

# **A revised estimate of peat reserves and loss in the East Anglian Fens**

**Commissioned by the RSPB**



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# **1 Introduction**

Lowland peat sites can deliver a range of valuable ecosystem services including supporting biodiversity, carbon storage, food production and flood attenuation. However, many lowland peat soils are suitable for agricultural uses where effectively drained and so have been primarily managed to support food production at the expense of other ecosystem services.

In 2009, the RSPB commissioned a report (Holman 2009) to gain an initial understanding of the impacts of current land management on peat reserves in the East Anglian Fens.

Analysis of the unpublished peat survey auger bore records, which are largely held in non-electronic formats, was outside the scope of the initial study. It was recommended that more detailed analysis of these should be carried out to collate the observed peat thickness data at each observation point, rather than the peat thickness classes used in Holman (2009). This report describes the results of this re-assessment of the available data.

## **1.1 Objectives**

The objectives of this project are to:

1. Collate available peat survey auger bore records to provide an improved assessment of the peat depth within the likely areas of remaining peat soils in Fenland identified by Holman (2009);
2. Update the estimates of the carbon storage within the peat soils in Fenland;
3. Update the assessment of the significance of the carbon emissions associated with peat losses in Fenland;
4. Evaluate the effects of ditch or drainage spacing and ditch water level management on Carbon emissions from re-wetted peats.

## **2 Peat soils, drainage and wastage**

### **2.1 Classification of soils containing peat horizons**

#### **2.1.1 Peat soil classification**

The soil classification used in England and Wales (Avery 1980, Clayden and Hollis, 1984) is a hierarchical system with classes in four categories (major soil group, soil group, soil subgroup and soil series) defined by progressive division.

Ten Major Soil Groups are recognised, of which Major Soil Group 10 is Peat Soils. They are required to meet both of the following criteria:

1. Either more than 40 cm of organic material within the upper 80 cm of the profile, or more than 30 cm of organic material resting directly on bedrock or skeletal material;
2. No superficial non-humose mineral horizon with a colour value of 4 or more that extent below 30 cm depth.

As a simplification, this therefore indicates that for a soil to be classified as a Peat, the peat must be at least 40 cm thick and not be buried by more than 30 cm of mineral layers with low organic carbon.

#### **2.1.2 Other soils which contain peat**

Peat horizons can occur within a number of other Soil Subgroups and soil series within the hierarchical soil classification that do not qualify under Soil Major Group 10 (Peat Soils). These will either have (1) surface peat horizons which are less than 40 cm thick, often as a result of wastage of previously thicker peat deposits, or (2) peat layers which start at a depth of greater than 30 cm (but which may be of significant thickness).

### **2.2 Drainage and wastage**

The use of peatlands for improved pasture, or for arable or horticultural production requires drainage. Drainage leads to subsidence of the ground surface and the eventual destruction of the fragile peat. There are several components to peat wastage, the general term used to account for the loss of peat:

- Shrinkage – the removal of large amounts of water from the peat produces rapid initial shrinkage, with rates of 18 cm/a in Holme Fen, Cambridgeshire, between 1850 and 1860 (Hutchinson, 1980);
- Compression – drainage also reduces the buoyancy effect of water which causes compression of the peat under its own weight and increased bulk density. Passage of machinery increases the compaction;
- Oxidation – under the ensuing aerobic conditions, decomposition (biochemical oxidation) becomes the dominant processes, mainly affecting the peat above the watertable;
- Other lesser components of wastage, including:
  - Wind erosion – where spring-sown crops offer a bare, loose soil surface to strong winds;
  - Removal of soil on root crops;
  - Accidental burning of dry peat.

Wastage is greatest in thick peat deposits and where watertables are lowest. The rate of decomposition may be accelerated by liming, by mixing with mineral soil material and by an increased frequency of wetting and drying cycles (Burton and Hodgson, 1987). The most complete record of peat wastage is that from Holme Fen, as described by Hutchinson (1980). The record shows four stages of peat wastage over the history of the record from the 1850s

until the 1970s, each associated with an 'improvement' in the drainage regime i.e. a lowering of the pumped water level. Within each stage, the rate of peat wastage exponentially decreases with time in each stage. Within the final Stage 4 (1962-1978) described by Hutchinson (1980) the peat surface lowered by around 1 cm/yr.

The original deep peatlands of the Fens are expected to have suffered more wastage than the 3.9 m measured at the Holme Post (Hutchinson, 1980), chiefly because they have been drained for longer and have been more continuously under intensive arable cultivation, particularly during the 20<sup>th</sup> Century. The alkalinity of fen peats will also have tended to produce higher wastage rates than in the acidic raised bog peats which form the upper part of the Holme Fen profile. The lowering of the surface levels in the "black Fens" was estimated by Fowler (1933) as up to 4.6 or 4.9 m (compared with about 3.3m at Holme Post at that time).

Other estimates of peat wastage are:

- average wastage value in the Fens of 0.6 cm/yr for the 200 years of wind pump drainage and about 2.5 cm/yr for the later more intensive drainage and cultivation period (Fowler et al. 1931)
- peat wastage of 1.8 cm/yr over the period 1934-1962 at Shippea Hill, Isle of Ely (Clark et al., 1935 and Clark and Godwin, 1962)
- mean annual wastage of 2.5cm/yr at Bourne South Fen, Lincolnshire (Miers, 1970)
- mean annual wastage between 1952-1962 of 0.7 cm/yr for shallow peat (less than 90cm depth) and 2.1 cm/yr for deeper peat, based on a systematic grid pattern of peat depth measurement at 131 points across the southern area of the Fens (Herbert, 1971).
- mean wastage rate of 1.37 ( $\pm 0.78$ ) cm/yr between 1941-1971 at 14 sites across the Fens (Richardson and Smith, 1978). When the data was sub-divided between 1941-55 and 1955-1971, wastage rates were higher at all but one site in the earlier period
- mean wastage rates for 'thick' and 'thin' peat of 1.27 cm/yr and 0.19 cm/yr, respectively are used for drained lowland wetlands including the East Anglian Fens by Milne et al. (2006). Although 'thin peats' have depths of up to 1 m, the low wastage rate used by Milne et al. (2006) for this group is likely to reflect the inclusion of non-peat 'Skirtland' soils.
- Burton (1989) estimated a mean decline of 1 cm/yr at seven coincident sampling sites from surveys undertaken in 1961/2 and 1984/9 for the peat soils at the Arthur Rickwood Experimental Husbandry Farm (EHF) in Mepal Fen, Cambridgeshire.
- Burton (1995) reports mean annual wastage rates of 1.27 cm/yr at Fortreys Hall, Mepal Fen over 22 years (Mendham series) and 1.06 cm/yr at Conington over 18 years (Turbary Moor series)
- Mean wastage rates between 1982 and 2004 at Methwold Fen are reported by Dawson et al. (2010). The lowest rate (1.05 cm/yr) was found for fibrous peats underlain by Fen Clay, with the highest (1.21 cm/yr) being for humified peat without underlying Fen Clay. Fibrous peat without underlying Fen Clay had an intermediate wastage rate of 1.19 cm/yr.
- Brunning (2001) suggests that peat wastage in pasture fields in the Somerset Levels is occurring at rates of between 44 cm and 79 cm a century
- Studies in the Netherlands show land levels lowering by 1 cm yr<sup>-1</sup> under normal agricultural use (Acreman and Miller, 2007)

### 3 Methodology and Results

The methodology used within the current study is different from that used by Holman (2009). It is described in detail below, but key differences are that:

- Actual peat thickness observations from the Lowland Peat Survey and other soil surveying are the starting point for the analysis, rather than peat thickness classes;
- The assumed rates of wastage differ according to peat type, peat thickness, presence of clay layers within the soil profile and land cover;
- The assumed rate of wastage reduces when wastage causes the peat thickness class to become less than 1 m;
- The estimation of current extent of peat is based on both the soil maps and peat observations;
- The estimation of Carbon stocks and emissions from the peat takes into account peat type (humified and semi-fibrous /fibrous) and their associated differing bulk density and organic carbon contents.

#### 3.1 Peat thickness

Within conventional soil survey, the total thickness of peat deposits is not usually determined, as the reference section for classifying the profile extends to no more than 1 m depth. For the current study, four main sources of peat thickness data have been collated:

- 1) The principal systematic dataset is the Lowland Peat Survey (Burton and Hodgson, 1987), which surveyed most of the main lowland peat areas of England and Wales below 200 mOD. The inventory incorporated information from earlier Soil Survey reports augmented by purpose-made site descriptions and samples. During fieldwork, sites were investigated by hand-auger borings, generally at 500m intersections of the National Grid. Where possible the borings were made through the whole of the peat sequence into older deposits. In all cases, the profile was manually recorded on record cards;
- 2) Peat auger bores held electronically within the Land Information System (LandIS) maintained by the National Soil Resources Institute at Cranfield University;
- 3) Peat auger bores that were recorded as part of detailed (1:25,000 scale) soil mapping contemporaneous with the Lowland Peat Survey;
- 4) Hand written field sheets, which contain summary descriptions of profiles, principally horizon depths and texture.

In total, data for 1823 soil profiles were collated, having removed duplicate observations. In all cases, the profile descriptions were synthesised to provide the following data:

- Total combined thickness of peat or peaty layers within the profile;
- Total combined thickness of humified peat within the profile;
- Presence of low permeability (clay, sandy clay, silty clay) layers below 40 cm depth within the soil profile;
- Whether the peat or peaty layers were buried below at least 40 cm of mineral surface layers.

