CATFIELD FEN COMMENTS

Some Ecological and Telmatological Considerations

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1. SYNTHESIS AND SUMMARY OF REPORT

1.1 BACKGROUND

This report is based upon (a) a short field visit made by Dr Bryan D. Wheeler (BDW) to the northern part of the fens of the Catfield Hall Estate (North Marsh, Middle Marsh and the northern end of Mill Dyke Marsh) on May 17th 2013; and (b) consideration of some material and comments presented in a report about the site (Mason, 2012) and some associated notes. Both the field visit, and Mason's report, were focussed upon the proposition that the 'Catfield Fens are drying out', but only limited supporting evidence has been provided for this. BDW was invited to visit the site by Natural England (NE) to assess, partly on the basis of past, locatable, relevé records, the nature and direction of significant species change of the fen vegetation. BDW has had a long research experience of these fens (Annexe 1, Annexe 3).

1.2 PRESENTED EVIDENCE OF BIOLOGICAL CHANGE

Biological information has been presented as evidence for drying-induced change at 'Catfield Fen' by NE, Harris & Harris (2011) (4.2) and by a list of declining species suggested by Mr A. Bull. (4.3).

There are obvious constraints upon the accuracy of unquantified and casual perceptions of species decline, but the suggestions of Mr Bull are taken here in good faith, with the proviso that the 'declining species' encountered in Middle Marsh and the northern part of Mill Dyke Marsh were still present in fair numbers in 2013, and that one of them (*Drosera rotundifolia*) had apparently expanded recently from Mill Dyke Marsh into Middle Marsh.

A greater concern with Mr Bull's (and other) observations is (a) a lack of localisation, *i.e.* it is not clear whether they relate to the Catfield Fens as a whole, or to specific areas within the Catfield Hall Estate (4.3.1); and (b), for some species at least, the interpretation of their apparent decline in terms of 'drying of the fen' (4.3.2).

For some of the species cited, the suggestion that their decline is related to 'fen drying' seems inadmissible. For example, three species (*Ceratophyllum demersum*, *Hydrocharis morsus-ranae* and *Utricularia vulgaris*) are aquatic plants which grow in standing water in the dykes at Catfield. Any drying-related decline in these species must surely imply a dramatic drying of the dykes in which they once grew. BDW knows of no reason to suppose that this has been the case, nor is this supported by the recent (and desirable) expansion of *Stratiotes aloides* vegetation within the internal dyke system.

Likewise, some of the fen species listed are not specifically associated with particularly wet conditions (*e.g. Osmunda regalis*, *Peucedanum palustre* and *Stellaria palustris*) and there is no reason to suppose that their populations should be particularly, or selectively, adversely affected by drying when those of some other fen species, for which decline has not been suggested, are not. These species are often, though not exclusively, associated with S24 vegetation and recently ELP (2010) has suggested that there has been a Broadland-wide "reduction in the extent and quality S24 tall herb fens", for reasons which have not been identified. The species composition of Broadland fen vegetation is determined by variables additional to water regime (*e.g.* nutrient status, dereliction) and S24 vegetation itself occurs across a wide range of 'water circumstances' in Broadland, most of them characterised by considerable fluctuations (both seasonal and unseasonal) of water level. Broadland-wide trends in species abundance and distribution may well be reflected in the fens at Catfield.

Of the species listed by Mr Bull, two (*Potentilla palustris* and, especially, *Cicuta virosa*) are often 'wet fen' species and a decline in them could be related to drying. Likewise, the reduced stature of reeds in the Catfield Hall Fens, reported by NE, Harris & Harris (2011) could – as these authors suggest – be related to drying, though this is not the only possible cause (for example, cumulative nutrient impoverishment is also detrimental to the vigour of reedbeds).

1.3 TERRESTRIALISATION OF TURF PONDS

The reedbeds of the Catfield Hall Estate, south of Middle Marsh, are all located in former 19th century, shallow turf ponds (Giller, 1978; Giller & Wheeler, 1986). On-going processes of peat and biomass accumulation within these lead to a gradual elevation of the fen surface relative to the water table (terrestrialisation) (Section 6). In its later stages this is manifest as a gradual, but progressive, increase in surface 'dryness'. An argument by Prof. D. Gilvear (in Mason, 2012), that regularly managed turf ponds do not terrestrialise is specious and is refuted (Section 6). The traditional management solution to terrestrialisation has been periodically to 'turf out' the marshes. When this is not done over a long period of time is to be expected that the surface of the marshes will rise and 'dry out'.

In some turf ponds, and apparently initiated on particularly buoyant surfaces within them, 'boils' of *Sphagnum*-based vegetation can form, and mature as a late phase of terrestrialisation (Giller & Wheeler, 1988) (Section 7). Such *Sphagnum* surfaces form only where vegetation and peat can accumulate above the level of base-rich flood and are primarily or exclusively dependent on precipitation for direct water supply. In dry summers in Broadland, such surfaces often become crisped and bleached, as observed by Mr Bull. This is a widespread and natural feature of the maturing *Sphagnum* surfaces which relates to their elevated context (relative to the fen water table). Although these maturing surfaces represent a relatively 'dry' and late phase of the terrestrialisation process, they have considerable conservation value (EC Habitats Directive Annex 1 habitat category of 'Transition Mire & Quaking Bog'), which is likely to be lost for a long period should they be turfed out. This provides a particularly acute challenge for the development of a management strategy for these areas. Their long-term prospects, in the climate of East Anglia, if not turfed-out but still mown-out, are not really known (Giller & Wheeler, 1988), but on-going mowing may well represent the 'safest', and certainly the simplest, holding solution.

1.4 FIELD INFORMATION (16TH MAY, 2013) AND INTERPRETATION

1.4.1 Mill Dyke Marsh

Field examination (16th May, 2013) of a maturing *Sphagnum* surface at the northern end of Mill Dyke Marsh indicated that this contained *more* species characteristic of the community than had been recorded from the less mature example examined in the same location in 1977 (Table 2). In the period between these two records, this area had apparently for a time become considerably invaded by scrub (data of Parmenter, 1995), and the re-instatement of the original community to its present condition appears attributable to sympathetic management of the location by the Catfield Hall Estate.

A reedbed some distance south of the *Sphagnum* area in Mill Dyke Marsh had also been examined in 1977, but constraints of time precluded its re-location and recording in May 2013. However, an area of wet reed immediately south of the *Sphagnum* area was located at recorded. This was not in the same location as the 1977 sample and all that be concluded from it is that some reed vegetation, with most of the species noted in 1977, does still occur in Mill Dyke Marsh (Table 2).

In the absence of a run of measured water table data, the FENSPEC application (Fen Species Prediction of Environmental Conditions and Change, based on the relationships determined between species occurrences and measured environmental conditions and developed by BDW, see Annexe 2) was used to calculate 'Water level Indicator Values' for the samples made in 1977 and 2013. [Higher values of the index, which is usually negative, indicate wetter conditions, but they do not relate directly to field water levels, and zero does *not* indicate surface level.]

Applied to the *Sphagnum* area in Mill Dyke Marsh, FENSPEC suggests a small reduction in the Water Level Index (1977: -6.9; 2013; -7.1), which implies slight drying (Table 2). Comparison of the S4 sample from 2013 with that collected from a location further south in 1977, gave the same WL Index value (-4.0) in both cases (Table 2), but no sensible comparison can be made between these two values as it is possible that drying-interpretable changes may have occurred at the original (1977) S4 location. A sample by ELP (2010) from Mill Dyke Marsh, which was probably nearer the original S4 sample location than that recorded in 2013, though doubtfully in even roughly the same spot, recorded vegetation referred to S24g with a WL Index value of -7.9. Again no real credence can be given to a comparison of this value with that from 1977, because the surface of Mill Dyke Marsh is vegetationally and topographically heterogeneous and it is necessary that between-year comparisons should be made with samples taken from essentially the same location. Moreover, the sampling protocol and area used by ELP (2010) was different (smaller sample area) to that used in 1977, which has almost certainly resulted in the capture of fewer species in their samples. Such considerations reinforce the need for a re-sampling of the locations of the 1977 data, where possible, if a more robust between-year comparison is required.

Mill Dyke Marsh is a terrestrialising turf pond and some autogenic increase in surface elevation and ‘dryness’ is to be expected – it would be more surprising if this was not the case. In 1977, vegetation comparable with the S24g sample recorded from Mill Dyke Marshes by ELP (2010) was mainly found on uncut peat surfaces, but even then some examples were found as a late-terrestrialisation feature of some turf pond locations.

1.4.2 Middle Marsh

Unlike Mill Dyke Marsh, the adjoining Middle Marsh is not a former turf pond site, and vegetation changes within it, based on relocated quadrat samples, can be examined without consideration of the complications introduced by on-going terrestrialisation.

The most obvious change in Middle Marsh, since examination in 1977 and 1986, has been a dramatic expansion of *Sphagnum*, mainly *S. fimbriatum* and *S. recurvum*, but also of *S. palustre* and *S. squarrosum* (Table 1). *Sphagnum* seems to have been increasing during the 1990s (suggested by data of Parmenter, 1995) and was well established by 2001 (HSI, 2001). The cause of this change is neither known nor obvious. pH data from May 2013 indicate acidic interstitial water (pH 4.7), which is well suitable for these *Sphagnum* species, but a similarly low pH (4.9) had been recorded in the same location in 1986, and Giller (1982) and Collins (1988) also measured particularly low ionic concentrations within this part of Middle Marsh. There is therefore no reason to suspect on-going base-depletion as a cause of *Sphagnum* expansion here, and it seems more likely that the cause may reside in a change of management, from the regular burning practised by Mr D.S.A. McDougall to the present mowing regimes. No evidence is known that supports the assertion by Mr A. Bull (in Baker *et al.*, 2008) that Middle Marsh “has a somewhat higher pH of the other fens”.

Two parts of Middle Marsh had previously been sampled: a quite large area of fen vegetation which had been referred to a (rather atypical) form of S27, which occupies some lower areas in the compartment, and was sampled in a location north-east of the pond; and a patch of M24 fen meadow, on somewhat higher ground near the fen margin in the south-east corner of the compartment (Table 1). Apart from the invasion by *Sphagnum* (which had occurred in both communities) and the spread of *Drosera rotundifolia* into the stand of M24, the species composition of the two areas examined was very similar to that recorded in 1986 (and also 1977, though these samples were probably not from exactly the same locations and they have not be tabulated).

In the absence of a run of measured water table data, the FENSPEC application was used to calculate ‘Water level Indicator Values’ for the samples recorded in 1986 and 2013. The value for the S27 vegetation was much the same in 2013 (-2.3) as in 1986 (-2.5), but the value for the M24 patch was considerably higher in 2013 (-4.3) than in 1986 (-6.2) (Table 1). [Higher values of the index indicate wetter conditions, but they do not relate directly to field water levels, and zero does *not* indicate surface level.]

