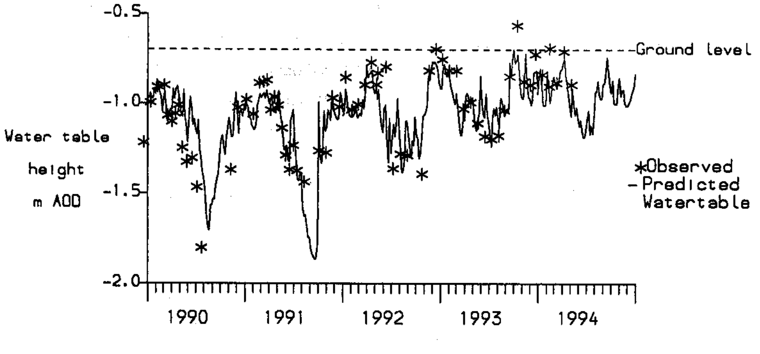

Fig. 5. *Halvergate. Comparison of observed (*) and modelled (continuous line) water tables*

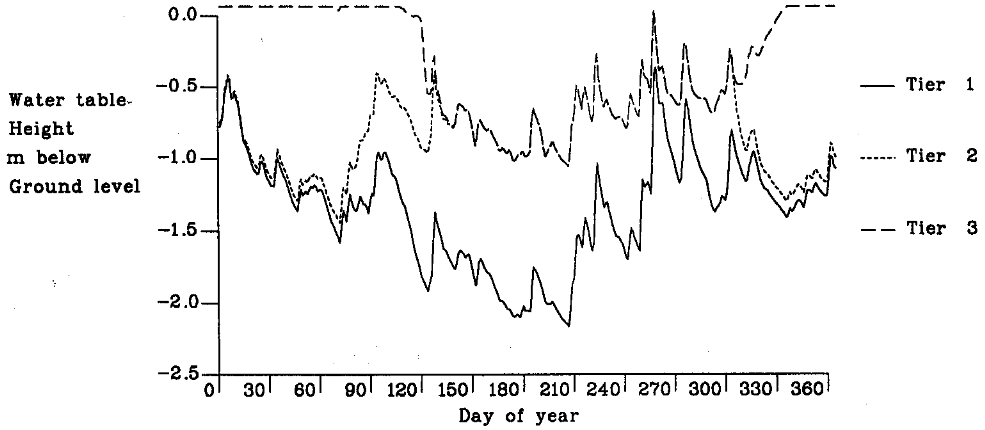

Fig. 6. *Halvergate: Predicted mean water tables in response to the levels of ditch management.*

to maintain the water table levels in the face of continuing evaporative demand.

Site 2: Southlake Moor, the Somerset levels and moors ESA

The Somerset Levels and Moors ESA extends over 27,680 ha of the central Somerset lowlands, bounded by the Mendips to the north, low limestone escarpments to the east, the Blackdown Hills to the south and the Quantocks to the west. The moors comprise an extensive area of very low lying basin peat, with a few remnants of raised bog, surrounded by alluvial silt and clay. The peat is overlain in places by a varying thickness of riverine clay. The whole area forms the largest remaining lowland wet grassland or grazing marsh system in Britain and is consequently of outstanding environmental interest (MAFF, 1991b)

Within the Somerset levels, Southlake Moor is a self-contained unit, isolated to the south by the River Parrett, to the East by the flood relief channel, and to the north by a causeway between Burrow Mump and Othery (Burrow Wall). Water is let into the catchment by a control structure in the East, along the Challis Wall Rhyne, and let out by another sluice under the Burrow Wall. Southlake Moor has soils of the Midelney series (Avery, 1955). These soils have a shallow clay cap (approximately 0.40 m deep on Southlake Moor) of river alluvium, overlying a peat substrate. This is the result of a practice of 'warping', which involves letting the area flood with the waters from the adjacent River Parrett, as has been the practice in this area since the 17th Century. This procedure was initiated in historic times for fertility and pest control purposes. It is now also a component of the flood management system. The peat extends to a depth of over 2 metres. The moor lies at an elevation of approximately 4 m AOD, with field centres typically around 3.8 m AOD.