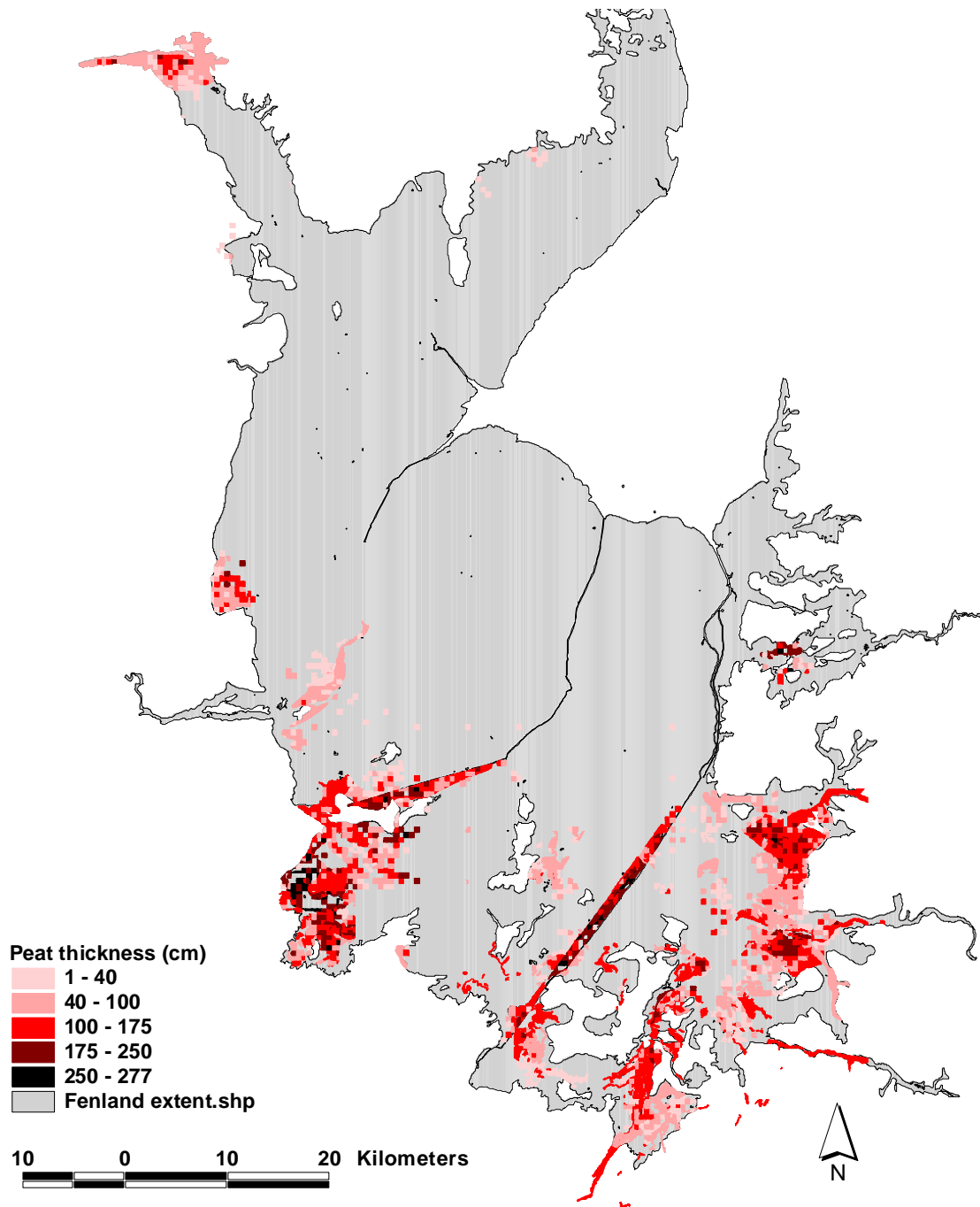
The data from each of the 1823 observation locations were assigned to both the *peat polygons* from Holman (2009) and to a cell on a 500m x 500m grid, using a 'point in polygon' procedure within a GIS. The 500m x 500m grid was aligned so that the grid cells were centred around the Lowland Peat Survey observation points. The original (i.e. 1980s) peat thickness has been calculated as follows:

- 1) Firstly, the peat polygons were intersected with the 500m x 500m grid cells to produce *peat-grid polygons*;



- 2) Each peat-grid polygon classified by Holman (2009) as “Deep Peat” was assigned a thickness based on:
  - a. The average of all peat observations located within the peat-grid polygon;
  - b. If there were no peat observations within the peat-grid polygon, the depth was based upon the average of all peat observations located within the peat polygon;
  - c. If there were no peat observations within either the peat-grid polygon or the peat polygon, it was assigned the average properties of all peat observations within all “Deep Peat” polygons.
- 3) Each peat-grid polygon originally classified as “Peat at depth” was assigned a thickness based on:
  - a. The average of all peat observations within the peat-grid polygon;
  - b. If there were no peat observations within the peat-grid polygon, the depth was based upon the average of all peat bores located within the peat polygon;
- 4) For other peat-grid polygons, the average of all peat observations within the peat-grid polygon was used.

Figure 1 shows the estimated peat thicknesses in the 1980s.



**Figure 1 Estimated peat thicknesses at the time of the Lowland Peat Survey (1980s)**

In order to estimate the current peat thickness, it is necessary to account for the wastage that has occurred in the intervening years. Based on the literature reviewed in the earlier section, a range of typical wastage rates are given in Table 1 which encapsulate increasing wastage rates with increasing need for drainage and with increasing peat thickness. Data in Dawson et al. (2010) show an increase in the subsidence rate of 30 to 40% for peat deposits thicker than 1.2-1.3 m, which is consistent with the increases in Table 1.

However, there is also evidence within the literature to suggest that these average wastage rates might be modified by the properties of the soil profile; in particular the presence of low permeability layers within the profile which may maintain higher soil water contents in overlying layers and the nature of the peat itself. The subsistence rates reported in Dawson

et al. (2010) from soil surveying suggest that the presence of Fen Clay within the profile reduced subsidence from 1.19 to 1.05 cm/yr, a reduction of around 10%; whilst profiles with predominantly fibrous peats have a subsidence rate that is approximately 2% lower than humified peats.

Assuming that it is around 25 years since the fieldwork for the lowland peat survey, Figure 2 shows an estimate of the loss in peat thickness over this time, calculated by combining the estimated original peat thickness and peat wastage rates. The peat wastage rate have been based on the estimated rates in Table 1 for the current landcover in each peat-grid-landcover polygon (derived from a simplification of the Land Cover Map 2000 shown in Table 2), modified according to soil profile properties (presence of clay and/or predominantly fibrous peats). In some cases, the original peat thickness is insufficient to maintain 25 years of wastage at the thick peat wastage rate without the peat thickness reducing to less than 1m (thin peat). In these cases, the wastage has been calculated using *Thick peat* wastage rates until the peat reaches 1m thickness, and then the *Thin peat* wastage rates for the remaining years. It has been assumed that wastage occurs in all polygons which were considered to have any peat in the 1980s (Fig. 1), so that some areas are estimated to have no surviving peat. Furthermore it has been assumed that buried peats are wasting at the same rates as surface peat, given the uncertainty in how these peats are affected by drainage. Figure 3 shows the estimated current thickness of peat across Fenland.

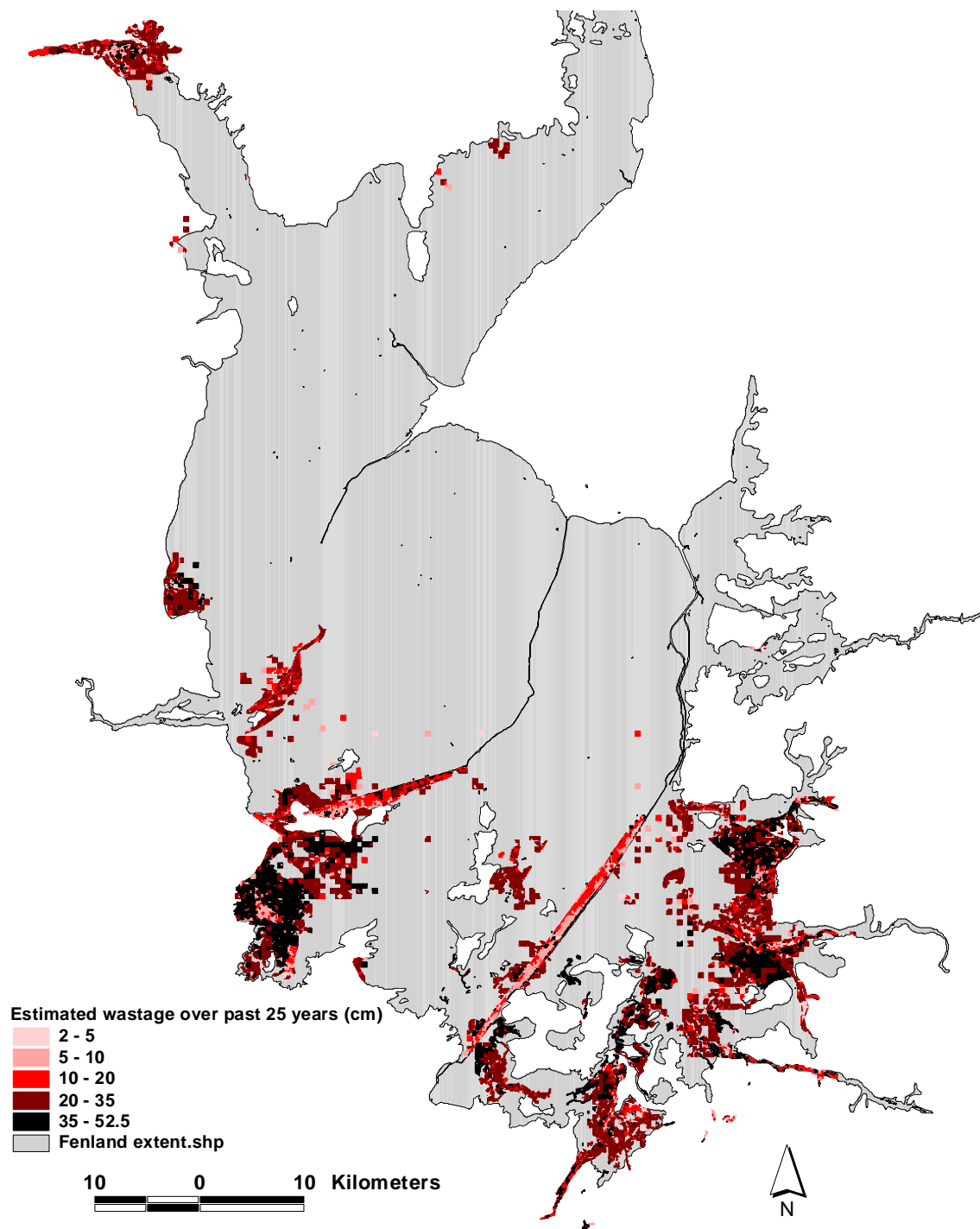
**Table 1 Estimated typical peat wastage rates (cm yr<sup>-1</sup>) according to landcover class (from Holman, 2009)**

Peat thickness	Land cover		
	Intensive arable (drained and cultivated)	Intensive grassland (drained)	Semi-natural (largely undrained)
Thick (> 1m)*	2.1	0.8	0.4
Thin (< 1 m)	1.3	0.7	0.1