The S27 vegetation occupies a hollow with a high (often well above surface) water level, and the similarity of the Water Level index between 1986 and 2013 is perhaps not surprising, as a considerable and sustained change in the water regime is likely to be needed here to be botanically-effective, *i.e.* to change the character of the vegetation. However, these conditions do not apply to the stand of M24, where the water level is normally sub-surface and where the higher and marginal location may make it particularly susceptible to water level change. The available data provide no evidence at all for a reduction of water level in the M24 stand since the record of 1986, and point instead to a possible sustained increase. Note that as the index is based on vegetation composition, the higher values in 2013 are not a reflection of recent ‘wetting’ events, such as the wet summer of 2012. This is because this type of wetland vegetation is composed mostly of perennial plants which show considerable inertia again short-, or even medium-, term water level change, especially increased wetness, unless these events are catastrophic. It is, however, possible that the (apparently recent) establishment in the M24 area of *Drosera rotundifolia*, a wetland plant with ruderal characteristics, could be in response to the wet summer of 2012.

In view of the propinquity of Middle Marsh with the northern end of Mill Dyke Marsh, these indications of fairly stable or increasing ‘wetness’ in Middle Marsh encourage the view that any apparent ‘drying’ at the northern end of Mill Dyke Marsh is a consequence of a progressive, autogenic elevation of the peat surface relative to the water table, rather than a response to a sustained decrease in the water table.

1.5 HISTORICAL CHANGES

A brief historical summary is provided (8.1)of apparent changes to the surface-water system of the Catfield & Irstead Fens since the end of the 18th century. This is based almost entirely upon cartographical data, and is subject to all of the limitations of these. It is possible that local records or other sources could materially enhance or modify this map-based material.

Probably the most significant hydro-ecological event as far as the Catfield Hall Fens are concerned was the construction of the Commissioner’s Rond, as a consequence of the Inclosure of Catfield parish in 1807. This was intended to permit the drainage of the fens internal to it, almost certainly with a view to their conversion to agriculture. In the event, the main use of the drainage was to facilitate shallow turbary, and before the end of the 19th century these fens and turbaries had become reflooded and ‘wet’. However, the Rond has continued largely to isolate the internal fens from the water dynamics and any episodic nutrient-enrichment formerly associated with the River Ant. The Internal Fens appear now to be dominantly fed by precipitation, especially as any marginal inflows of surface water and groundwater that may occur appear mainly to enter the dyke system rather than the fen compartments.

The extensive dyke system of the fens south of Middle Marsh appears to be a product of post-1905 dyking (dates not known to BDW) (8.2.1). The hydrodynamics of the dyked fens are probably rather different to those before they were dug, possibly resulting in generally less wet conditions in the fen compartments, particularly away from the main drainage points.

There is a ‘low bund’ blocking a dyke connection to Sharp Street at the south end of Long Marsh, (8.2.2), possibly originating from between 1965 and 1975. This location may correspond with the main drainage axis of this part of the site (*cf.* Faden, 1797) and the bund presumably helps retain water in the Internal Fens, but it also enhances their isolation from the river. The level of the bund is likely to have become lowered over the years resulting in some reduction, of unknown magnitude, of the amount of water retained.

2. BACKGROUND TO REPORT

In May 2013, Dr Bryan D Wheeler (BDW), a retired Reader in Wetland Ecology at Sheffield University, was invited by Natural England (NE) staff to participate in a field visit to the Catfield Hall Marshes in a voluntary (*i.e.* unremunerated) and informal capacity. It was understood that this was because of his past research and botanical activities in the Catfield & Irstead Fens (Annexe 1), and was with a view to assessing how the vegetation of parts of the site had changed since the 1970s and 80s based on past, locatable, species data.

The field visit that took place was shorter than expected and was supervised and accompanied by a group of other interested parties. It was curtailed by required attendance at an indoor discussion and lunch arranged by Mr & Mrs T Harris. In consequence, only the northern part of the Catfield Hall marshes was examined, and that mostly rather superficially. Dr R. Tratt (who had accompanied BDW) was able to record some useful vegetation data from previously-examined locations in Middle Marsh and in part of Mill Dyke Marsh, but recording and measurement in the latter was truncated by the lunch-time meeting. As this field examination was made early in the season, some 2 months before most other recording visits have been made, and probably before some wetland plants had emerged, its timing was in any case not ideal. It would be of undoubted value to extend the field examination to the more southern parts of the fen, but in the lunch-time meeting Mr T Harris indicated that he would not sanction further investigation on his property unless support was given *a priori* for a proposed moratorium on local groundwater abstraction.

Mr Harris had apparently originally requested that each attendee of the field meeting should produce a short report, but this was declined by NE, at least as far as BDW was concerned, on the grounds that his involvement was essentially informal. However, it became clear that some observations made on the field visit deserved dissemination amongst interested parties. In addition, on 10th May 2013 a copy of the ‘Catfield Fen Investigation’ (Mason, 2012) was downloaded from the Environment Agency web-site. This report has since been considered and it became evident that some useful and factual comment could be made on some of its contents, and on some remarks of interested third parties. It was therefore decided to produce this present report, based both upon the field observations and some salient considerations relating to the Mason report. This present report has not be commissioned or solicited by NE, or by any other party, nor is it the subject of any remuneration.

It is considered that some (by no means all) of the discussion and comments concerning the issues about vegetation and environmental changes in the fens of the Catfield Hall Estate has been dogged by a lack of clarity, detail and focus. This report concentrates on ecological and telmatological issues which hitherto seem to have received limited critical attention. It is hoped that it will help provide some clarification of these matters, and that it will be accepted as an objective and independent assessment of the issues concerned. The comments are offered not just with specific regard to the Catfield Hall marshes but because some of them also may have a greater, Broadland-wide, significance.

Locations and some Abbreviations

A map of the Catfield & Irstead Fens, and the names of its subdivisions, is given in Figure 1.

agl: above ground level; bgl: below ground level

BDC: *Betulo-Dryopteridetum cristatae*: a non-*NVC* (National Vegetation Classification) community of *Sphagnum* ‘boils’

M24 : *Molinia caerulea* - *Cirsium dissectum* fen meadow

S24: *Phragmites australis* - *Peucedanum palustre* tall-herb fen

S27: *Carex rostrata* - *Potentilla palustris* fen

3. INTRODUCTION: PERCEPTIONS OF WATER CONDITIONS AND CHANGE

3.1 WATER LEVEL FLUCTUATIONS AND THE PERCEPTION OF 'WETNESS'

Water level data (relative to the peat surface) reported from some of the Catfield & Irstead Fens (Giller & Wheeler, 1986) indicate fluctuations of up to almost 50 cm. The degree to which these are above or below the peat surface depends primarily upon the underlying topography, *i.e.* the elevation of the surface, which itself can vary by about 50 cm in different parts of the fen, and also upon its buoyancy. Where there are buoyant or 'loose peats' water table fluctuations relative to their surfaces can be considerably damped (Giller & Wheeler, 1988).

Water level fluctuations relative to the surface, rather than to Ordnance Datum, are stressed here because they are of most relevance to the vegetation. They also form the basis for any *ad hoc* assessment of the degree of 'wetness' of the site by human visitors, though, without measuring apparatus, these latter can have only limited awareness of the actual position of the water table when it is below the surface (and in some locations it most usually is). Also, because of the strongly fluctuating hydrodynamics of the site[1], which can show much within-year and between-year variation, and because episodes of particularly 'high' or 'low' water levels can be short-lived, little reliance can be placed upon occasional, informal, spot measurements of water levels. These strong fluctuations may also help constrain the 'prediction' of impact of suspected changes in the duration and magnitude of 'water events' upon the vegetation, not least because different plant species may respond to different components of the hydroperiod (Wheeler, 1999). Nonetheless, all of the plant species that routinely grow in the Catfield & Irstead Fens self-evidently accommodate the fluctuations that occur in their particular locations, and are tolerant to episodes of flooding and drying of varying depth and duration that can occur at various times of the year.

It is not possible to concur with a proposition advanced by Harding (2010) that "Fens such as Catfield are very sensitive to even small changes in the hydrological regime, both in terms of quality and quantity". BDW knows of no evidence that suggests great sensitivity of Broadland fen vegetation *in general*[2] to small changes in water regime, whilst there is plenty of reason to suppose that this is not the case (year-on-year changes in the water regime, and irregular seasonal hydrodynamics, at individual sites; the widescale occurrence of similar vegetation across a quite wide range of water conditions (Wheeler *et al*, 2004); persistence through changing water circumstances). For example, the mean summer water table reported for S24 (the 'flagship' plant-community of Broadland) is 16.7 cm bgl[3], with a standard deviation of ± 20.11 cm and a range from 78.4 cm bgl to 3.8 cm agl (Wheeler *et al.*¸2004). These authors further commented that "The summer water level is typically around 15 cm bgl. However, relatively deep subsurface water table in the summer may be a perfectly natural feature of some sites." Such comments do not imply that S24 vegetation shows no variation with regard to water level, nor that large and prolonged changes in water regime would not be

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[1] Unless specified otherwise 'the site' refers to the entire 'Catfield & Irstead Fens', as adopted and mapped by Giller (1982) (Figure 1).

[2] Some of the rarer types of Broadland fen vegetation probably are sensitive to small, but sustained drying and, in some instances also to flooding, but these typically grow on buoyant surfaces where the impact of absolute water level changes can mitigated by the buoyancy or expansibility of the peat surface. Because of this, they sometimes occur in locations subject to quite large absolute but small relative water level fluctuations. The more sensitive of such communities and species are not known ever to have occurred in the marshes of the present Catfield Hall Estate.

[3] The most recent mean water level value for S24, based on a somewhat larger data set than that available to Wheeler *et al.* (2004), is 16.2 cm bgl. The end points of the range are still the same.

damaging to the community, but neither do they support the proposition that such vegetation is "very sensitive to even small changes in the hydrological regime".

It is likewise possible to challenge the assertion (Harding, 2010) that "Catfield Fen is characterised by plant communities typically associated with infertile substrates and very high water tables", in this instance depending partly on just what is meant to be implied by "very high water tables". For example, is an average summer water table of 16.7 cm bgl (the mean summer water table recorded for S24) considered to be "very high"?