Prior to the establishment of the ESA, the ditch water levels in Southlake Moor were maintained at 3.50 m AOD from mid-November to the end of March, and at 3.65 m AOD from April to mid-November. On this site, a raised water level regime was initiated at the beginning of December 1988. The water levels were maintained at 3.65 m at the outlet sluice throughout the year, except for March, when the levels were lowered to 3.50 m to facilitate ditch-cleaning operations. Excepting March, this higher ditch level was equivalent to the previous summer penning level.

MONITORING

Water table levels have been monitored with dipwells, in four fields (Fig. 7) within Southlake Moor and one reference field (field 6) outside the moor, since June 1989. Gauge boards, recording the water levels in the ditches, at the inlet to the moor and at the outlet were also recorded on a weekly basis. The mean ditch water level and in-field water table are shown in Fig. 7, for one typical field, Field 1 inside the moor, and the control field immediately outside the moor, Field 6. The water table remains close to the ditch water levels during the winter months but, in the summer months, it falls to around 1 m below ground level, which is below the ditch level. There is apparently some element of recharge, because the dipwells do not dry out, although this is insufficient to maintain the water tables at the high levels set in the ditches throughout the summer months.

For the most part, the levels at the two boards at the inlet and outlet to Southlake Moor are very close together, confirming that there is seldom a significant hydraulic gradient through the moor. Modelling procedures can therefore use a single water level to characterise the ditch level in the whole of the Moor. For the period of observation, the levels were kept very largely at about 3.7 m AOD, cor-

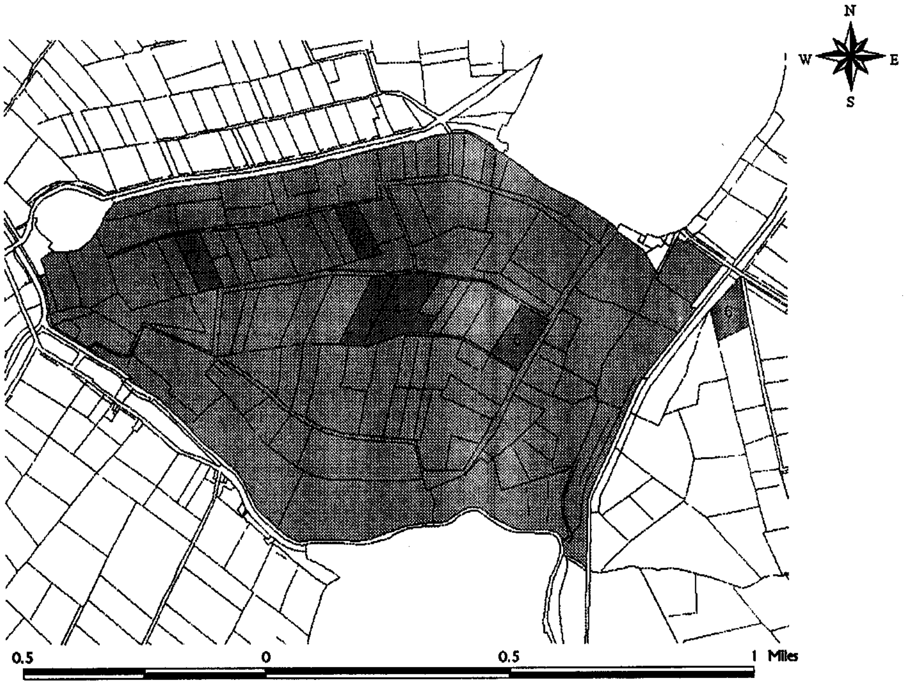

Fig. 7. *Southlake Moor. Location of the fields studied.*

responding to a position 0.3 m below ground level. However, for the period in Jan and February 1990, the levels were allowed to rise close to 5.0 m OD and thus flood the site.

The water levels in the adjacent control field show a very similar pattern, being high in the winter, with the water table falling to around 0.7 m below the ground surface in the summer. However, because this field is adjacent to a control ditch, it is not allowed to flood in the same way as the fields within Southlake Moor proper.