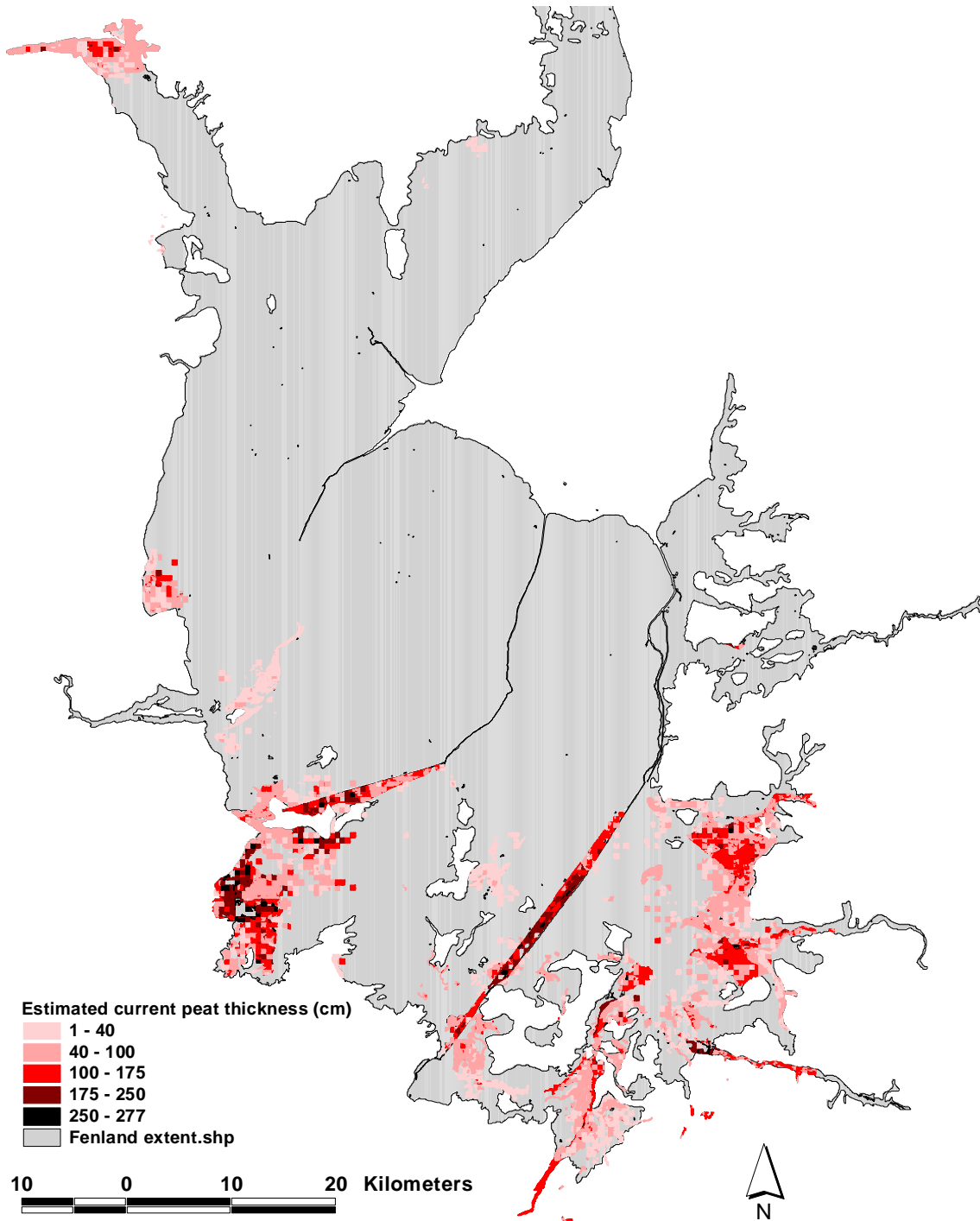
\* Referred to as 'Deep peat' in Holman (2009)

**Table 2 Relationship between LandCover Map 2000 classes and the simplified landcover classes used to estimate wastage rates**

Simplified landcover class	Constituent LCM2000 Level 2 classes (and codes)
Intensive arable (drained and cultivated)	Cereals (4.1) Horticulture/non-cereal (4.2) Not annual crop (4.3) Set-aside grass (5.2)
Intensive grassland (drained)	Improved grassland (5.1) Neutral grass (6.1) Calcareous grass (7.1) Sub-urban (17.1) Urban (17.2)
Semi-natural (largely undrained)	All remaining classes



**Figure 2** Estimated reduction in peat thickness over the past 25 years



**Figure 3 Estimated current thickness of peat across Fenland.**

### 3.2 Area of peat

Holman (2009) estimated the likely area of surviving peat, based on an analysis of the legends and reports accompanying the available soil maps to identify those soils either classified as Peat Soils (Major Group 10) or likely to contain peat layers within the profile. Given the continuing peat wastage since the original soil surveying, which in some cases was more than forty years ago, Holman (2009) assumed that all of the original areas of Thin peat (defined as having a combined thickness of organic horizons of less than 100 cm at the time of mapping) will have wasted to skirtland or peat remnant, but that areas of Deep Peat (defined as having a combined thickness of organic horizons of more than 100 cm) will still

currently be Deep Peat. The figures of surviving peat soils given in Holman (2009) were therefore based on the areas of the originally mapped *Deep Peat* soils.

In this study, the estimated current extent of peat from Holman (2009) has been re-evaluated in the light of the peat thickness results (Figure 3) from this study. Figure 3 has been re-classified to represent the current extent of 'Thick Peat', 'Thin peat' and 'Peat at depth' (Table 3).

**Table 3 Estimated current extent of peat soils within Fenland**

Peat class	Estimated area (ha)
Thick peat*	9,251
Thin peat	14,164
Peat at depth	8,102
Total	31,517

\* Referred to as 'Deep peat' in Holman (2009)

The spatial distribution of these soils and possible remnant or buried peats have been mapped by amalgamating the data within Figure 3 with the areas of 'Remnant Peat', 'Localised peat' and 'Possible peat at depth' from Holman (2009). Areas of 'Peat at depth' identified by Holman (2009) for which auger bore data were unavailable (and hence not captured in Figure 3) have been included in the 'Possible peat at depth' category. The resultant estimate of the current spatial distribution of peat is shown in Figure 4.

Not all of these surviving peats are found within the areas of the Internal Drainage Boards. As a result, the five Drainage Board Groups in Fenland contain an estimated combined 8,000 ha of surviving *Thick (>1m) peat*, around 12,500 ha of *Thin (<1m) peats*, and around 6,700 ha of *Peat at Depth* (Table 4). Within these, 3 Internal Drainage Districts (IDD) are estimated to contain over 50% of the surviving area of *Thick peat* - Southery and District IDD, Holmewood and District IDB and Whittlesey IDD. The Burnt Fen IDD, Haddenham Level DCA, Middle Fen and Mere IDD, Southery and District IDD, Waterbeach Level IDD, Whittlesey IDD, Witham 1st District IDD and Witham 3rd District IDD each contain more than an estimated 500 ha of *Thin peat*. The estimate surviving peat areas by IDD are given in Appendix 1.

**Table 4 Estimated current areas of peat within Drainage Board Groups**

Drainage Board Group	Peat class			Total area (ha)
	Thick peat	Thin peat	Peat at depth	
Middle Level	3,751	2,476	2,131	8,357
Nene	565	643	1,162	2,370
South Level	3,079	7,053	2,632	12,763
Tidal Witham	137	150	0	288
Welland	88	445	865	1,399
Witham	343	1,715	0	2,058
Total area (ha)	7,964	12,481	6,790	27,234

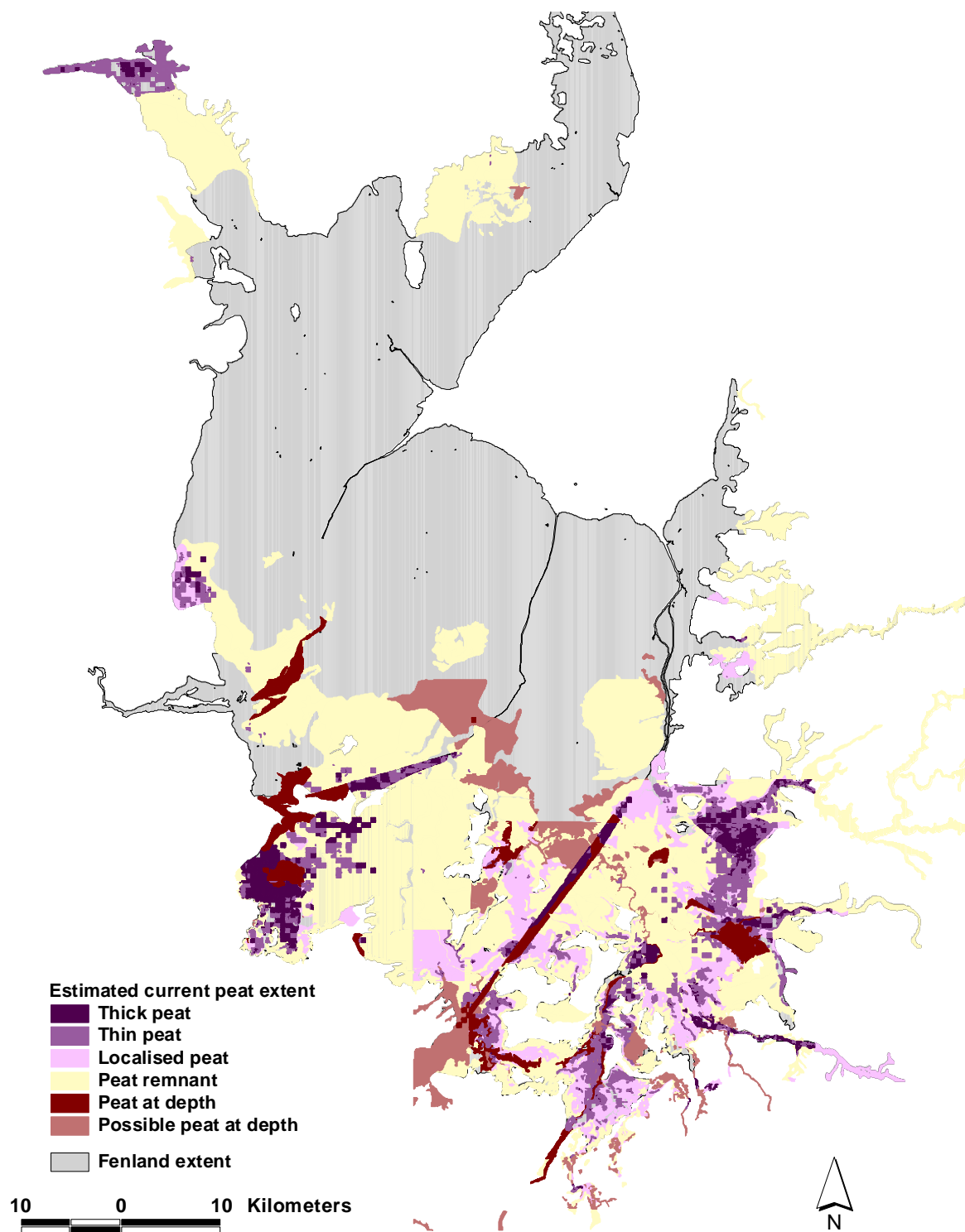


Figure 4 Revised estimated extent of current peat soils within Fenland

### 3.3 Carbon emissions from Fenland peats

#### 3.3.1 Methodology

The subsidence of peatlands refers to the loss of peat soil volume. The rate of subsidence (mm or cm per year) is a measure of the decrease in peat soil surface with time relative to a known datum (e.g. sea-level). Subsidence rates are usually estimated over long periods of

time (often decades) as seasonal short term surface variations, which are reversible, can induce non negligible errors.