Professor D. Gilvear (in Mason, 2012) has picked up on Harding's theme and points out that "in a wetland where the critical factor is that the water table remains close to the surface drawdown of a few centimetres can be a significant percentage drawdown". This proposition is, of course, self-evidently true, but any ecological significance it may have is, by its own terms of reference, applicable only to *"a wetland where the critical factor* is that the water table remains close to the surface*"*. This is certainly sometimes the case, for example in some soligenous fens with a normally fairly stable and high water table, and where a reduction of water table of, say, 5 cm might well be detrimental to the existing vegetation if sustained for a number of years. But in general fens in Broadland have a strong and irregular water dynamic, and for S24 vegetation having a near-surface water table is clearly not critical (Wheeler *et al.*, 2004). One has to compare like with like, and neither the water supply mechanisms nor the vegetation of soligenous fens are at all like those of most Broadland examples (Wheeler, Shaw & Tanner, 2009). This is expressed perhaps most obviously in the striking differences between their species compositions.

Harding (2010) also asserted that the plant communities of the Catfield Fens are "typically associated with infertile substrates", but cites no evidence to support this proposition. Phytometric data from the Catfield & Irstead fens (Wheeler & Shaw, 1987) show that the plant communities of this site span the entire fertility range from oligotrophic to eutrophic, whilst the mean phytometric fertility (± SE) for S24 samples is 16.6 mg[4] (Wheeler *et al.*, 2004) [18 mg is the notional phytometric value adopted by Wheeler, Shaw & Tanner (2009) as the boundary between their fertility categories of mesotrophic and eutrophic]. Thus, whilst some vegetation stands in the Catfield Fens are undoubtedly associated with oligotrophic conditions, there is no reason to suppose that this is a characteristic across all of the site.

3.2 WATER REGIME AND HYDROTOPOGRAPHICAL CIRCUMSTANCE

The surface of the Catfield & Irstead Fens is not uniform, but has been much modified by various historical activities. At least five informal 'hydrotopographical' categories can be recognised. These may show different relationships to water level change and differences in biological response in the event of considerable and prolonged change in water level.

The surface of the areas of 'solid peat' is largely fixed. In these areas, ongoing accumulation of peat, if it occurs at all, is likely to be very slow, and it is possible that the present-day peat level of some such surfaces is uncoupled from their current water regime, but relates more to the former (pre-19th century?) water conditions in which it originally formed (Wells & Wheeler, 1999). By contrast, the surface of the terrestrialising turf ponds is more dynamic and more likely be more in equilibrium with the contemporary water regime, though this relationship can change with time. In the early stages of terrestrialisation at least, the colonising mat of reeds *etc* can show a buoyancy which damps water level fluctuations relative to its surface. As the mat matures, the vegetation surface may grow above the 'normal' water level, and stabilise, so that not only is it higher, it may also be more subject to water level fluctuations.

[4] The most recent mean fertility value (± SE) for S24 is 18.6 ± 0.37 mg. This is based on a somewhat larger dataset than was available to Wheeler *et al.* (2004).

Box 1: Informal Hydrotopographical Categories in the fens of the Catfield Hall Estate

At least five broad topo-stratigraphical categories of wetland can be identified within the Catfield Hall Estate:

1. Marginal areas of shallow, probably undug (but once drained), peat (*e.g.* North Marsh, Middle Marsh)
2. Areas of deep, ‘solid’ (apparently undug) peat (± Romano-British estuarine clay)
3. Former 19th century turf ponds, terrestrialising with less ‘solid’, often ± buoyant, peat in the top 70 – 100 cm depth (*e.g.* Mill Dyke Marsh, Long Marsh, Catfield Broad Marshes *p.p.*)
4. Open water broad: (*e.g.* Catfield Broad, apparently created by excavation within a former turf pond
5. Open water dykes

These currently support rather different types of vegetation and may show different responses to any external environmental changes, as well as different degrees of autogenic (‘self-made’) or internal change (*e.g.* peat accumulation; mud deposition).

The dykes form part of a rather different system, whose linkage to the hydrodynamics of the fens has yet to be resolved. However, they are mostly filled with deep surface water and support aquatic plants. A permanent reduction of water level by, say, 50 cm or more, which would undoubtedly be injurious if it occurred below the peat surface of a fen, may have little, if any, affect upon the biota of the dykes (depending on the residual depth of free water). Likewise, any reduction in the depth of above-surface, standing water in fen pools or turf ponds may have but limited impact upon their biota, whilst a comparable lowering below the surface is likely to have greater consequence..

4. EVIDENCE THAT 'CATFIELD FEN' IS 'DRYING'

4.1 THE NATURE OF THE EVIDENCE

Claims have been made that Catfield Fen 'drying out'. Various observers, including Mr T. Harris, Mrs A Harris, Mr A. Bull and Mr A. Alston, have suggested that some drying has occurred. Natural England (represented by Mr C. Doarks) are co-partners in a Compendium (NE, Harris & Harris, 2011) which brings together evidence about the current state of the site, and which expresses concern about possible 'drying'. Professor D Gilvear (in Mason, 2012), stated that there is now general acceptance for the first time that the site is drying. However, Mason (2012), in a comprehensive and much-commented report, provided little evidence in support of this proposition, beyond recording the concerns of Mr K. McDougall in 1991 and citing the Compendium of 2011. In a perceptive comment, Mr N. Walters (Anglian Water) observed that "It is not clear from reading the report exactly what is the basis for the concerns about the fen drying".

There seems to be both confusion and disagreement. This may partly reflect the different perspectives of individual observers, but also a more fundamental failure to identify and recognise the localisation of suspected drying across a large and heterogeneous site, and to separate 'natural' causes of drying from those that are a response to events external to the marshes.

Many of the claims of suspected drying are nebulous and lack specificity, especially of location. The claims often relate to 'Catfield Fen', but it is not clear whether this unit is intended to relate specifically to the eastern marginal fens associated with the Catfield Hall Estate, to the wider expanse of 'Catfield Fen' (*i.e.* the area within Catfield parish), or to the even wider compass of the 'Catfield & Irstead Fens' (as adopted by Giller, 1982). Even within the limited compass of the Catfield Hall Estate it is not usually stated whether 'drying' is supposed to have affected all of the marshes or just some of them. Such lack of localisation of the reputed drying hampers any assessment of its reality, and determination of a likely cause. This consideration is of the greatest importance because suspected species declines and changes are not just a feature of 'Catfield Fen', but have been suggested or reported from other parts of Broadland. Reflecting on their recent survey, ELP (2010) concluded that amongst other changes in the Broadland Fens there has been "a reduction in the extent and quality of S24 tall herb fens" The causes of this decline, if it is real, have yet to be identified, but in terms of establishing likely causalities it is clearly important to try to distinguish between changes that are part of a pervasive decline in the quality of fen vegetation throughout Broadland and those that are specific to a handful of compartments along the eastern edge of the Catfield & Irstead Fens. It should also be appreciated that water conditions are not the only variables that help determine the composition of fen vegetation – changes in fertility or management are also key determinands. Thus any suspected species (or other) changes need to be identified and localised, and then considered holistically before reaching conclusions about possible causality.

It is presumed that considerations such as these encouraged NE to invite BDW to visit the Catfield Hall marshes, with a view to assessing the evidence for vegetation change within this specific area since the 1970s and 80s

Two documents have been made available which contain some stated evidence for drying at 'Catfield Fen': the Compendium (NE, Harris & Harris (2011) and a letter from Mr A Bull (to Mr P. Riches) which listed some perceived botanical changes which were considered to indicate drying. These documents are examined separately below.

4.2 COMPENDIUM OF ECOLOGICAL AND ECO-HYDROLOGICAL EVIDENCE FROM CATFIELD FEN (NE, HARRIS & HARRIS, 2011)

4.2.1 Summary of Content

This short report itemises a series of features relating to ‘Catfield Fen’. It is not made clear whether it encompasses consideration of the Catfield fens *in toto* or is concerned just with the marshes of the Catfield Hall Estate.

As well as presenting some evidence for drying, this report also includes bullet points of the ecological and conservation importance of the fens along with some further items derived from Harding (2010) on his assessment of the relationship between the fen vegetation and water regime (see 3.1 and 3.2).

With regard to actual or suspected changes in habitat and vegetation, several points emerge:

1. “There is no evidence of major shifts in the *NVC* community within Catfield Fen to suggest that irreversible damage has occurred”. [The time period of comparison is not stated.]
2. Evidence from aerial photographs etc indicates that large parts of the fen have become colonised by woody species – “a process that appears to have accelerated since the 1980s”
3. “There also appears to be evidence [presumably from aerial photographs] of a reduction in the area of shallow open water”. [The time period is not stated, nor are the areas of “shallow open water” identified.]
4. “There has been a significant reduction in the stature of reed within the reedbed areas in the Catfield Hall Fen”
5. Some points are also made on species change in the fens, stemming from the work of Mr A. Bull[5]. [These items are considered separately below (4.3).]

4.2.2 Comment on the Compendium

With some significant specific exceptions, such as the comments on the particular sensitivity of the vegetation at Catfield Fen to small-scale hydrological change (see 3.1), it is possible to concur with much of the material presented in the Compendium. This is partly because a number of the points made are generalities, are not necessarily specific to concerns about fen drying or could be made equally well for various other fens throughout Broadland.

Importance of the Catfield Fens

In aggregate, there is no doubt that the ‘Catfield Fens’ (*i.e.* the Ant valley fens within Catfield parish) were of exceptional botanical interest, supporting some of the rarest species, communities and habitats of Broadland. However, most of their *exceptional* interest was always located outwith the compass of the Catfield Hall Estate, in its current truncated form, *i.e.* it was in Fenside, Sedge Marshes, Little Fen and, particularly, Great Fen.

In the opinion of BDW, the main particular botanical interest-features of the current Catfield Hall marshes were, and probably still are, the stands of *Sphagnum – Dryopteris cristata* vegetation (especially the example at the northern end of Mill Dyke Marsh) and the stands of M24 and S27 (both in Middle Marsh). The first of these vegetation types, although not specifically recognised by *NVC*, is nationally rare and is probably now confined to Broadland. It can be allocated to the EC Habitats Directive Annex 1 habitat category of ‘Transition Mire

[5] Reference is made to a report entitled ‘An ecological assessment of the effect of water extraction for irrigation purposes on the flora and faun of the fens at Catfield Hall’. This has not been seen by BDW.

& Quaking Bog'. The other two are more widespread nationally. M24 is quite frequent in Norfolk, but generally scarce in Broadland, and the example in Middle Marsh undoubtedly makes an important contribution to the Broadland resource of this community. S27 is rather widespread, locally almost common, in England as a whole, but is scarce in much of lowland England where, as at Middle Marsh, it is often developed in a rather impoverished and atypical form.