MODELLING MANAGEMENT OPTIONS.

The same hydrological model used for the Halvergate studies was also used for Southlake Moor. However, the soils of Southlake Moor show a marked contrast between the permeable peaty subsoil and the less permeable silty topsoil, so that the prediction of the fluxes between the field and the ditch required the implementation of the analysis of the drainage fluxes in a two layered soil given by Wesseling (1973) and Ritzema (1994) in place of Eqn. 3. For a two layered soil with the drain or ditch in the lower layer, the drainage flux is given by:

$$\frac{H}{q} = \frac{D_1}{K_1} + \frac{L^2}{8(K_1D_1 + K_2D_2)} + \frac{L}{\pi K_1}\ln\frac{aD_0}{u} \qquad (4)$$

in which the layers are of depth D and conductivity K, with subscripts 1 and 2 for the upper and lower layers respectively. The three components of the right hand side of the equation refer to the three components of the flow: the vertical flow in the upper soil level, the horizontal flow through the whole soil, and the radial resistance. The shape factor, a, is set to 4 where the water table is in the upper layer, and to 1 in the lower. The direction of the overall flux, however, which is determined by the sign of the head difference driving the flow, H, can still be either positive or negative, depending on the circumstances. When the moving water table crosses different layers, the drainable porosity will also change, and care needs to be taken to ensure that water budgets are maintained.

The soil parameters used were: for the clay topsoil, porosity of 12% and a hydraulic conductivity of 0.08 m day^{-1}; for the subsoil peat, porosity of 15% and hydraulic conductivity of 1.0 m day^{-1}.

Although some rainfall data were available close to the site, many of the variables required to calculate potential evapotranspiration are not recorded anywhere on the Somerset Levels, and adjacent stations are either at higher altitudes or on the coast. Consequently, the estimates of Potential Evapotranspiration obtained by use of the MORECS program (Thompson *et al.*, 1981) were subject to some uncertainty.

To test the model, it was first run against the sets of observations for Southlake Moor, using the observed gauge board heights at the Burrow Wall Sluice to define the input boundary conditions. The modelled water tables were compared to observations (Fig. 8) for the recording period. A statistical comparison of the model results gave a simple correlation coefficient of 0.633 and the Model

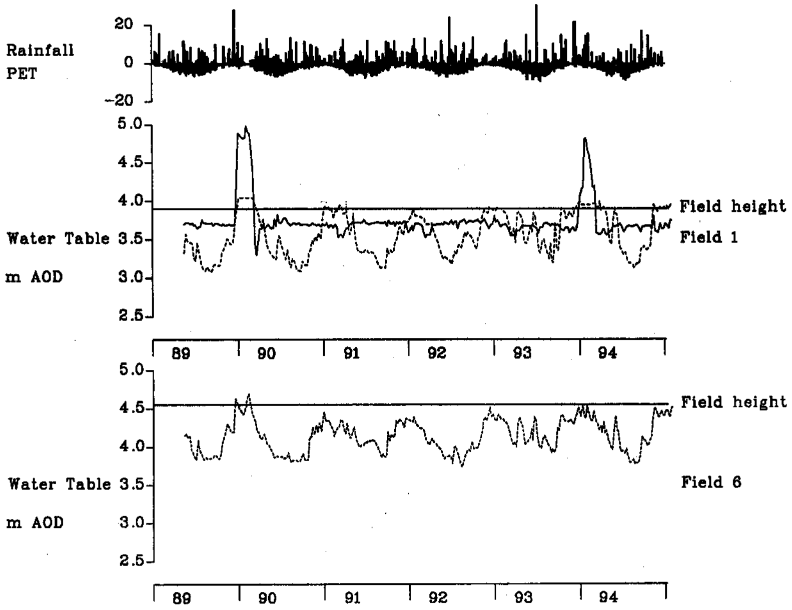

Fig. 8. *Southlake Moor. Rainfall, potential evapotranspiration, ditch water levels (solid line) and observed water tables (dotted line), Field 1, 1989 to 1994 within Southlake Moor, and the water tables only for reference field 6 outside the Moor.*

Efficiency of 0.38. Although these results are not quite as good as the results for Halvergate, they indicate an adequate model performance.