The subsidence or wastage (i.e. loss of volume) of peat soils following drainage is due to the combined effect of several mechanisms. First, consolidation occurs when the groundwater level is lowered because the buoyant force of water is lost in the upper soil layers. The deeper layers below the water table which then have to bear an increased weight start to consolidate. Second, shrinkage occurs in the vadose (or unsaturated) zone above the water table due to the increase in soil water tension, especially at the surface where evapotranspiration is highest. Finally, mineralisation of soil organic carbon through biochemical processes can account for a large proportion of peat soil loss. Schothorst (1977), in studying Dutch peats, assessed that 28 % of the subsidence could be ascribed to consolidation, 20 % to irreversible shrinkage and 52 % to mineralisation. These results are in agreement with other findings, notably those of Armentano and Menges (1986) who estimate the contribution of mineralisation to total subsidence to vary between 33 and 67%.

In theory it is possible to calculate the amount of carbon lost through mineralisation for a series peat layers within a peat deposit providing the changes in layer thickness (i.e. peat volume), bulk density and in organic carbon fraction are known for each peat type. The mass balance for C states that the original mass of C is equal to the final mass added to that lost through mineralisation. Hence, the mass of carbon lost (kg) over the period considered is:

$$C_{loss} = \sum_k (\rho_{bik} f_{ocik} z_{ik} - \rho_{bfk} f_{ocfk} z_{fk}) \quad (1)$$

where  $\rho_b$ ,  $f_{oc}$  and  $z$  are the bulk density ( $\text{kg/m}^3$ ), the organic carbon fraction ( $\text{kg/kg}$ ) and the thickness of the peat layer (m)  $k$ , respectively. The subscript  $i$  and  $f$  refer to the initial and final values of these variables. In this approach the contribution to subsidence (changes in  $z$ ) of both consolidation and shrinkage (changes in bulk density) and mineralisation (loss of organic carbon) is considered.

Calculating carbon loss from peatlands using the above approach is only possible if the changes in bulk density, organic carbon content and layer thickness are known throughout the entire soil profile (i.e. for each peat type layer). These data are rarely available in practice however and alternative approaches have been proposed.

Commonly the estimation of C loss based on subsidence data is carried out by considering the surface peat layer because bulk density and organic matter or carbon content are often measured from surface samples. This however requires an estimate of the contribution of mineralisation to total subsidence because the approach is based on the latest available estimates of bulk density and carbon content and does not consider changes in these properties. The rate of carbon loss ( $\text{kg/yr}$ ) per unit surface area is estimated as:

$$C_{loss} = SF\rho_{bH}f_{ocH} \quad (2)$$

where  $\rho_{bH}$  and  $f_{ocH}$  are the bulk density ( $\text{kg/m}^3$ ) and the organic carbon fraction ( $\text{kg/kg}$ ) of the humified surface layer, respectively;  $F$  is the contribution of mineralisation to total subsidence (dimensionless) and  $S$  is the total rate of subsidence ( $\text{m/yr}$ ). A major source of uncertainty with this approach is the value of the fraction  $F$  which, as mentioned above, has been reported to vary between 0.33 and 0.67 (Armentano and Menges, 1986). Nevertheless, it is generally believed that the initial contribution of consolidation, which largely dominates the subsidence process following drainage, becomes stable after several years and that the rate of subsidence becomes relatively constant until a new lowering of the water levels in surrounding ditches is necessary. Hence some authors use a value of 0.7 for  $F$  (Kasimir-



Klemedtsson, 1997). This implies that the subsidence rates used to calculate C losses from mineralisation should be rates occurring several years (decades) after the commencement of drainage.

To circumvent this uncertainty we use the approach proposed by van den Akker et al. (2008). The main assumption made is that over time the thickness of the humified peat surface layer (drained layer) remains constant. Since this layer is drained it contributes to subsidence through mineralisation and shrinkage, but the above assumption means that the rate at which the underlying more fibrous peat layer is being degraded (humified) is equal to the subsidence rate. Also implicit in the above assumption is that the bulk density and the organic carbon fraction of the humified surface layer are not changing (in reality the mineral content of this layer will increase but the process is slow since the layer is generally already highly humified). Hence, the amount of C contained in this layer is constant over time. In other words, this layer is losing carbon at the same rate as it is gaining C through the mineralisation and humification of the underlying fibrous peat layer. Therefore the amount of carbon lost from this system is equivalent to that lost through the complete disappearance of a fibrous peat layer with a thickness equal to the subsidence and can simply be calculated using eq (1) noting that the only parameter changing with time is the thickness of the fibrous peat layer:

$$C_{loss} = S \rho_{bF} f_{ocF} \quad (3)$$

where  $\rho_{bF}$  and  $f_{ocF}$  are the bulk density (kg/m<sup>3</sup>) and the organic carbon fraction (kg/kg) of the semi-fibrous or fibrous subsurface layer, respectively; and  $S$  is the total rate of subsidence (m/yr).

Where the subsidence is greater than the thickness of the fibrous layers, the carbon loss is derived from the complete disappearance of the fibrous layers and the remaining subsidence from the humified layers:

$$C_{loss} = (z_F \rho_{bF} f_{ocF}) + ((S - z_F) \rho_{bH} f_{ocH}) \quad (4)$$

where  $\rho_{bH}$  and  $f_{ocH}$  are the bulk density (kg/m<sup>3</sup>) and the organic carbon fraction (kg/kg) of the humified subsurface layer, respectively, and  $z_F$  is the thickness of the semi-fibrous or fibrous subsurface layers.

The estimated  $C_{loss}$  can be used to calculate the contribution of mineralisation to total subsidence,  $F$ , by equating (2) and (3):

$$F = \frac{\rho_{bF} f_{ocF}}{\rho_{bH} f_{ocH}} \quad (5)$$

Based on the bulk density and organic carbon contents given in Table 5,  $F$  is around 0.88 for surface peats and 0.64 for buried peats

### 3.3.2 Annual volume loss or wastage

The estimated annual wastage has been calculated from the estimated reduction in peat thickness over the past 25 years (Figure 2) and the areas within the IDB boundaries. It is estimated that the peat has been wasting by approximately  $4.5 \times 10^6$  m<sup>3</sup>/yr (Table 5), equivalent to an average wastage rate of around 1.2 cm/yr. Of this, approximately 80% represents wastage of surface (thin and thick) peats, with only 20% from the uncertain wastage of buried peats.

**Table 5 Estimated annual volume loss of peat soils by peat class and IDB Group**

IDB Group	Estimated annual volume loss (m <sup>3</sup> /yr) from:			
	Thick peats	Thin peat	Peat at depth	All peats
Middle Level	803238	346948	256953	1407138
Nene	77015	147064	123831	347910
South Level	1003614	849201	376541	2229356
Tidal Witham	33653	49161	0	82815
Welland	35720	92552	99424	227696
Witham	48823	200923	0	249746
Total	2002063	1685849	856749	4544660

The six IDD with the greatest volume losses of more than 250x10<sup>3</sup> m<sup>3</sup>/yr were the Southery and District IDD, Whittlesey IDD, Holmewood and District IDB, Middle Fen and Mere IDD, Burnt Fen IDD and the North Level IDB.

### **3.3.3 Estimated carbon emissions from drained Fenland peat**

To calculate the carbon emissions associated with the above estimated wastage, the loss of peat thickness has been ascribed to the semi fibrous / fibrous and humified layers within the soil profile. Where the total original thickness of semi fibrous and fibrous peat was greater than the wastage, all of the wastage has been assumed to occur from the fibrous and semi fibrous layers (Equation 3). Where the total original thickness of semi fibrous and fibrous peat was less than the estimated wastage, the fibrous and semi fibrous layers have been assumed to have completely disappeared, and the remaining wastage has occurred from the humified layers (Equation 4).

Bulk density is not routinely measured within soil surveys but available data from organic horizons within peat soils below 100 m above sea level within the Land Information System at Cranfield University have been analysed (Table 6). These values differ from the fixed bulk density value of 480 kg m<sup>-3</sup> used by Holman (2009), which was taken from Milne et al. (2006).

Thickness-weighted average organic carbon contents have been determined for humified and fibrous or semi-fibrous horizons for peat and buried peat soils (Table 6), based on analysis of published analytical data for organic horizons within Fenland soils in Hodge and Seale (1966), Seale (1975a, b), Robson (1985), Seale and Hodge (1976), Burton and Seale (1981). Data for Peat soils are predominantly from Adventurers', Turbary Moor and Prickwillow series, while the buried peat horizons are mostly from profiles of Willingham, Midelney, Dowels and Padney series.

**Table 6 Average organic carbon contents and bulk density for Fenland peat horizons**

	Humified horizons	Fibrous or semi-fibrous horizons
Organic Carbon content (%)		
Within Thin and Deep Peat soils	27	44
Within buried peat soils	33	39
Bulk density (kg m <sup>-3</sup> )		
All peat soils	400	215