Performance of Phragmites

In relation to the possibility of fen drying, perhaps the most pertinent point raised in the Compemdium, because both the problem and location involved is specified reasonably clearly, relates to the reduction of reed stature within the reedbed areas of the Catfield Hall marshes. The authors of the Compendium are correct in recognising that low stature (and vigour) of reed may be related to low water levels (*e.g.* Haslam, 1972). However, it may also be determined *inter alia* by low nutrient availability, presence of 'weed' species, inappropriate management, unusual irrigation with brackish water *etc.* (Haslam *loc cit.*). Some of these influences can operate in complex tandem. For example, invasion of weed species in the aftermath of a temporary environmental set-back to reed growth can sometimes result in the establishment of a vegetation layer that continues to constrain reed growth even when otherwise 'better' conditions return.

'Drying' could account for the reported reduction of reed growth in the Catfield Hall marshes. However, the likely cause of any such 'drying' needs to be assessed carefully. The vegetation map of Giller (1978) showed clearly that, with the possible exception of North Marsh (whose status was uncertain), all of the reed beds in the area of the Catfield Hall Estate were located in former turf-ponds (Giller & Wheeler, 1986) (*e.g.* Mill Dyke Marshes, Goose (Long) Marsh and (small patches only) the Catfield Broad Marshes. These turf ponds have been shown to be subject to on-going terrestrialisation (Giller & Wheeler, 1986, 1988) and this natural autogenic process results in an elevation of the 'peat' surface relative to the water table (*i.e.* it leads to 'drying') and species change (see TERRESTRIALISATION OF TURF PONDS). For example, Giller & Wheeler (1986) observed, partly from the stratigraphy of their infill, that in turf ponds in the External fens reedbeds were becoming gradually invaded by *Cladium* as a late-successional event. *Cladium* is reported similarly to be spreading into the reedbeds of Mill Dyke Marsh (Mr P. Riches, *pers. comm.*) Prof D. Gilvear (in Mason, 2012) has argued that managed reed beds are not subject to terrestrialisation, but this proposition is specious and is rejected below (see TERRESTRIALISATION OF TURF PONDS).

Although reed is cut in winter when the standing stock of nutrients in the dead material that is removed by mowing is low, Haslam (1972) considered that mowing forms "a steady annual drain from the reedbed". She estimated annual values of nutrient loss of: Ca: 2.5 – 6.5; P: 0.8 – 3; N: 16 – 42; K: 4 – 15; Mg: 2 – 5 (all values kg ha^{-1}), with "well-managed reedbeds" tending to the higher values in each case. She considered that "pollution" of water sources should generally compensate for these losses, but also noted a marshman's tradition that singe-wale cutting "weakens beds far from the river (*i.e.* nutrient-poor ones)". The Catfield Hall marshes are not only fairly remote from the R. Ant, they are largely isolated from it by the Commissioner's Rond and the 'low bund' (see THE COMMISSIONER'S ROND AND DRAINAGE, below). Giller & Wheeler (1988) and HSI (2001) have drawn attention to apparent base-depletion and ombrotrophication within the Internal System fens, especially in locations remote from the dykes. Nutrient depletion cannot be ignored as an important cause of biomass reduction in these reedbeds.

4.3 PLANT SPECIES DECLINE IN CATFIELD FEN (MR A. BULL)

4.3.1 Species considered to be in decline

In a letter to Mr P. Riches (dated 7/11/2010) Mr A Bull expressed the view that certain plant species were in decline at 'Catfield Fen', which he attributed to drying of the site. He listed 15 species that were considered likely to be in decline due to drying:

Ceratophyllum demersum
Hydrocharis morsus-ranae
Utricularia vulgaris

Dryopteris cristata
Osmunda regalis
Drosera rotundifolia
Eriophorum angustifolium
Sphagnum papillosum

Carex lasiocarpa
Dactylorhiza maculata
Moerckia hibernica

Cicuta virosa
Potentilla palustris
Peucedanum palustre
Stellaria palustris

Mr Bull is a capable botanist and his observations and his views deserve careful consideration. It is, however, clear that some of them, at least, do not withstand close scrutiny, particularly with regard to likely causation.

A generic problem of *any* assessment of species change which is not based on quantified data is that it is essentially subjective or anecdotal. This does not of itself necessarily invalidate its veracity, and in many instances such informal observations of change provide the only evidence available. Another frequent problem, which is particularly relevant to a heterogeneous site such as Catfield, and also to Mr Bull's assessment, is that the locations of suspected change are often not specified. Species may be in decline in some areas but not in others, and when this is the case locations of decline need to be clearly identified, to help determine possible causes. It is not known to BDW whether the remarks of Mr Bull refer to the entire 'Catfield' site or just to the wetlands of the Catfield Hall Estate and, within the latter, to which compartments.

4.3.2 Comments on causes of the suggested species declines

The following comments can be made in response to Mr Bull's identification of species and other changes that are thought to indicate drying:

1. Three of the suggested declining species (*Ceratophyllum demersum, Hydrocharis morsus-ranae* and *Utricularia vulgaris*) are aquatic plants which grow in standing water in the dykes at Catfield. As all three species can grow over a wide range of dyke water depths, the proposition that their apparent decline indicates that 'the site is drying' is tantamount to suggesting that the dykes where they once grew have lost most or all of their water. There is no reason to suppose that this is the case, especially given the rich populations of some other aquatic species that still occur. Any decline in these species, if real, is likely to have a quite different explanation which, on the Catfield Hall Estate at least, could include their replacement by the expanding populations of *Stratiotes aloides.*
2. Drying and bleaching of the maturing *Sphagnum* surfaces has been observed widely across the Catfield & Irstead Fens (and elsewhere) in 'dry' summers since first visited by BDW in 1972 and is a consequence of the terrestrialisation process (see

ACIDIFICATION AND *SPHAGNUM* SURFACES IN TURF PONDS). This is not a recent event, nor is it at all restricted to the eastern margins of the Catfield site. There is also little reason to suppose that, in the locations observed, such drying is necessarily injurious to the *Sphagnum* carpets or to the species that grow in them, though it is acknowledged that year-on-year population counts of such species as *Dryopteris cristata* have not been made. A bigger threat to the populations of *D. cristata* is likely to be scrub invasion and shading. It is also clear that the maturing *Sphagnum* area at the north end of Mill Dyke Marsh is currently *richer* in wetland species typical of this habitat than was the case in 1977, despite evidence that it is somewhat drier now than then (see 5.3).

3. Similar comments may apply to the reported decline of *Osmunda regalis* (royal fern). This is a robust, long-lived and persistent fern which tolerates both open conditions and shading, and a quite wide range of water conditions (except for very wet or very dry). It is widely grown in normal garden soils without supplementary watering. If this species has declined at Catfield, it has occurred in the absence of a reported decline of species more sensitive to water conditions and is most unlikely to be a consequence of site drying. A similar comment can be made for *Eriophorum angustifolium* (cotton grass), a species for which conditions at Middle Marsh would seem to be well suitable. *E. angustifolium* often grows in the company of *Drosera rotundifolia*, *Sphagnum fimbriatum* and other *Sphagnum* species. These species grow in similar communities and have similar water level requirements to *E. angustifolium* but they have *expanded* into Middle Marsh since 1986. It is difficult to see how such species can have increased in Middle Marsh, dramatically in the case of *Sphagnum,* whilst their (probably tougher) companion *E. angustifolium* has declined on account of drying (see 5.2.2).

4. In a comment reported by NE, Harris & Harris (2011) Mr A. Bull has suggested that "There is evidence of changes in the moss community with wetland sphagnum species being replaced by common heathland species." The location of this suggested loss of *Sphagnum* is not identified, but it clearly does not refer to Middle Marsh where there has been a remarkable and extensive spread of *Sphagnum* since sometime after 1986.

5. *Drosera rotundifolia* has been observed in *Sphagnum* patches in various parts of the Catfield & Irstead Fens. Numbers of individuals typically fluctuate considerably between years, and the plant may 'disappear' for a time. *D. rotundifolia* is generally a short-lived, sometimes monocarpic, species which has ruderal ('weedy') characteristics. It is possible that its abundance in any one year reflects the suitability of conditions for regeneration from seed, which in the climate of East Anglia may vary considerably between years. Concerns about its reported decline, which presumably refer to the population in Mill Dyke Marsh as this was stated to be the only location for this species on the Catfield Hall Estate (Mr A. Bull, in Baker *et al.*, 2008), can perhaps be allayed by its evident spread into Middle Marsh, where it was noted in 2013 (5.2.2).

6. Some of the species mentioned by Mr Bull are very localised at Catfield and intrinsically hard to find, which makes any assessment of apparent changes in their abundance difficult. This relates particularly to *Carex lasiocarpa*, *Sphagnum papillosum* and *Moerckia hibernica* (which can be particularly difficult and chancy to find). BDW also recalls a comment by Mr Bull that *Moerckia* had been recorded from just one location in Mill Dyke Marsh. If this is correct, the basis on which this species is considered to have declined there is not clear.

7. Two species listed (*Cicuta virosa* and *Potentilla palustris*) can be regarded as 'wet fen' species (especially the former), and any decline of these in the fens may be related to some 'drying'. *Cicuta* is, in these fens, *par excellence* a species of wet reedbeds, and declines or disappears with their on-going terrestrialisation, whilst *P. palustris* is less demanding and can be more persistent.

8. *Peucedanum palustre* – perhaps the 'flagship' plant species of the Broadland fens – is not specifically a species of especially wet conditions in fens. It occupies a quite wide water-

table range and is often sparse in, or absent from, particularly wet swampy contexts. Any decline of this species in the 'Catfield Fens' would be consonant with a Broadland-wide decline in typical S24 species and vegetation suggested by ELP (2010). A similar comment may be applicable also to *Stellaria palustris* (marsh stitchwort) which can be a rather fugacious species, which again is not associated with particularly wet conditions within fens.

4.3.3 Plant Species decline in Broadland

ELP (2010) concluded that amongst other changes in the Broadland Fens there has been "a reduction in the extent and quality of S24 tall herb fens… There are also some questions as to the continued presence of Wheeler's *Peucedano-Phragmitetum caricetosum*…" A limitation of the ELP survey was that it used a slightly different sampling approach to that of Parmenter (1995) and Wheeler (1978 *etc.*) which probably resulted in individual ELP samples containing fewer species than did the earlier studies. However, Mr M. Harding has commented specifically (*pers. comm.* and *in litt.*) about the apparent current sparsity in Broadland of vegetation with the full range of S24 species, which suggests that this may be more than just a sampling issue and is a manifestation of a widespread decline of uncertain causation. Any similar changes that may have taken place within a fairly small area of fen vegetation along the eastern margin of the Catfield & Irstead Fens need to be assessed with regard to this wider perspective of apparent changes in Broadland as a whole.