The model was used to identify the impacts of varying ditch water regimes on the water levels within the field, by simulating the water table under both Tier 3 with water levels held at mean field height (3.85 m AOD) from November 15 to March 31; and under 'normal conditions' unmodified by the current ESA agreements; and under the current Tier 2 levels (3.65 m AOD throughout the year except when reduced to 3.50 m AOD in March for ditch maintenance).

The model was then run over a ten year period, and the effects of the water management options were identified by calculating the mean depth to water table during the year. The mean results for the uncontrolled regime (prior to the raised water levels trials) and for the Tier 2 and Tier 3 regimes are given in Fig. 9. Although the three tiers represent three very different ways of managing the ditches, the effects on the mean in-field water tables are quite small. This reflects the fact that the variations between the ditch water regimes adopted by the various tiers within Southlake Moor are not large. This is in contrast with the observations from Halvergate, where the differences between field 1, with raised water levels, and field 6, adjacent to a large pumped ditch gives a much greater contrast

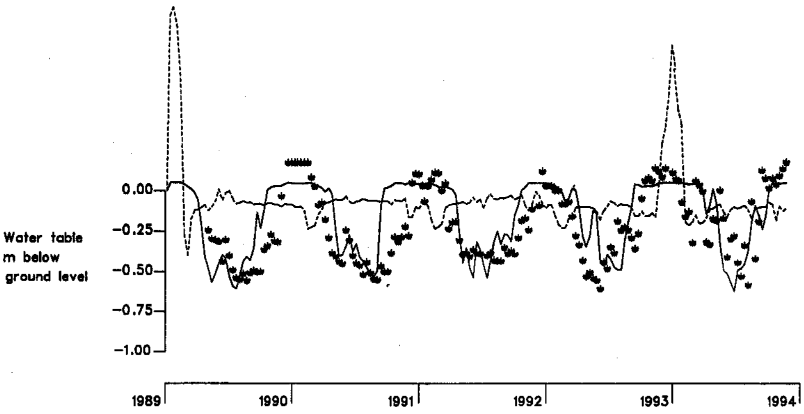

Fig. 9. *Southlake Moor. Comparison of observed (*) and modelled water tables, (solid line) Field 1 in response to the imposed ditch water levels (dotted line).*

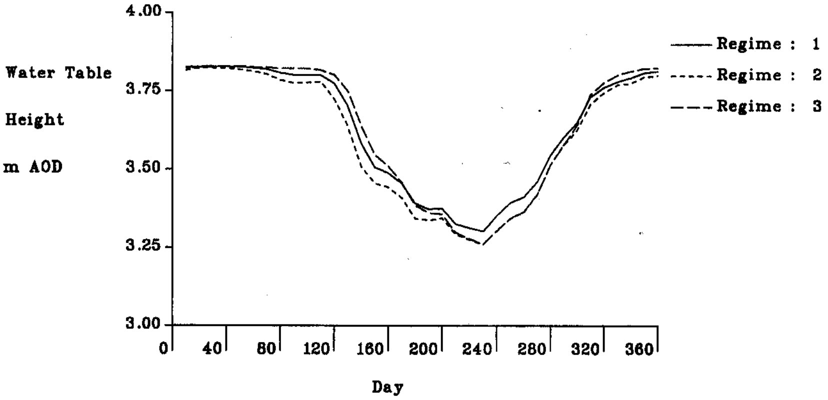

Fig. 10. *Southlake Moor. Mean water tables predicted for each of the three ditch management options.*

in field water regimes. Similar situations to Halvergate field 6, where fields are adjacent to major pumping ditches, have been observed, but not monitored, in the Somerset Levels. The primary conclusion must be that, where the arterial conditions restricted the range of water management options that are available, then the range of water table conditions achievable in the soil is also limited.