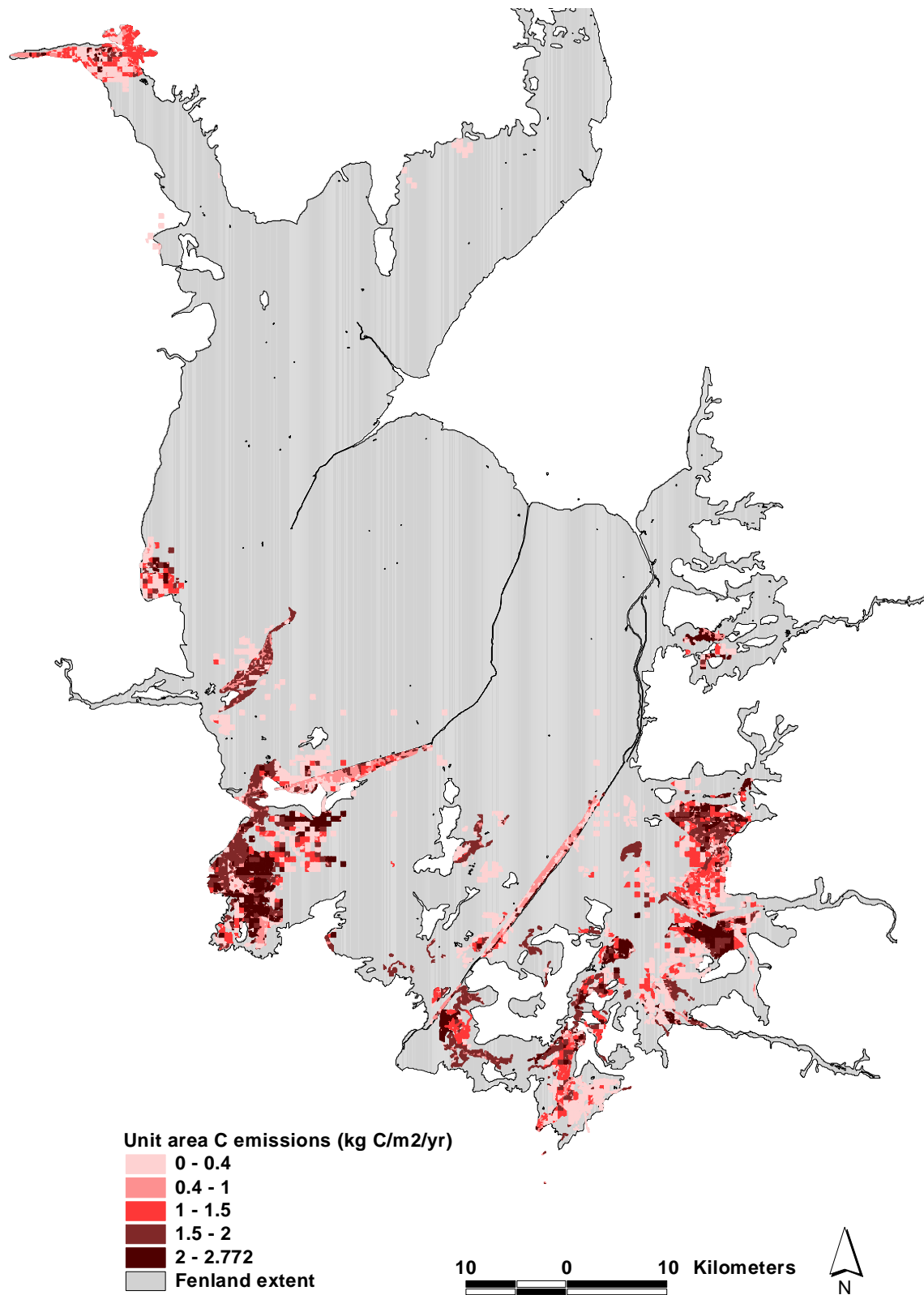
Based on the above values of wastage, bulk density and organic carbon content, the carbon emissions from Fenland peat wastage within the IDD within the period from the 1980s to the present is estimated at approximately  $5 \times 10^8$  kg C/yr or 0.5 Tg C/yr, of which about 80% comes from surface (thin and thick) peats (Table 7). With the smaller current area of surviving peat, the current annual emissions are estimated at around 0.4 Tg C/yr within the IDDs, of which about 70% comes from surface (thin and thick) peats (Table 7). Figure 5 shows the current annual C emissions per unit area of peat within the IDDs, for areas of both surface and buried peat.

**Table 7 Estimated C emissions from Fenland peats by IDB Group**

IDB Group	Estimated average 1980s to present C emissions (kg/yr)			
	Thick peat	Thin peat	Peat at depth	Total
Middle Level	82193083	36896290	26272774	145362146
Nene	7587003	15734735	13723545	37045283
South Level	101880144	90852826	48370436	241103407
Tidal Witham	3479958	5309425	0	8789383
Welland	3835083	9969135	12366078	26170296
Witham	5009351	20755031	0	25764382
Grand Total	203,984,622	179,517,441	100,732,833	484,234,896

IDB Group	Estimated current C emissions (kg/yr)			
	Thick peat	Thin peat	Peat at depth	Grand Total
Middle Level	60096638	35450820	30658663	126206121
Nene	3968132	7073946	14438099	25480177
South Level	44645199	96680849	49019021	190345069
Tidal Witham	2442262	1879155	0	4321417
Welland	1174428	5835809	12064214	19074451
Witham	3343542	16067545	0	19411086
Grand Total	115,670,201	162,988,123	106,179,997	384,838,320



**Figure 5** Estimate current annual C emissions per unit area (kg C/m<sup>2</sup>/yr) due to peat wastage within the IDD.

### 3.4 Carbon storage within the peat soils in Fenland

The carbon storage within the peat has been estimated from:

$$\text{Carbon mass (kg)} = (V_h \times \rho_h \times (\text{OC}_h/100)) + (V_f \times \rho_f \times (\text{OC}_f/100))$$

Where V is the volume of peat,  $\rho$  is the bulk density and OC is the soil organic carbon content (%), and the subscripts  $_h$  and  $_f$  refer to the humified and semi-fibrous/fibrous proportions of the peat thickness.

The estimated peat volume of the humified and semi-fibrous/fibrous proportions of the current peat thickness have been estimated from the area, thickness and relative proportions of humified and semi-fibrous/fibrous peat of each *Thick peat*, *Thin Peat* and *Peat at Depth* polygon in Fig. 4.

Based on the above assumptions and simplifications, the estimate carbon storage within the peat of Fenland at the time of the Lowland Peat Survey was estimated at around 53 Tg, with around 46 Tg of this being within the areas of the IDD.

With wastage, this has reduced to an estimated current total stock of around 37 Tg of carbon held within the peats of Fenland, which is slightly lower than that estimated by Holman (2009). Within the smaller IDB area, the estimated current carbon storage is slightly lower at around 32 Tg of carbon, with over 80% of this resource being within the Middle Level and South Level IDB Groups. 5 IDDs each containing more than 5% of the total resource (Table 6).

**Table 6 Estimated remaining carbon resources within the top 5 Internal Drainage Districts**

Internal Drainage Districts	Estimated carbon resource (x 10 <sup>6</sup> kg)	Percentage of total C resource within IDB areas
Southery and District IDD	4386	13.7
Whittlesey IDD	4068	12.8
Holmewood and District IDB	4063	12.7
Hundred Foot Washes IDD	2396	7.5
Middle Fen and Mere IDD	1669	5.2

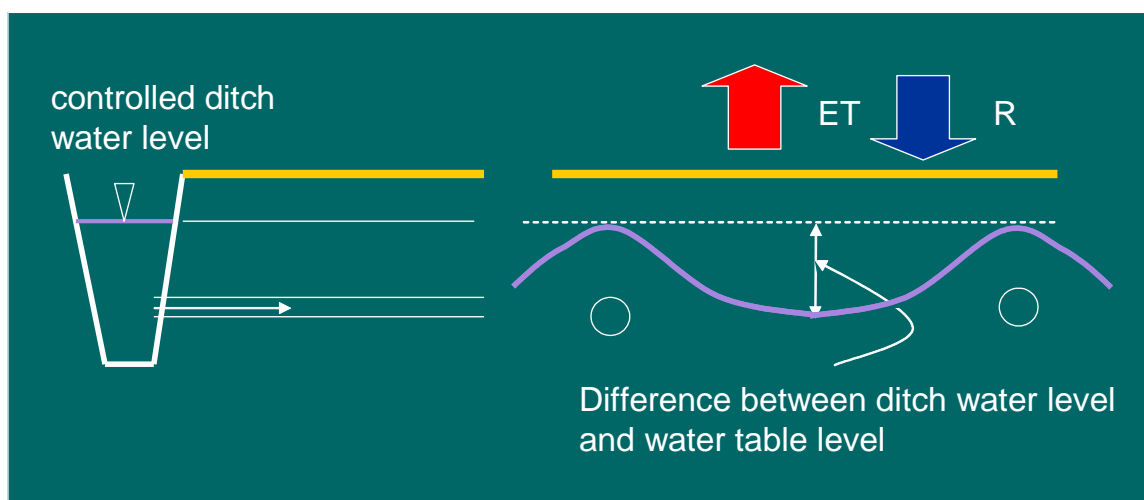
It must be recognised that there is still considerable uncertainty in these estimates, given the uncertainties in wastage rates and peat properties (bulk density and organic carbon content).

## 4 Modelling of peat water tables and their influence on C emissions

### 4.1 Introduction

In a drained or sub-irrigated field, the water table depth is not constant across the field. In a sub-irrigated field (i.e. one in which the water level in the ditches is maintained at a high level to facilitate the movement of water from the ditch into the soil profile) this depth is lowest at the ditch or the sub-irrigation pipes in the summer and highest mid-way between two parallel ditches. The water table depth depends on the rate at which soil water can be recharged from the ditches in order to offset losses due to evapotranspiration and deep percolation (Figure 6)

The water table depth in the field therefore depends on the ditch water regime, climate and soil hydraulic properties (in particular the saturated hydraulic conductivity and the drainable porosity) as well as depth of the ditches and ditch spacing.



**Figure 6 Schematic diagram of the relationship between watertable depth and ditch water levels in a sub-irrigated field**

### 4.2 Methodology

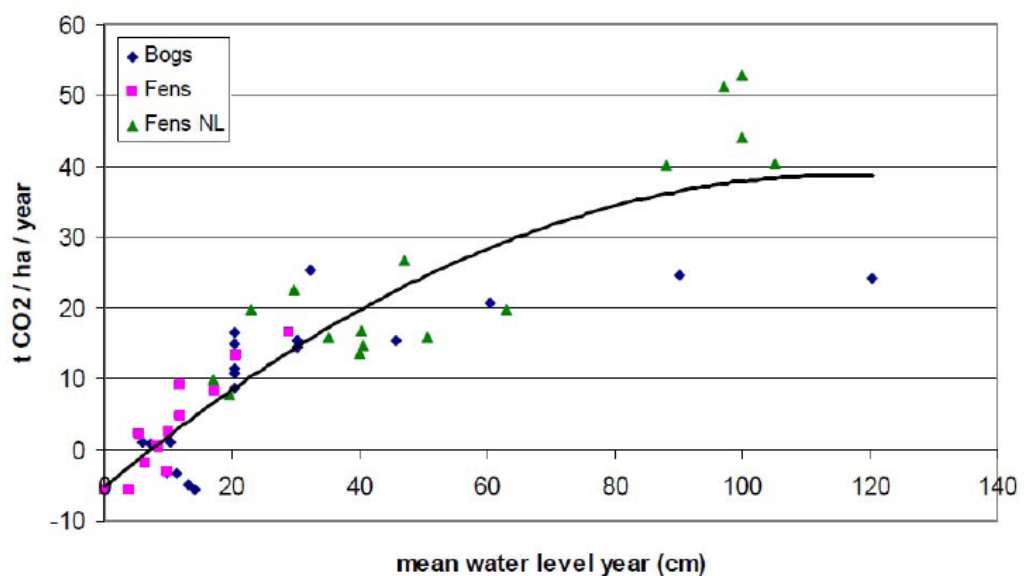
The variation in mid-drain (or mid-field) water table levels has been modelled as function of ditch water regime using the analytical model presented in Kechavarzi et al. (2007). This model has previously been successfully used to simulate the watertable within the drained and grazed peat soils at West Sedgemoor Fen in the Somerset Levels and Moors and the intensively drained and cultivated peat soils at Methwold Fen, in the north-eastern part of Fenland (52°31.52'N 0°28.16'E). In this study the model has been set-up using:

- Peat hydraulic properties - the hydraulic properties of the peats studied at Methwold Fens and presented in Kechavarzi et al. (2010) and Dawson et al. (2010) have been used.
- Ditch spacing – the model has been set-up to simulate a range of different ditch spacings (200, 150, 100, 80, 50, 30 and 10m). In addition, a baseline sub-irrigation spacing of 20m (as observed in the cultivated fields at Methwold Fens) has been used
- Ditch water regime - a baseline simulation of ditch water levels at 0.5m below soil surface all year round (as observed at Methwold Fens) has been augmented by simulating two hypothetical ditch water regimes:
  - Ditch-full in the autumn and winter months (flooded) but with ditch water at 0.3m below the soil surface level in the spring and summer months;

- Ditches full all year.
- Climate – data on daily precipitation and reference potential evapotranspiration for the period 1975-2005 has been analysed to select two years for study - 1990 (as the driest year within the data) and 2004 (the wettest).
- Peat depth - a peat depth of 2m has been assumed.