When Parmenter (1995) reported the results of her Fen Resource Survey, it was clear that some of her samples also contained fewer species than samples recorded from approximately the same locations by Wheeler and associates in the 1970s and 1980s. This was raised as an issue at a meeting of the Broads Research Advisory Panel and it was proposed that some of the areas sampled by Wheeler etc should be revisited, where the original sample locations were defined sufficiently clearly[6], to determine their actual condition in the mid 1990s. This suggestion was enacted only for some former sample locations in Sedge Marshes and Great Fen at Catfield (ECUS, 1997). In Sedge Marshes (Internal System) there were no major differences from samples recorded in 1972, except for "some localised change, some suggestive of increased wetness, presumably due to regulation imposed by the level of the sluice that connects to Great Fen" whereas at Great Fen (External system) some of the formerly-'best' vegetation was "a rather impoverished reflection of its condition in the 1970s". This comparative approach has now been used at Middle Marsh and part of Mill Dyke Marsh in 2013 (see 5. FIELD OBSERVATIONS, 16th May 2013), and desirably could be implemented elsewhere, in the Catfield & Irstead Fens, and in other locations in Broadland.

4.3.4 Plant species decline and vegetation management

One cause of plant species decline in Broadland fens has been dereliction (*i.e.* lack of appropriate vegetation management). However, this seems unlikely to be a *general* cause of any species decline in the northern half of the Catfield Hall marshes (*i.e.* the area visited in May 2013) as this area appeared to be managed well and sympathetically. The estate and its workers are to be congratulated on this. One exception that can perhaps be made to the general plaudit relates to the reported turf-stripping on Rose Fen. It is appreciated that even in 1978 Rose Fen appeared to be 'dry' in summer conditions, and supported an impoverished vegetation. However, the possible biological benefits of removing peat to create wetter conditions need to be set against the palaeoecological, and possibly archaeological, benefits of retaining the intact blocks of undug peat. Peatlands have sometimes been compared to

[6] GPS facilities were not available in the 1970s and 1980s, but the location of some of the samples collected then was defined by descriptions or maps intended at the time to assist their subsequent re-location.

libraries, from which the removal of intact peat is akin to the tearing of pages from rare or irreplaceable books.

4.4 CHANGES IN AQUATIC PLANTS IN THE DYKES OF THE CATFIELD HALL ESTATE

The dykes of the Catfield Hall Estate have long been known for supporting a quite rich and variable aquatic flora, surveyed and documented by Wheeler & Giller (1982). These authors distinguished three vegetation noda: an *Elodea-Potamogeton crispus* community, confined to a few parts of the fen margin; a *Ceratophyllum-Stratiotes* community, present to a variable extent in the more marginal reaches of some of the fen dykes; and a rather species poor *Utricularia vulgaris* community, which occupied the dykes further out into the fen. This latter community often contained few macrophytes other than the nominate species, and even this was very sparse in some reaches of the dykes deep in the fens.

Stratiotes vegetation is often considered to have particular conservation value (it was once the dominant community of some of the broads prior to macrophyte decline in the 1950s and 60s). When examined in the early 1980s, *Stratiotes* vegetation was quite widespread in some of the dykes of the Catfield Hall Estate (Wheeler & Giller, 1982), but not as extensive as had apparently once been the case (D.S.A. McDougall, *pers. comm.*). Subsequently, during the later 1980s and 1990s, there was a substantial decline in the distribution of *Stratiotes*, in which the species tended to become confined to short (*e.g.* 30 m) stretches at the land-marginal ends of some of the dykes. However, in recent years there has been a resurgence of this species to re-occupy the stretches of the dykes in which it was observed by Wheeler & Giller, and even beyond these, returning perhaps to the distribution known to Mr D.S.A. McDougall. This pleasing trend was observed during the field visit on 16th May 2013.

Although overall infrequent, *Stratiotes* occurs in dykes in a number of locations in Broadland, some of them undoubtedly groundwater-fed (Doarkes & Storer, 1990), leading to the suspicion amongst some workers that declining distributions, such as that which had been observed at Catfield, have been a response to a reduction in groundwater supply. This view was not shared by BDW, but presumably those who supported it will attribute the recrudescence of *Stratiotes* at Catfield to *increased* outflow and penetration of the dykes by groundwater since the 1990s.

The expansion of *Stratiotes* in the dykes of the Catfield Hall Estate is incongruent with the claim by Mr A. Bull that *Ceratophyllum*, *Hydrocharis* and *Utricularia* have been declining because of drying of the fen. If these species have been in retreat, then this may have been before an advancing front of water soldiers.

5. FIELD OBSERVATIONS, 16TH MAY 2013

When sufficient details of location are available, the present state of the fen surfaces on the Catfield Hall Estate can in some instances be compared with their former condition, as recorded by Giller (1978), Wheeler & Shaw (1987) and Parmenter (1995), all of whom used broadly similar protocols to sample the vegetation. It is not so possible to make a simple, direct comparison with the most recent vegetation survey of ELP (2012) because (a) this did not plot vegetation polygons; and (b) used an effectively smaller sampling area than the other workers.

The field visit on 16th May 2013 was time-constrained and only a cursory examination of the vegetation was possible. Nonetheless, general observations were made and Dr R Tratt was also able to record four samples of vegetation from former relevé locations in Middle Marsh and Mill Dyke Marsh, and to measure water pH and conductivity values (Middle Marsh only – the process was interrupted at Mill Dyke Marsh) (Figure 2).

The visit was quite early in the growing season (roughly about two-months in advance of the previous, reference, studies) and was made before all, and in some cases perhaps even any, of the shoots of some wetland species had emerged (many wetland species emerge rather late in the season). For example, at Middle Marsh many leaves of *Cirsium dissectum* were rather erect and spindly, and in the process of expanding, rather than well spread across the ground surface. This may well have influenced the cover values recorded for some species.

5.1 NORTH MARSH

Most of the vegetation pattern in North Marsh was examined just by superficial inspection (mostly from the path). This was because it was considered that the reported turfing out of this area in the 1990s was likely to have reduced significantly its surface level, and modified its vegetation, so that a meaningful comparison with previous vegetation samples could not been made. Nonetheless, the superficial examination did suggest that the present vegetation pattern may be broadly similar to that mapped by previously by Giller (1978) and Parmenter (1995), despite the reported removal of surface peat. Details of the turf-removal operation (depth removed etc.) are not known to BDW, but it is suspected that only a relatively thin scrape was taken off. This is partly because Mr P. Riches has reported that the turf removal did not materially assist the rewetting of the marsh, but also because the preservation of the former vegetation patterns suggests that excavation did not eradicate the underground biomass and that regeneration has occurred readily from this.

Turf was apparently not removed in the 1990s from the birch-*Sphagnum* scrub in the south-western corner of North Marsh, and this was visited and examined in more detail. A quadrat sample was not recorded, because no previous locatable samples from this patch are known with which it could be compared. As far as can be recalled, this scrub retains much of its former character. *Dryopteris cristata*, which had formerly been seen here, but only in small quantity, was not refound. If it has been lost, it is most probably a consequence of on-going maturation and shading by the scrub. The scrub retains a healthy population of *Carex rostrata*. This can be regarded as a ‘wet fen species’ (mean associated summer water level = 1 cm agl; data from FENBASE database) and its continued prevalence here would suggest that this location does not normally suffer sustained low water tables.

5.2 MIDDLE MARSH

Middle Marsh is a small, almost square, compartment in which dykes surround a sump-like depression of fen. The centre is occupied by a shallow pond, apparently dug down to the underlying Crag in 1947. Aspects of the history and other characteristics of the compartment have been summarised by HSI (2001).

Two parts of Middle Marsh were examined in May 2013. Both had been examined in 1986 (and earlier) and locatable sample data were available. These locations were re-sampled (Table 1). The appearance of the vegetation of some of this area had changed considerably since 1986 in consequence of (a) mowing management; and (b) extensive spread of *Sphagnum* species (together with *Drosera rotundifolia*).

5.2.1 Vegetation and Habitat

Vvegetation features of particular note in Middle Marsh are the patches of a rather impoverished version of S27 (much of it dominated by *Juncus effusus*) and a stand of M24 in the south-eastern corner. These were mapped by Giller (1978) and, with little change (except in community identity), by Parmenter (1994) (Parmenter designated the M24 stands as M22d). Samples available up to 1986 provide no indication of significant *Sphagnum* in either of these communities (except for a small amount of *Sphagnum subnitens* recorded in an M24 sample by BDW in 1974). Subsequently, Parmenter recorded some *S. fimbriatum* and *S. squarrosum* in 1994 in one of her S27 samples, but not in the other two, and a small amount of *S. squarrosum* from one sample in the 'M24' area. By 2001 BDW (in HSI (2001)) reported that the S27 vegetation of Middle Marsh "contains abundant *Sphagnum*" and further noted that "The wet, base-poor water in Middle Marsh provides an ideal environment for the luxuriant growth of *Sphagnum* species – and whereas the *Sphagnum*-rich vegetation can perhaps still mostly be referred to *Carex rostrata–Potentilla palustris* tall herb fen (S27), patches are similar to *Carex rostrata–Sphagnum recurvum* mire (M4) and it seems likely that this latter community will become more prominent. The development of *Sphagnum* in this context is different to that in most other compartments, where it is associated with buoyant mats upon base-rich water, as here the irrigating water is itself rather base poor."

It has long been recognised that the water in Middle Marsh is of low pH, and apparently uncoupled from the more base-rich water of the surrounding dykes, since at least the 1980s, with values as low as pH 4.5 being recorded (K.E. Giller, unpublished data). In their sample of S27, Wheeler & Shaw measured pH 4.9 in 1986, whilst in May 2013 Dr R. Tratt recorded pH 4.7 from approximately the same location. Collins (1988) also recorded unusually low ionic concentrations[7] in a sample from Middle Marsh, which appears to have been quite close to the S27 area. The consistently low values that have been measured contrast strikingly with a statement of Mr. A. Bull (in Baker *et al.* 2008) that Middle Marsh "has a somewhat higher pH than most of the other fens" (p.18) and that Middle Marsh "is the marsh with the higher pH" (p.20). Bull does not provide pH data and the basis for these propositions is not known, but they appear to be erroneous.