The dominant feature of the soil moisture regime is always the alternation of winter saturation and the summer period of drying out. Holding the water levels higher in the summer months has only a very limited effect on the water table in the summer. This implies that, even in a moderately high conductivity soil, the possibilities for maintaining in-field water tables close to the surface are strictly limited. Nevertheless, within this broad pattern, the model predicts a consistently higher field water table under the Tier 3 regime, compared to either the Tier 2 or the 'unaltered' regime, and this effect is greatest in the spring and early summer. These results show that the effect of the Tier 3 management is to increase field water table levels, and that the effect is especially pronounced in the spring and early summer. The effect in the centre of the field in terms of changing from the 'old regime' to the new Tier 3 regimes with raised water levels in the ditches, is thus to delay the start of the drying out phase by an average of 20 days.

One option to enhance the wetland status of such fields would be to re-instate the surface water controls. Most wetlands in both Somerset Levels and the Broads areas have the remains of old channels, either artificial or natural, which are now largely non-functional. Relict ditch lines, surface drains, or old river channels are clearly visible. Although these channels may seem in the first instance to offer a means of drainage, they also offer a means of increasing the hydrological interaction between the ditches and the field centres. The impact is illustrated by Fig. 10, which took as its basis the model for Southlake Moor, which produced Fig. 9, and then halved the ditch spacing twice. The effect of reducing the ditch spacing, as has been suggested for example by Gilbert *et al.* (1997), on the

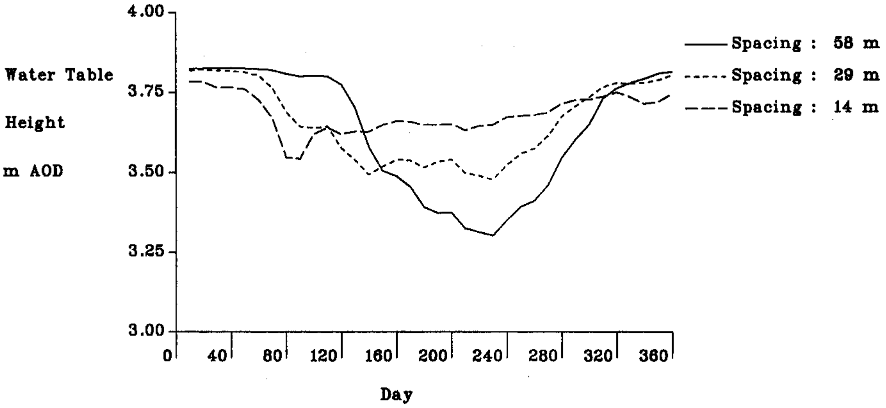

Fig. 11. *Southlake Moor. Mean water tables predicted for different ditch spacing.*

in-field water regime is dramatic, and contrasts strongly with the relatively small and subtle effects of the different ditch management regimes.

It is probably not a realistic option to fill agricultural wetlands with ditches every 15 m, but similar effects might be expected where open ditches are replaced by other water channels, particularly artificial drainage pipes, which is a technique that is both well known and easy to install. A less drastic solution is positively to maintain the small-scale drainage features, which are easily blocked, particularly at the ditch bank, by spoil left after ditch clearance operations.

Conclusions

The observations in this paper have shown that ability to manage water tables in field centres depends strongly on the arterial drainage infrastructure. Where there are the possibilities for marked contrasts of arterial ditch levels (as in the observations from the Broads area), then markedly different field water regimes are observed. Where, however, the arterial possibilities are much more limited, then the possibilities for field wetness are also limited.

The observations also show that within the constraints of normal agricultural management, water tables in the centres of fields consistently fall in the summer, and that high ditch water levels have only a small effect on recharging the evaporative loss.

This paper has shown that hydrological budget models can be used effectively to estimate the soil water and ditch regimes in small catchments where the ditch levels are being manipulated. The validation tests of the models using the two data sets suggests that the two models offer a good representation of each system. However, the results also show that the effects of ditch management options are not easily converted into impacts in the centre of the fields.

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