For each of the combinations, the model has been used to simulate the mid-drain watertable levels over the 12 month period. The relationship proposed by Verhagen et al. (2009) between mean yearly water table levels and CO<sub>2</sub> emissions (Figure 7) has then been used to estimate CO<sub>2</sub> emissions for the different scenarios.

**Note: the water table levels obtained with the model are the mid-drain levels and therefore the lowest within a field. The CO<sub>2</sub> emission values calculated are therefore the upper range of the true field emissions and should be treated with caution.**



**Figure 7 The relationship between mean water level below ground surface and annual CO<sub>2</sub> fluxes from peatlands in mainland Western Europe (Verhagen et al. 2009)**

## 4.3 Results

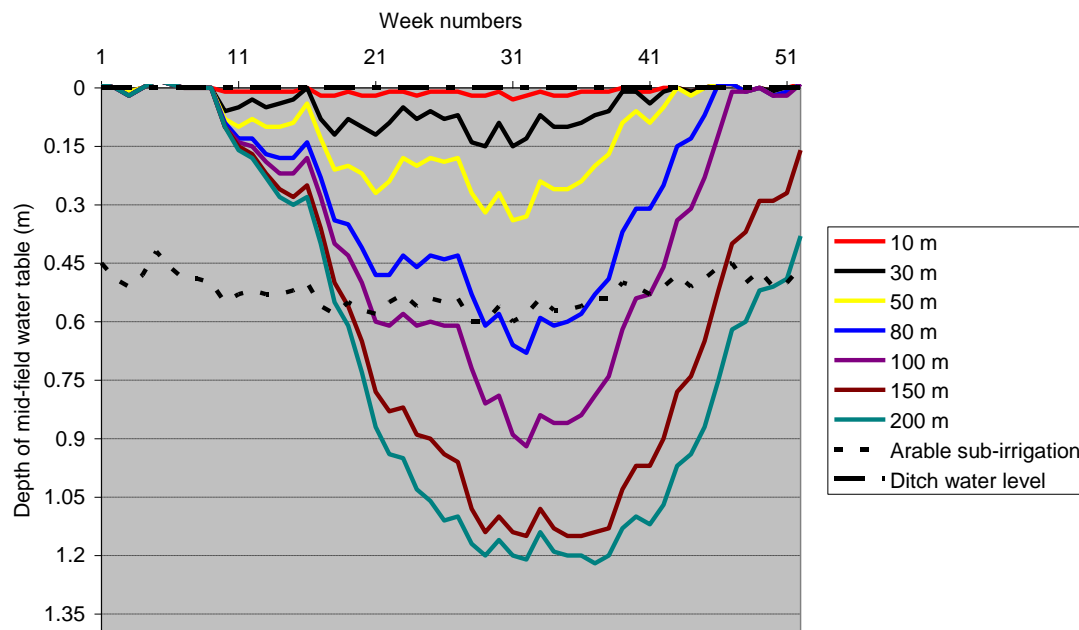
### 4.3.1 Effect of ditch spacing on mid-drain water table depth

Figure 8 shows the simulated mid-field watertable depth when ditches are maintained full in the dry year of 1990, for a range of ditch spacings. Also shown is the simulated baseline watertable for the drained field with 20m ditch spacing and a ditch water level that is 0.5 m below field level to provide sub-irrigation. The figure shows that:

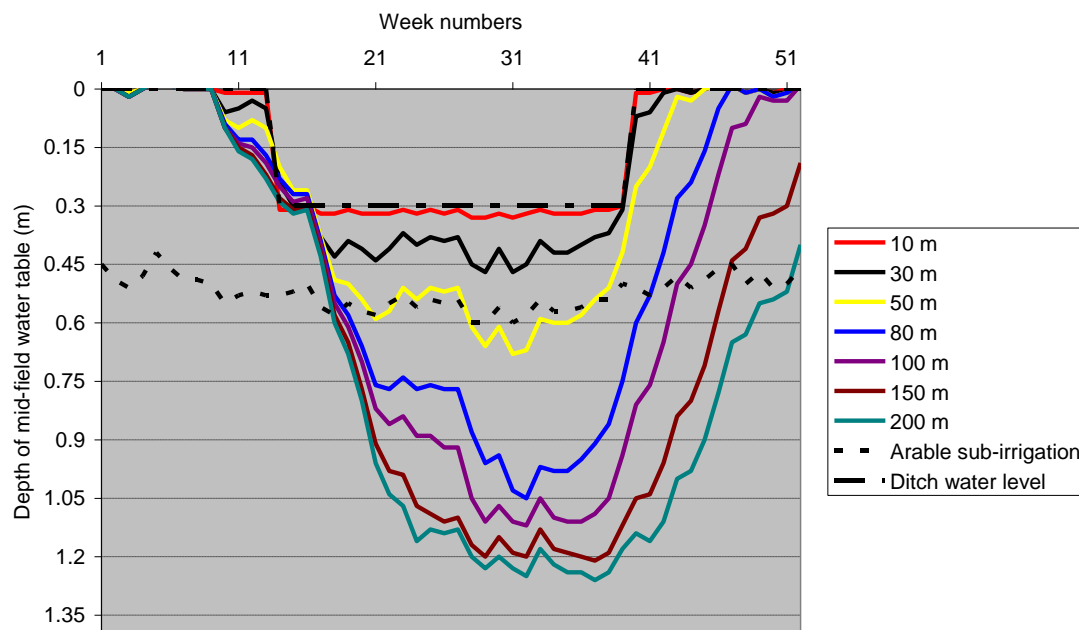
- Even if the ditches are full, mid-field water table can reach 1.2m depth for large spacings (200, 150) in the summer in a very dry year.
- Mid-field summer water table depth starts to reduce for a drain spacing of 100m, allowing better control of the water table which becomes higher than that of the conventional sub-irrigated field in the summer for spacings of less than 80 m.
- Flooded conditions in such a dry year are only achieved for spacing as low as 10m.

Figure 9 shows the simulated mid-field watertable depth in 1990, but with the seasonally varying ditch water levels (upper dashed black line). This figure shows that:

- At 150-200m spacing, summer water table levels are as low as for the full ditches conditions showing that evapo-transpiration dominates the watertable response and that the ditch regime exerts no effective control of the mid-field water table.
- At other spacing the water table depth is deeper than for full ditch conditions in the spring-summer because of the drained conditions (i.e. 0.3m ditch levels).
- Full control of the water table (mid-field) is only achieved for spacing of 10-30m.



**Figure 8 Effect of ditch spacing on simulated mid-field watertable depths in a dry year(1990) when ditch water levels are constantly maintained at the ditch-full level.**

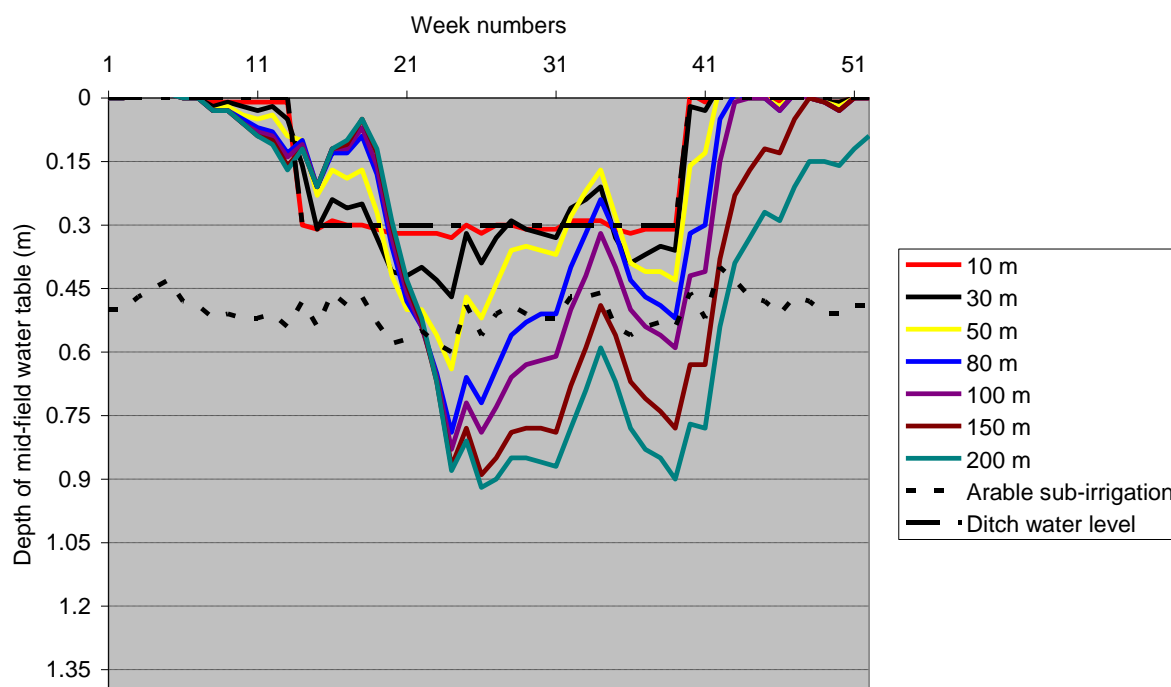




**Figure 9 Effect of ditch spacing on simulated mid-field watertable depths in a dry year(1990) when ditch water levels are seasonally managed (ditch-full level for winter and spring; 0.3 m below field level during summer and autumn)**

#### 4.3.2 Effect of weather on mid-drain water table depth

Figure 10 shows the simulated mid-field watertable depth in 2004 (the wet year), with the seasonally varying ditch water level (upper dashed black line). In such a wet year (especially summer), water table levels are much higher and exceed the imposed 0.3m ditch water level for some rainfall events in the summer for ditch spacings as high as 80m.