The cause of the particularly low pH and base-status of Middle Marsh is not known (HSI, 2001), nor is the trigger that has led to the expansion of *Sphagnum* since 1986. Even in 1986, and before then, the low base-status of the water would have been well suited to the *Sphagnum* species that have subsequently colonised the marsh, so perhaps the more pertinent question is why *Sphagnum* was so scarce up to 1986. Possibilities include the affect of changing management practises. It is believed that Middle Marsh was once managed by burning, at least in the 1970s (D.S.A. McDougall, *pers. comm.*; see HSI, 2002). BDW recalls Mr D.S.A. McDougall once stating that Middle Marsh was his best 'butterfly marsh' because

[7] For example, Collins reported a Ca concentration from Middle Marsh of 6 mg l^{-1}. Values elsewhere in the Internal sytem fens were in the range 20 – 40 mg l^{-1} whilst the concentration from adjoining dykes were 77 and 133 mg l^{-1}.

burning encouraged the occurrence of the emergent plants of *Peucedanum palustre* that were favoured by *Papilio machaon.* Burning may be inimical to *Sphagnum* species, especially in 'marginal' contexts, both through direct damage and the deposition of ash. The current mowing-based management avoids such affects and, given removal of the mowings, may further encourage base- and nutrient-depletion in this habitat by the export of elements from the marsh. It is also possible that mowing could assist the spread of *Sphagnum* fragments around the marsh (*Sphagnum* species are known to regenerate readily from vegetative fragments when conditions are appropriate). The more surprising spread of *Sphagnum* into the area of M24 could also reflect a persistent *increase* in the wetness of this location (see below). This could also account for the observed occurrence of frequent plants of *Drosera rotundifolia* in the M24 area in 2013, which Mr. A. Bull (in Baker *et al.* 2008, p. 18) considered to be restricted to 'Mill Marsh' (= 'Mill Dyke Marsh' of this report). Harding (2010), apparently quoting Mr. Bull, stated that "heath spotted orchid has not appeared in middle marsh for two years", but several individuals of this species were observed in May 2013.

5.2.2 FENSPEC analyses of Species Change

In the absence of a run of water level measurements it is not possible to make a direct assessment of any changes in water levels in Middle Marsh. However, the FENSPEC application has been developed (by BDW) specifically for use in this situation, to make a proxy assessment of likely water levels using the measured water-level affinities of individual plant species (see Annexe 2). The FENSPEC–derived indices of Water Level have been determined for the two pairs of quadrat samples available from Middle Marsh (Table 1). In the case of the S27 sample the index is little different between 1986 and 2013, as might perhaps be expected from samples in a sump area with a water level that is generally well above ground level for much or all of the year. The change of Water Level Index in the M24 samples, located on higher, drier ground near the margin of the marsh is of greater magnitude and significance, as it indicates that this 'dry' part of the compartment now supports more species indicative of wetter conditions than was the case in 1986

It is important to recognise that the Water Level indices integrate water conditions, including their fluctuations, as experienced by the vegetation over a long period of time. Thus the data in Table 1 do *not* indicate that the measured water table in May 2013 would necessarily have been higher than in July 1986, but that, overall, between the two years there has been some increase in plants that are indicative of more wet conditions. For this same reason, the higher wetness index values in 2013 cannot be attributed to, say, the wet summer of 2012, not least because fen vegetation is mostly composed of perennial plants with considerable tolerance of both periods of dryness and wetness, and does not normally show a quick or capricious response to variation in water supply unless the change is catastrophic (*e.g.* months of deep flooding)[8].

[8] An exception to this generalisation may be provided by *Drosera rotundifolia*, which, unlike most wetland plants, has ruderal characteristics, including short longevity and high rates of seed production. It is possible that this species may have colonised the higher, acidic, more marginal, parts of Middle Marsh in response to the wet summer of 2012.

Table 1. Species records and Water Level Index values for pairs of samples of M24 and S27 vegetation recorded from the same locations on Middle Marsh in 1986 and 2013. Species data are Domin values (0 = outside sample) Water Level Index data derived from the FENSPEC protocol. Higher values indicate higher water levels.

	Community: Year:	**S27: 1986**	**S27: 2013**	**M24: 1986**	**M24: 2013**
	Sample ID:	**12125001**	**12125021**	**12125005**	**12125025**
	FENSPEC water level index:	**-2.5**	**-2.3**	**-6.2**	**-4.3**
122	*Agrostis stolonifera*	9	6	4	3
171	*Anthoxanthum odoratum*			5	5
269	*Calamagrostis canescens*			0	
295	*Cardamine pratensis*	1			
333	*Carex nigra*			6	5
339	*Carex panicea*			0	
352	*Carex rostrata*	6	6		1
468	*Dactylorhiza maculata ericetorum*				0
494	*Drosera rotundifolia*				1
501	*Dryopteris carthusiana*		1		
521	*Epilobium hirsutum*			0	
525	*Epilobium palustre*	3	3		
533	*Equisetum fluviatile*	4	4		1
546	*Eriophorum angustifolium*	6	5	4	3
609	*Galium palustre*	0	0	1	
680	*Holcus lanatus*			4	2
690	*Hydrocotyle vulgaris*		2	7	5
715	*Iris pseudacorus*	1	1	0	1
719	*Juncus acutiflorus*			8	7
730	*Juncus effusus*	6	5		
802	*Lotus pedunculatus*			4	3
809	*Luzula multiflora*			0	2
813	*Lychnis flos-cuculi*			2	1
830	*Lysimachia vulgaris*	3	1	2	1
831	*Lythrum salicaria*			2	2
862	*Menyanthes trifoliata*	0	2		
876	*Molinia caerulea*			6	5
1046	*Potentilla erecta*			3	3
1049	*Potentilla palustris*	5	5		
1089	*Ranunculus flammula*			3	1
1169	*Salix cinerea*	1	1		
1305	*Succisa pratensis*			3	3
1362	*Typha latifolia*	1	0		
1381	*Valeriana officinalis*			2	1
1427	*Viola palustris*			3	
1444	*Calliergon cordifolium*	1	1		
1445	*Calliergon cuspidatum*			3	1
1482	*Aulacomnium palustre*				2
1891	*Polytrichum commune*				0
1914	*Pseudoscleropodium purum*			4	
1940	*Rhytidiadelphus squarrosus*			3	
1964	*Sphagnum fimbriatum*		7		6
1971	*Sphagnum palustre*		2		3
1973	*Sphagnum subnitens*		2		
1976	*Sphagnum recurvum*				7
1980	*Sphagnum squarrosum*		3		
2714	*Cirsium dissectum*			7	7
3198	*Peucedanum palustre*	3	3	2	1

5.2.3 Other evidence for species change

Reports have been forthcoming about other aspects of species change in Middle Marsh. Both Mr A. Bull and Mrs A Harris have stated that there has been a decline in *Eriophorum angustifolium* in this area but it is not clear if the suggested decline relates to all shoots of the plant or just to the more conspicuous flowering shoots. A good number of vegetative shoots were still present in this location in May 2013, but there was a small decline in cover estimates for this species in both samples between 1986 and 2013 (Table 1). If a real decline has occurred, its cause is far from clear, as this species can grow across a wide pH range and is often most prominent in exactly the sort of and water conditions measured at Middle Marsh in 1982, 1986 and 2013. It would be difficult to sustain an argument that *E. angustifolium* was declining due to ‘drying’ whilst other, equally wet-loving associates such as *Drosera rotundifolia, Sphagnum fimbriatum, S. palustre* and *S. recurvum* have been expanding.

5.3 MILL DYKE MARSHES

Time was granted for examination of only the northern end of Mill Dyke Marshes, where two vegetation samples were recorded (Table 2).

The main vegetation examined was a *Sphagnum*-based community with *Dryopteris cristata.* Other species characteristic of this vegetation included *Drosera rotundifolia, Eriophorum angustifolia* and *Osmunda regalis* (sample 220059). This same community was also present in 1977, but in a wetter, immature state with fewer characteristic species (sample 220039). In 1995 this location was mapped as W2 by J. Parmenter, who did not record a relevé sample, but made the following Target Note: “T30: Birch scrub with occasional *Dryopteris cristata*, some *Osmunda regalis.”* It seems likely that by then the patch had become quite strongly dominated by birch, which obscured its real floristic character. Since then, and presumably in response to sympathetic management by the Catfield Hall Estate, the patch has essentially regained its former character, but in a more mature (and richer) form. This can be seen as a very desirable expansion of the *Sphagnum-Dryopteris cristata* community (which can be allocated to the EC Habitats Directive Annex 1 habitat category of ‘Transition Mire & Quaking Bog’).

A rather curious feature of the *Sphagnum* area in 1977, which still prevails, is that it straddled the central dyke that split Mill Dyke Marsh into east and west compartments. This may suggest that this dyke was dug after the initiation of the *Sphagnum* ‘boil’ (see 8.2.1). If the dyke was dug partly in an attempt to improve water circulation and stall the acidification process, this initiative was singularly ineffective!

In the 1970s much of the western half of Mill Dyke Marsh was comprised of wet reed beds; the eastern half was then rather more mixed and in some part ‘drier’, partly referable to S24a. The eastward ‘toe’, projecting along the southern edge of South Marsh supported S24g and stands of *Myrica gale* and other srub[9]. A sample was recorded (220053) from the main, wet reed area in the western compartment in 1977, some distance south of the *Sphagnum – Dryopteris* ‘boil’. No time was available to re-sample this area in 2013, but a sample was recorded (220060) immediately south of the *Sphagnum* patch. This cannot be used as evidence for the present state of 220053, which remains to be established, but it does at least show that similar vegetation persists in part of this compartment.

On the basis of the evidence available, there is no reason to suspect that the botanical condition of the north end of Mill Dyke Marshes has deteriorated since the surveys of Giller (1978) and Parmenter (1995). The re-emergence, since Parmenter’s survey, of a *Sphagnum*-based community at the northern end of the compartment, richer than in 1977, can be regarded as an enhancement of the conservation value of the marsh, and may be partly attributable to a sympathetic and effective management regime. This area had a somewhat lower FENSPEC Water Level Index in 2013 compared with 1977, probably reflecting the maturation and associated drying of the surface.

It would clearly be desirable to make a comparative examination of the central and southern parts of Mill Dyke Marsh and of some compartments south of this.

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[9] The eastward-projecting extension at the southern end of Mill Dyke Marsh, which penetrates into the south-west corner of South Marsh is considerably drier, and contains a greater preponderance of communities such as S24g, than the rest of Mill Dyke Marsh. This is because this part of the compartment is comprised of uncut peat, which was formerly continuous with that in South Marsh (25” OS plan, 1905), and is not a former turf pond.

Table 2: Species records and Water Level Index values for pairs of samples of '*Sphagnum "boil*"' vegetation (BDC) recorded from the same location on Mill Dyke Marsh in 1977 and 2013 and samples of S4 recorded from different locations. Species data are Domin values (0 = outside sample) Water Level Index data derived from the FENSPEC protocol. Higher values indicate higher water levels.