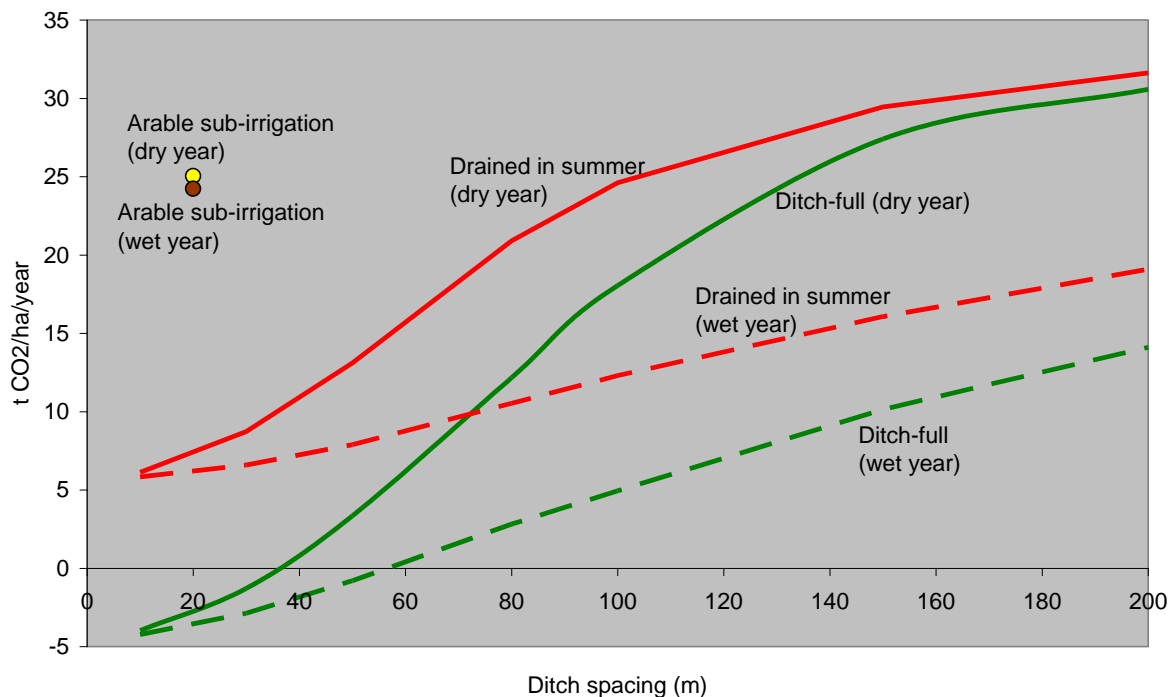
**Figure 9 Effect of ditch spacing on simulated mid-field watertable depths in a wet year(2004) when ditch water levels are seasonally managed (ditch-full level for winter and spring; 0.3 m below field level during summer and autumn)**

#### 4.3.3 Effect of drain spacing, drain water level and weather on mid-field C emissions

Combining the simulated annual average water table depth from the above Figures with the Veerhagen et al. (2009) relationship shown in Fig. 7, the mid-drain emissions of C associated with the different water management regimes can be estimated. A number of factors can be observed:

- In the arable system, there is little difference between the mid-field emissions in wet and dry years, because of the very good control of watertable levels;
- Within both of the high water level management regimes, differences as great as approx 15 t CO<sub>2</sub>/ha/year are observed between dry and wet year for ditch spacings of greater than around 100m;
- On a wet year the arable system emits more than both high water level management regimes irrespective of their drain spacing, but in a dry year mid-field emissions associated with both high water level management regimes with drain spacing of 100m and above result in higher emissions than the arable system;
- For full ditches and spacing lower than 50m, C emissions are much reduced compared to the arable system;

- Full ditches with large spacing have no effect on reducing emissions whereas full ditches with small spacing can result in shallow mid-field watertables and carbon sequestration;
- Lowering the ditch water levels to 0.3m in the summer results in large C emissions above 50m spacing.



**Figure 11** Estimated mid-field CO<sub>2</sub> emissions, calculated from the mean yearly water table level for the two ditch regimes, as a function of spacing for 1990 and 2004. The dots represent emissions from the arable field (20m spacing).

#### 4.3.4 Influence of model input parameters

The previous sections investigated the effects of drainage management (ditch spacing and water levels) on mid-field watertables, for a fixed set of physical conditions based on Methwold Fen. To assess the sensitivity of the mid-field watertables to changes in the physical properties of a site, the influence of changes in drainable porosity, saturated hydraulic conductivity, peat thickness and ditch depth were examined for the dry year of 1990 with seasonally managed ditch water levels (ditch-full level for winter and spring; 0.3 m below field level during summer and autumn) and a fixed ditch spacing of 50m (Table 7).

The parameters influencing water table depth the greatest are the hydraulic conductivity and the peat thickness. Both these parameters affect the transmissivity of the peat or the overall flow rate from and to the ditches which is the determinant of water table dynamics. This suggests that accurate knowledge of the hydraulic conductivity is needed. However, this is a soil property which can be difficult to measure in peat soils. It will also vary with depth depending on the degree of peat humification (Kechavarzi et al., 2010). Although it is possible to use a weighted average hydraulic conductivity if the conductivity of the individual peat layers is known, horizontal flow will dominate in the layers with the highest conductivity. Field methods such as the auger-hole method which gives the average conductivity of the layers might be preferable to laboratory method carried out on small samples.

**Table 7 Influence of soil hydraulic properties, peat thickness and ditch depth on mean yearly mid-field water table levels and CO<sub>2</sub> emissions**

Parameters	% change and value	Mean water table depth (cm)	CO <sub>2</sub> emissions (t CO <sub>2</sub> /ha/year)	% change in CO <sub>2</sub> emission
Benchmark (50m ditch spacing; seasonally varying water level)	No change	27.7	13.1	-
Peat thickness	-25% (from 2 to 1.5m)	31.0	14.9	+12.0
Saturated conductivity	+100% (from 1.78 to 3.56 m/d)	21.8	9.7	-35.0
Saturated conductivity	-50% (from 1.78 to 0.89 m/d)	38.2	18.6	+29.7
Drainable porosity	-33% (from 0.15 to 0.10)	27.9	13.2	+0.7
Drainable porosity	+33% (from 0.15 to 0.20)	27.4	13.0	-1.2
Ditch depth	from 0.7 to 0.5m	28.1	13.3	+1.6
Ditch depth	from 0.7 to 1m	27.2	12.8	-2.0

#### 4.4 Discussion regarding water management regimes for C sequestration

The results of the mid-field water table modelling have demonstrated that maintaining high water tables within peat fields is not simply a function of having high ditch water levels. To achieve high water tables across a field requires the drainage design (particularly the spacing of drains) to take into account the soil properties- the soil properties are important in determining how easily water can move from the ditches into the field to compensate for evapo-transpiration, and how much the watertable falls/rises for a given amount of loss or gain of water.

For the peat properties used, a ditch spacing of no more than around 30m would be required for the mid-field watertable position to be sufficiently high in a dry year (even with the ditches at bank-full) to not be a net emitter of C. In contrast, the mid-field area will be a net C emitter for all drain spacings when there is a seasonally-varying water level regime as allowed within agri-environmental schemes. As shown above, this will vary depending on the peat properties, notably the hydraulic conductivity. Higher hydraulic conductivity and deeper peat will have a higher transmissivity which will result in higher water table levels and lower mineralisation rates for a given ditch spacing. This suggests that degraded thin peat deposits would be more difficult to rewet since a higher degree of humification usually results in a lower conductivity (Kechavarzi et al, 2010). It should be noted that the model does not consider changes to the hydraulic properties of the peat following prolonged drainage such as shrinkage and changes to its wettability. These will have a pronounced hysteretic effect on the hydraulic properties resulting in a reduction in conductivity and water retention which could both result in lower water table levels.

In addition, it must be acknowledged that the mid-field (or mid-drain) water table levels simulated by the model represent the lowest summer watertable levels within a field, and so the CO<sub>2</sub> emission values calculated represent the upper range of the true field emissions. However, they are lower than that calculated with bulk density in the previous section which is either because the relationship in Fig. 7 is derived for Western European peats with lower BD or that a different methodology such as flux chambers was used. Furthermore, the emission factors presented are obtained from mean yearly water table levels using an

empirical relationship developed with data from temperate regions. For a given water depth, peat mineralisation and CO<sub>2</sub> emission will vary seasonally and be influenced by temperature among other environmental factors. Hence, the data presented here provide a valuable analysis of the relative influence of soil properties, ditch water regimes and climate on water table levels and peat mineralisation but the intrinsic values of CO<sub>2</sub> emissions need to be treated with caution.

## 5 Conclusions

An reappraisal has been carried out of the current extent and wastage of peat in the Fenland of East Anglia. Data for 1823 soil profiles were collated to provide observed data on the total combined thickness of peat or peaty layers within the profile, total combined thickness of humified peat within the profile, presence of low permeability layers below 40 cm depth within the soil profile and whether the peat or peaty layers were buried below at least 40 cm of mineral surface layers. These were combined with the peat map produced by Holman (2009) and estimates of peat wastage based on land use and peat properties to produce a revised estimate of the spatial extent of peat within Fenland. It is estimated that there are around 20,000 ha of surviving peat soils, predominantly within the South Level, Middle Level, Witham and Nene Internal Drainage Board areas, and a further area of around 7,000 ha of peat buried beneath mineral surface layers.

It is estimated that the carbon storage within the peat of Fenland at the time of the Lowland Peat Survey was around 53 Tg, with around 46 Tg of this being within the areas of the IDD. It is estimated that the Fenland peats within the IDB boundaries have been wasting by approximately  $4.5 \times 10^6 \text{ m}^3/\text{yr}$ , equivalent to an average wastage rate of around 1.2 cm/yr, which represents approximately  $5 \times 10^8 \text{ kg C/yr}$  or 0.5 Tg C/yr. Of this, approximately 80% represents wastage of surface (thin and thick) peats, with only 20% from the uncertain wastage of buried peats. With the smaller current area of surviving peat, the current annual emissions are estimated at around 0.4 Tg C/yr within the IDDs, of which about 70% comes from surface (thin and thick) peats.

Wastage has reduced the estimated current total carbon stock held within the peats of Fenland to around 37 Tg, which is slightly lower than that estimated by Holman (2009). Within the smaller IDB area, the estimated current carbon storage is slightly lower at around 32 Tg of carbon, with over 80% of this resource being within the Middle Level and South Level IDB Groups.

The mid-field water table modelling has demonstrated that maintaining high ditch water levels may not be sufficient to keep high water tables within peat fields. To achieve high water tables across a field requires the drainage design (particularly the spacing of drains) to take into account the soil properties- the soil properties are important in determining how easily water can move from the ditches into the field to compensate for evapo-transpiration, and how much the watertable falls/rises for a given amount of loss or gain of water.

**Table 7 Summary of results by Internal Drainage Board District**

IDB District	Estimated peat area (ha) <sup>1</sup>	% of deep peat	IDB District area (ha)	Annual volume loss (m <sup>3</sup> /yr) <sup>2</sup>	C emissions (x10 <sup>3</sup> kg/yr) <sup>2</sup>	% of total IDD emissions
Benwick IDD	2	0.00	2124	192	21	0.0
Black Sluice IDD	284	1.72	50399	59775	6301	1.3
Burnt Fen IDD	1388	0.75	6493	284155	32923	6.8
Cawdle Fen IDD	129	0.13	802	18538	2212	0.5
Conington & Holme IDD	256	0.80	1153	54335	5700	1.2
Downham & Stow Bardolph IDD	0	0.00	2910	1800	194	0.0
Dryslides IDD	146	0.00	320	18454	2215	0.5
East of Ouse, Polver & Nar IDD	452	4.33	7666	75646	8108	1.7
Feldale IDD	10	0.00	369	5977	645	0.1
Haddenham Level DCA	1388	0.42	3866	187324	22076	4.6
Holmewood & District IDB	2103	17.58	2643	352746	34444	7.1
Hundred Foot Washes IDD	1080	4.43	1550	72218	7409	1.5
Lakenheath IDD	618	1.54	1949	127801	14293	3.0
Littleport & Downham IDD	467	0.22	11935	102190	11276	2.3
Manea & Welney DCA	14	0.04	2826	10179	1096	0.2
March & Whittlesey IDD	0	0.00	3437	2375	256	0.1
March East IDD	295	0.00	2804	56098	6721	1.4
Middle Fen & Mere IDD	1390	4.82	8248	288598	30236	6.2
Mildenhall IDD	405	1.07	3435	74813	7696	1.6
Nene Washlands DCA	1082	5.36	1949	97503	9711	2.0
North Level IDB	1288	1.73	32295	250407	27334	5.6
Northwold IDD	133	0.38	258	16960	1716	0.4
Old West DD	174	0.00	4701	23863	3001	0.6
Padnal & Waterden IDD	474	3.52	1236	82750	8853	1.8
Ramsey 1st IDD	83	0.30	1510	10963	1310	0.3
Ramsey 4th IDD	250	1.07	1534	46163	4739	1.0
Ramsey, Upwood & Great Raveley IDD	223	1.68	1315	40622	4156	0.9
Ransonmoor DCA	2	0.00	1420	212	23	0.0
Sawtry IDD	277	1.59	1660	33581	3521	0.7
Southery & District IDD	4287	21.00	9122	633762	64685	13.4
Stoke Ferry IDD	85	0.07	2078	21637	2279	0.5
Sutton & Mepal IDD	282	0.75	4369	60265	6380	1.3
Swaffham IDD	473	0.30	5511	152230	16426	3.4
The Curf & Wimblington Combined IDB	10	0.00	2486	29867	3232	0.7
Upper Witham IDD	0	0.00	25001	20	2	0.0
Upwell IDD	24	0.23	4468	2079	204	0.0
Waldersley IDD	4	0.00	2239	7689	802	0.2
Warboys, Somersham & Pidley IDD	65	0.02	4818	11618	1154	0.2
Waterbeach Level IDD	899	0.11	2738	137291	15130	3.1
Welland & Deepings IDD	1399	1.11	33742	227696	26170	5.4
Whittlesey IDD	2777	14.82	8431	514213	53211	11.0
Witham 1st District IDD	755	2.34	17249	116415	12070	2.5
Witham 3rd District IDD	1303	1.97	16237	133312	13693	2.8
Witham 4th District IDD	4	0.00	41082	23040	2488	0.5
Woodwalton DCA	455	3.77	690	77291	8123	1.7
<b>Grand Total</b>	<b>27234</b>	<b>100</b>		<b>4544660</b>	<b>484235</b>	<b>100</b>

<sup>1</sup> Represents the combined area of *Thick peat*, *Thin peat* and *Peat at depth*<sup>2</sup> Over the period from the mid-1980s to present

## 6 Recommendations for further work

The work reported represents revised appraisal of the extent and wastage of peat in the Fenland of East Anglia. The work has still required a number of assumptions and simplifications to be made. A number of recommendations for further work are therefore made:

- 1) The spatial soil data for the Fenland area is between 40 and 25 years old, whilst the peat inventory data was collected around 25 years ago. Given the continuing wastage of peat soils and the uncertainty in these rates, it is recommended that an update of the Lowland Peat Survey inventory is carried out to further improve the quantification of the current extent and depth of peat soils in the area;
- 2) There are limited data on the organic carbon content and bulk density of lowland peat soils, yet these data are critical for the quantification of carbon stores in the peat and emissions of carbon-based greenhouse gases from peat soils. It is recommended that an improved data set is collected- at the time of writing a Defra-funded research project to improve the understanding of peat bulk density is proposed.
- 3) It is likely that the lowland peat survey failed to capture all areas of soils with peat starting below 40 cm. Furthermore, the extent to which these buried peats are affected by wastage is uncertain. It is recommended that further studies are carried out to ascertain the carbon storage within, and emissions from, these peat layers.
- 4) Although the model used in this study has been validated against field data (Kechavarzi et al., 2007), further improvements would be beneficial. Modifications should include the calculation of a mean field water table depth rather than that of the mid-drain depth which is the maximum depth in the field. In addition subsidence should be added to the model. The effect of temperature should also be investigated. Model results for more complex scenarios such as in highly layered soils should be compared to simulations carried out with numerical models such as Hydrus 2D and compared to field data. A study on the long term influence of climate change in which dynamic changes in peat hydraulic properties and peat deposit thickness due to ongoing mineralisation are included would be useful in the design of long-term water management strategies aimed at peat conservation

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## Appendix 1 Estimated current peat extent by Internal Drainage District

Internal Drainage District	Area (ha) by peat class			Total area (ha)
	Thick peat (> 1m)	Peat at depth	Thin peat (< 1 m)	
Benwick IDD	0	2	0	2
Black Sluice IDD	137	147	0	284
Burnt Fen IDD	60	601	728	1388
Cawdle Fen IDD	10	38	81	129
Conington and Holme IDD	64	190	2	256
Drysidles IDD	0	0	146	146
East of Ouse, Polver and Nar IDD	345	107	0	452
Feldale IDD	0	10	0	10
Haddenham Level DCA	33	540	815	1388
Holmewood and District IDB	1400	213	490	2103
Hundred Foot Washes IDD	353	60	666	1080
Lakenheath IDD	122	203	293	618
Littleport and Downham IDD	18	257	192	467
Manea and Welney DCA	3	11	0	14
March East IDD	0	36	259	295
Middle Fen and Mere IDD	384	952	54	1390
Mildenhall IDD	86	320	0	405
Nene Washlands DCA	427	356	299	1082
North Level IDB	138	287	863	1288
Northwold IDD	31	102	0	133
Old West DD	0	25	149	174
Padnal and Waterden IDD	280	167	27	474
Ramsey 1st IDD	24	9	49	83
Ramsey 4th IDD	85	155	10	250
Ramsey, Upwood and Great Raveley IDD	134	89	0	223
Ransonmoor DCA	0	2	0	2
Sawtry IDD	127	149	1	277
Southery and District IDD	1672	2556	59	4287
Stoke Ferry IDD	6	80	0	85
Sutton and Mepal IDD	59	218	4	282
Swaffham IDD	24	410	38	473
The Curf and Wimblington Combined IDB	0	6	4	10
Upwell IDD	18	5	0	24
Waldersley IDD	0	4	0	4
Warboys, Somersham and Pidley IDD	2	63	0	65
Waterbeach Level IDD	9	695	196	899
Welland and Deepings IDD	88	445	865	1399
Whittlesey IDD	1181	1097	499	2777
Witham 1st District IDD	186	569	0	755
Witham 3rd District IDD	157	1146	0	1303
Witham 4th District IDD	0	4	0	4
Woodwalton DCA	300	155	0	455
Grand Total	7964	12,481	6790	27,234

## Appendix 2 Estimated volume wastage, Carbon stores, emissions by IDD

Internal Drainage District	Past (1980s) situation*			Current situation*	
	Mass of C in peat (x10 <sup>6</sup> kg C)	Annual volume loss (m <sup>3</sup> /yr)	C emissions (x10 <sup>3</sup> kg C/yr)	Mass of C in peat (x10 <sup>6</sup> kg C)	C emissions (x10 <sup>3</sup> kg C/yr)
Benwick IDD	1.3	192	21	0.8	21
Black Sluice IDD	495.0	59775	6301	315.3	4318
Burnt Fen IDD	2443.9	284155	32923	1515.9	25879
Cawdle Fen IDD	250.9	18538	2212	193.0	2164
Conington and Holme IDD	405.4	54335	5700	231.4	4235
Downham and Stow Bardolph IDD	4.9	1800	194	0.0	0
Drysidles IDD	193.0	18454	2215	137.7	2325
East of Ouse, Polver and Nar IDD	955.2	75646	8108	737.7	7166
Feldale IDD	31.2	5977	645	8.3	138
Haddenham Level DCA	1589.5	187324	22076	1033.2	22313
Holmewood and District IDB	4945.6	352746	34444	4062.3	36333
Hundred Foot Washes IDD	2594.0	72218	7409	2396.5	7252
Lakenheath IDD	1286.1	127801	14293	867.9	11020
Littleport and Downham IDD	744.5	102190	11276	414.9	7397
Manea and Welney DCA	41.8	10179	1096	11.2	113
March and Whittlesey IDD	10.3	2375	256	0.0	0
March East IDD	294.4	56098	6721	99.1	4328
Middle Fen and Mere IDD	2531.3	288598	30236	1669.5	21087
Mildenhall IDD	664.6	74813	7696	430.9	5657
Nene Washlands DCA	1809.2	97503	9711	1542.7	8931
North Level IDB	2177.7	250407	27334	1347.1	16549
Northwold IDD	168.1	16960	1716	125.1	1787
Old West DD	132.2	23863	3001	57.2	3040
Padnal and Waterden IDD	856.8	82750	8853	611.3	8091
Ramsey 1st IDD	85.4	10963	1310	52.6	1303
Ramsey 4th IDD	392.6	46163	4739	260.5	3839
Ramsey, Upwood and Great Raveley IDD	406.5	40622	4156	296.7	3831
Ransonmoor DCA	1.5	212	23	0.9	23
Sawtry IDD	432.1	33581	3521	324.6	2702
Southery and District IDD	6154.4	633762	64685	4386.5	56141
Stoke Ferry IDD	150.1	21637	2279	71.5	1063
Sutton and Mepal IDD	435.0	60265	6380	249.6	3932
Swaffham IDD	987.7	152230	16426	385.5	5095
The Curf and Wimblington Combined IDB	119.1	29867	3232	5.1	105
Upper Witham IDD	0.2	20	2	0.2	2
Upwell IDD	32.0	2079	204	26.9	204
Waldersley IDD	27.2	7689	802	1.9	14
Warboys, Somersham and Pidley IDD	97.7	11618	1154	68.8	1253
Waterbeach Level IDD	1236.9	137291	15130	828.1	12446
Welland and Deepings IDD	1460.3	227696	26170	707.9	19074
Whittlesey IDD	5521.3	514213	53211	4068.1	46294
Witham 1st District IDD	1041.5	116415	12070	661.0	6821
Witham 3rd District IDD	1382.1	133312	13693	1009.5	12588
Witham 4th District IDD	90.4	23040	2488	2.2	4
Woodwalton DCA	865.7	77291	8123	651.0	7961
Grand Total	45546.4	4544660	484235	31868.0	384838

\* Based on assumption that C is being lost from surface peats and peats buried below mineral surface layers