	Community: Year:	**BDC: 1977**	**BDC: 2013**	**S4: 1977**	**S4: 2013**
	Name	**11220039**	**11220059**	**11220053**	**11220060**
	FENSPEC water level index:	**-6.9**	**-7.1**	**-4.0**	**-4.0**
122	*Agrostis stolonifera*	3	3		
236	*Betula pubescens*		5		
269	*Calamagrostis canescens*	6	6		
320	*Carex elata*		3	5	5
346	*Carex pseudocyperus*			4	
411	*Cicuta virosa*			4	1
420	*Cladium mariscus*		0		4
501	*Dryopteris carthusiana*	3	3		
525	*Epilobium palustre*	3	1	3	2
546	*Eriophorum angustifolium*		0		
558	*Eupatorium cannabinum*	3	3		
609	*Galium palustre*	3	3		
715	*Iris pseudacorus*		3		
823	*Lycopus europaeus*	3	0		
830	*Lysimachia vulgaris*	3	3		
831	*Lythrum salicaria*	3	3		
855	*Mentha aquatica*			4	3
931	*Osmunda regalis*		3		
961	*Phragmites australis*	7	7	9	9
1049	*Potentilla palustris*	3	3		2
1093	*Ranunculus lingua*			3	3
1144	*Rumex hydrolapathum*	3	2		
1268	*Solanum dulcamara*	3			
1328	*Thelypteris palustris*		1		
1361	*Typha angustifolia*	3		5	0
1444	*Calliergon cordifolium*				3
1964	*Sphagnum fimbriatum*		6		
1971	*Sphagnum palustre*	4	3		
2732	*Juncus subnodulosus*	3	3		
2973	*Sium latifolium*			4	
3198	*Peucedanum palustre*	3	3	3	3
3518	*Dryopteris cristata*	3	3		

6. TERRESTRIALISATION OF TURF PONDS

Cartographical sources (*e.g.* the 1st edition 'County Series' Ordnance Survey plan, 1884) and stratigraphical evidence (*e.g.* Giller & Wheeler, 1986) indicate that large parts of the Catfield & Irstead fens are covered with extensive rectilinear compartments that have been interpreted as former turf ponds (Jennings, 1952; Giller & Wheeler, 1986) (Figure 3). These are shallow peat workings, dug typically to a depth of *c.* 80 cm, or slightly shallower where over estuarine clay. The proportion of the fen surface occupied by the turf ponds can be estimated as between about 40 and 60%, the estimate depending on the precise compass envisaged of the 'Catfield & Irstead Fens' (the lower value is recorded when the Sharp Street Fens – which are in Catfield parish and part of the same broad fen unit – are included within this compass, as was done by Giller & Wheeler).

Direct historical evidence for peat extraction is sparse, but unpublished records of the Neatishead Charity Trustees for the period 1815–1875 indicate turf removal from Neatishead Poor's Fen[10] for the period 1815 to 1855, with production peaking in the 1830s when between 16,000 and 17,000 turves were cut in some years (Figure 4). The resulting depressions subsequently re-flooded and became colonised by reed, reedmace and, in places, saw-sedge, to form wet swamp and open water. This early, very wet, condition in the Catfield & Irstead fens is evidenced by the historic OS plans (1884, 1905), the diary of R. Gurney, and by peat stratigraphical evidence (Giller & Wheeler, 1986).

Giller and Wheeler were particularly interested in the terrestrialisation of the turf ponds, both in terms of the processes involved and their relationship to 'present-day' (then 1980s) vegetation patterns. They recorded a series of stratigraphical sections across the fens, along with macrofossil analyses of the upper (turf pond) part of the peat cores. Macrofossil composition and change was considered further and in greater detail by Wells (1988).

The macrofossil cores from the turf ponds typically showed a terrestrialisation sequence from open water muds to wet reedswamp and thence (except in those locations that were still wet reedswamp) to a more diverse fen vegetation, first with 'wet fen' species and then 'dry fen' species. This process, and its associated change in water conditions towards surface drying, occurred whilst the compartments were being mown for reed (or, in some cases, sedge). Professor D. Gilvear (in Mason, 2012) has stated that terrestrialisation cannot have led to autogenic drying in the Catfield Hall Fens because their management regime has not changed, but his proposition misses the key points that (1) stratigraphical, ambulatory and piscatorial evidence indicates that terrestrialisation-induced drying has *de facto* occurred in all of the mown turf ponds, in both the internal and external systems; and that (2) vegetation management does not stop the process of terrestrialisation (though it may slow its rate).

It is important to appreciate that growth and production of biomass and necromass is not confined to the above-ground parts of plants. Their below-ground structures also grow and die. Most wetland ecologists have been understandably reluctant to try to quantify below-ground biomass accumulation in *Phragmites*, particularly in field conditions, and have mostly contented themselves with measurements of above-ground material. However, it appears that more than 60% of the biomass of *Phragmites* can be located underground (*e.g.* Soetart *et al*, 2004). The partly-buoyant underground structures, both living and dead, contribute to the process of terrestrialisation and, in the early stages at least, probably disproportionately so, relative to the contribution from above-ground material, even when the latter is *not* mown and

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[10] Neatishead Poor's Fen is an extraparochial fen compartment, located in the Irstead parish portion of the Catfield & Irstead Fens. Comparable records from the Irstead and Catfield Poor's Charities have not been found, but White (1845), with regard to Irstead, referred to "The *Poor's Allotment*, awarded at the enclosure in 1805, is 39A. 2R. 6P., on which turf is cut" whilst Gunn (1864) refers to "the discovery of several coins in digging turf in Catfield, near Ludham, the latest of which was of the reign of Edward VI" [1537-1553].

removed. This is partly because below-ground, saturated conditions provide suitable conditions for the growth of living rhizomes, so that root material, proto-peat and peat can accumulate readily, even when surface conditions are too dry for peat accumulation above ground. This process can be enhanced by two other factors: one is the buoyancy of the rhizome and proto-peat mat, which can help to produce precociously high surface levels; the other is the annual upward growth of reed shoots from submerged rhizomes which can exert some upward pressure. [Haslam (2010) has described the interesting situation where reed-growth continues upwards into *Sphagnum*-invaded reedbeds and can help elevate the surface.] In addition, unless they are deliberately mown-out by marsh-men, the natural growth of invasive tussocky wet-fen species (such as *Carex elata*) can help form an elevated, living platform in the later-successional stages of turf ponds, and this can be colonised readily by less wet-loving wetland species. For all of these reasons, whilst the formation of peat *mass* in turf ponds generally *is* a slow process, the occlusion of their shallow water by a loose volume infill of rhizomes and proto-peat is much quicker, which probably accounts for the high rates of 'peat' accumulation that have been reported (*e.g.* "a foot [30 cm] in twenty years" (Gunn, 1864)). This is not a slow, acropetal accumulation of plant remains that have sunk to the bottom of a turf pond, but a process based upon buoyant rhizomes and their remnants, which can form floating islands that "become massed and compacted together, and in time form marshy ground" (Gunn, 1864).

As the reality of this process has been contested by Professor Gilvear (in Mason, 2012), a simple analogy may help. Consider a bath kept full of water, regulated by an overflow hole, into which it is possible somehow to introduce at the bottom an on-going supply of slightly buoyant, somewhat compressible balls. The initial balls will form a loose raft, at or just below the water surface, but as more balls continue to be added at the bottom a point is eventually reached at which the density of balls is such that the uppermost ones are displaced upwards above the water surface. As the balls are somewhat compressible, this will not be a linear process as spatial constraints provided by the sides of the bath and the accumulating mass of balls at the surface will tend to compress some of the lower balls and reduce the volume each one occupies. Like most crude analogies, this one has clear limitations, but it helps make the point that, in its early stages, the accumulation of turf pond infill, and its elevation, is essentially a volume-based process, controlled by the growth of rhizomes (*i.e.* uncompressed balls) and the gradual disintegration of their derivative necromass (*i.e.* partly compressed balls). Above-ground plant biomass production, and the impact of vegetation management, can be represented by the addition or removal (respectively) of balls at the surface, a process which is in considerable measure distinct from the addition of new balls from below Of course, this analogy can be pushed too far: whilst the accumulation of balls in a bath could potentially continue indefinitely, pushing them ever further above the water level, the infilling of turf ponds is essentially asymptotic, through the supervention of the position of the water table as a control on the continued gross accumulation of peat *mass* as the infill consolidates, coupled with the balance of decomposition. The actual height of the fen surface at any one time in the terrestrialisation process is determined by a number of interacting variables, including the polymorphic growth patterns of the underground structures of *Phragmites* (Haslam, 2010), growing in a first unconfined, and then – as root mass accumulates – an increasingly confined, sub-surface space; positive upward pressure created by the upward growth of shoots; and the accumulating mass of surface material. Because much of the process is determined by conditions below the water line, it is possible for the surface to rise proud of this to, or even beyond, the point at which any significant surface-based gross peat accumulation would be possible. On the other hand, the eventual accumulation of a substantial above-ground mass of vegetation *etc* can sometimes result in the lowering of the accumulating raft. This can be seen most obviously where the growth of high mass plants (such as trees) can cause depression of the fen surface and reverse, at least temporarily and locally, the 'drying' process of terrestrialisation.

These points have been made in some detail to provide an ecological and biological basis for a process that is (or at least was) well known to most marsh-men, namely the autogenic drying of reed-beds, their invasion by what they saw as ‘weeds’, and a concomitant reduced vigour and crop-mass of *Phragmites.* This process has rarely been documented by them, but George (1992) reported that “When shown such a site, older marshmen will say that it has ‘gone rotten’ and that the remedy in the past was to ‘turf it out’. According to Mr. H. Grapes, one time marsh foreman on the Ranworth Estate, this involved digging away the top 18 inches or so (*c.* 45 cm) in *c.* 10 feet (3 m) wide strips. The peat thus obtained was allowed to dry out on the baulks left between the ‘reed dykes’, before being barrowed away for use as fuel. Once this Herculean task had been completed, the Reed would, it is alleged, start to grow again with renewed vigour.” It has been reported, by Mr A. Alston, that the process of ‘turfing-out’ occurred in the Catfield Fens in the 1920s, but it is not known to which compartments, or parts of the fen, it was applied, or even if it applied at all to the fens of the Catfield Hall Estate.

If ‘turfing out’ was found necessary at Catfield in the 1920s, this was probably some 70 to 100 years after the peat pits had been abandoned and reflooded (assuming that the Catfield workings were more-or-less contemporaneous with those in Neatishead Poor’s Fen). As a similar time interval has elapsed since then, it is perhaps to be expected that some reedbeds are once more over-mature and ripe for turfing out. Given this time line, it is perhaps not surprising that some or all of the former turf pond sites are perceived now as ‘drying out’. This would, of course, apply particularly to any compartments that were not turfed out in the 1920s.

Mr P Ritchie has commented that his attempts to turf out North Marsh and Rose Fen, to rewet them, were unsuccessful. A simple response to this could be that he had not removed a sufficient depth of peat to facilitate water penetration from the adjoining dykes. This would, however, ignore the potentially significant point that neither of these compartments (and certainly not Rose Fen) appear to have been former turf ponds (Box 1).

It is important to recognise, as has been emphasised by Wheeler, Shaw & Tanner (2009), that the ecohydrological functioning of turf ponds does not just relate to the height of the accumulated ‘peat’ surface; it relates also to the storage of water (*e.g.* precipitation excess) in what are effectively large ‘tanks’; to the buoyancy of the vegetation mat, and its capacity to accommodate gross changes in water level; and also to the transmissivity of the turf pond infill, which can relate particularly to its capacity to permit lateral water flow from adjoining dykes (*etc.*) in response to an evapotranspiration-driven reduction in water level in locations distant from the dykes in dry, summer conditions. ‘Solid’ (*i.e.* undug) blocks of peat in Broadland do not generally have buoyant surfaces or a high free water storage capacity, and the K values of their peat are usually lower than those of adjoining turf ponds, sometimes much lower. Similarly, the process of terrestrialisation in turf ponds does not just involve an accumulation of peat and elevation of the fen ‘surface’, but also usually an eventual loss or reduction of any surface buoyancy and storativity and a decrease in ‘peat’ permeability.

An understanding of the topographical relationships within and between turf ponds can materially help understand their ecohydrological status and functioning. The recognition that the LIDAR survey of Catfield has not demonstrated any clear height differences within the drying turf ponds is not surprising given the suggested resolution of 25 cm, as stated by Mason (2012) (a value which can encompass the entire normal water table range separating some types of fen and grassland), and the uncertainties introduced by the varying height and layering of the vegetation. More traditional field-based levelling methods can also often be of limited accuracy in this difficult terrain, where the irregularity or instability of the surface can impose their own constraints on the secure or consistent location of apparatus, and where the overall ‘base-level’ height variation between any two points may be much less than the local topographical variation at and around either of them! Such constraints led ECUS (1997) to use a water manometer to level parts of Upton Fen. It is also should be recognised that the key parameter with regard to ‘drying out’ is *not* the absolute height of the surface levelled to Ordnance Datum, but the level of the surface relative to the water table. This latter may or may not be related consistently to its elevation aOD, depending on local circumstances.

7. ACIDIFICATION AND *SPHAGNUM* SURFACES IN TURF PONDS

Vegetation rich in *Sphagnum* species occurs in two main circumstances in Broadland:

1. As (scarce) patches of marginal vegetation near the edges of the fens. At Catfield this is (now) the case at Middle Marsh.
2. As late-successional developments within terrestrialising turf ponds

Vegetation belonging to the second of these categories is usually of small extent, but is quite widely scattered in Broadland, particularly in the northern river valleys, such as that of the Ant (Figure 5) where *Sphagnum* forms the basis of a distinctive, and valued, vegetation-type that provides the most typical habitat for the rare fern *Dryopteris cristata*, and sometimes also *Pyrola rotundifolia.*

Sphagnum stands in turf ponds in the Catfield & Irstead Fens, as elsewhere in Broadland, are mostly quite small, but they are quite widespread (Figure 6). They occur both in unmown and regularly mown situations and in the latter are often regarded by marsh-men as having nuisance value[11], because they are associated with a strong decline in the vigour of reed and, growing up some tens of centimetres above the former peat surface, form nuclei which can be colonised readily by a number of drier-loving plant species, including scrub. Mr D.S.A. McDougall described these patches rather aptly as 'boils' which erupted within reedbeds, and very often within the best reedbeds too. Marsh-men have sometimes described them as indicating that the fens are 'going "sour"'. As with the more general problem of late-terrestrialisation states in the turf ponds, the only real solution to Mr McDougall's 'boils', from a marsh-man's perspective, is to lance them by 'turfing them out', but this option is particularly constrained with the *Sphagnum* surfaces as these are rare and have a highly-regarded conservation status (as 'Transition Mire'). In any case, the more general response of marsh-men to the 'boils', at least in the 1980s, was to mow around them. In this unmown state, these shallow mounds were often susceptible to quite rapid invasion by woody species such as *Myrica gale, Rubus fruticosus* and eventually *Betula pubsecens.* The resulting development of woody vegetation eventually created small islands of trees within the fens, from which *Dryopteris cristata* (which appears to be shade-intolerant) was gradually lost as was, in some extreme instances, living *Sphagnum* (so that the former presence of a *Sphagnum* surface was in some locations detectable only by stratigraphical probing). Elsewhere, however, *Sphagnum* has often remained as an important component of the maturing 'boils', within what Wheeler (1978) categorised as the *Sphagnum* variant of a '*Beula-Myrica*' community and where "Cushions – even carpets – of Sphagna occur – *S. fimbriatum, S. palustre, S. squarroum* – which in summer are frequently dry and bleached" (Wheeler, 1978). Thus observations of 'drying' in summer conditions on the maturing *Sphagnum* surfaces are of long-standing and relate to a widespread process, not one that is specific to 'Catfield Fen' or to the Catfield Hall Estate.

The acidification of base-rich fen surfaces, leading to the establishment of *Sphagnum* vegetation is a widespread late-successional trend in fens in the oceanic climates of north-west Europe. The main eco-hydrological requirement is the occurrence of surfaces that form above the normal influence of inundation by base-rich, telluric[12] water. Traditionally, the process has been considered to occur by the progressive accumulation of peat up to and above the level of base-rich flood (Weber, 1908). However, more recently it has been recognised

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[11] Mr P. Neave (*pers. comm.*) described the *Sphagnum* areas at Catfield as being "all over the place"… "grey, loose moss, choking the reed".

[12] Telluric water is water that has been associated with the mineral ground, as opposed to meteoric water (direct precipitation). It is a useful generic term that encompasses both 'surface water' and 'groundwater'.

that the process sometimes can be triggered by a *reduction* of telluric water levels, be this in response to a period of climatic drying (Hughes & Dumayne-Peaty, 2002) or groundwater abstraction (Lamers, Smolders & Roelofs, 2002), or by lateral separation from base-rich water sources (Walker (1970) suggested that the acidification of some buoyant mats in basins occurred because a surrounding marginal band of fen vegetation intercepted nutrients and bases). Hence, when Wheeler and Giller examined the occurrence of acidifying nuclei in the Catfield & Irstead fens, it was with the expectation that these would be associated with fen surfaces that were generally deficient in bases, and probably well separated from sources of enrichment. However, both spatial and chemical analyses indicated that this supposition was incorrect because, whilst "there was evidence for progressive base-depletion in parts of the fens remote from the river … *Sphagnum* communities are not restricted to these places but are also developed in fen compartments with cation-rich water and adjacent to dykes and waterways with eutrophic water" (Giller & Wheeler, 1988). They found that the most consistent feature of the *Sphagnum* 'boils' was that they had a quaking surface and that the amplitude of water level fluctuation *relative to the surface* was much damped compared with adjoining non-*Sphagnum* fen surfaces. They concluded that "Isolation from inundation by base-rich water is necessary for the development of *Sphagnum* lawns. Where *Sphagnum* has invaded fen compartments with base-rich waters, flooding is avoided by vertical movement of the peat surface which also prevents desiccation of the *Sphagnum* surface during prolonged dry periods. … Vertical movement occurs both through floating rhizome rafts and, more commonly, by expansion and contraction of a loose peat matrix".

It was thus clear that, in the Catfield & Irstead Fens, as elsewhere in Broadland, initiation of *Sphagnum* surfaces was not conditional on a reduction of base-rich water level and its substitution by a 'rain-water lens', as had been suggested in the Netherlands. This is perhaps most obviously seen at Heater Swamp (Figure 6), where buoyant *Sphagnum* communities occur in close juxtaposition and hydraulic connection with the eutrophic, base-rich waters of Barton Broad.

Elsewhere in Britain, Tratt (1997) has also demonstrated that the formation of buoyant, seral *Sphagnum* surfaces was independent of the base-status of the underlying water. She found that *Sphagnum* invasion could occur upon buoyant reed (and other) communities, even over highly calcareous waters, except upon a band along the margins of the fen basins, where the raft was attached to the rising mineral ground and thereby 'grounded'.

8. THE COMMISSIONER'S ROND AND DRAINAGE OF THE CATFIELD & IRSTEAD FENS

8.1 CARTOGRAPHIC EVIDENCE OF DRAINAGE HISTORY

8.1.1 Faden's map of 1797

The 1797 map of Faden (Barringer 1989) indicates that in the late 18th century 'Catfield Marsh' was drained by a short tributary of the Ant, which originated in the shallow valley below what is now Catfield school and flowed west from Church Wood through the fen a short distance north of, and roughly parallel with, its south-eastern margin, to enter the current River Ant on a small east-looping bight about halfway between Mud Point and Irstead church. This course presumably represents a natural drainage axis of the fen from the eastern upland margin. It is possible, even likely, that before the tributary reached the present-day Ant it joined the Hundred Stream (the original course of the Ant before it was diverted through Barton Broad), as it looped east through the fens, and that the western section of the tributary stream as mapped by Faden corresponds with the stretch of the old Ant which once flowed west to what is now 'Mud Point'. About 200 m east of its confluence with the present course of the Ant, the 'Church Wood' stream was mapped as being joined by a gently-curving dyke that had been dug more-or-less parallel to the eastern side of the Ant and Barton Broad and which extended north from the stream to the end of the Fenside track (Fen Street) near the north-west corner of the marsh. It is presumed that this dyke had been dug to serve a staithe at the end of Fen Street. The northern half of this dyke does not obviously conform to the course of any existing dykes, though it is in very roughly the same general position as the former (but more winding) course of the River Ant through the northern part of the fen. The southern half of this dyke may possibly broadly correspond with dykes that currently separate the southern section of Moores Head Marsh and Home Marsh from the turf-pond compartments of the interior to their east.

8.1.2 Maps of the early 19th century

Inclosure Award and Map for Catfield & Sutton (1807)

Apart from the two water channels mentioned above, Faden provided no indication of any internal subdivisions within the Catfield & Irstead fens. The mapping of the stream from Church Wood, which is not shown on any later maps other than that of Bryant (1826) (which may partly be derived from Faden), may represent a pre-Inclosure feature of the site, but it is not known what, if any, other features and subdivisions of the fens were also present before Inclosure. The map associated with the Inclosure Award for Catfield & Sutton (1807) indicates a subdivision of the areas of fen rather similar to, but not identical with, that shown on the Tithe Apportionment of 1843 (map surveyed in 1840) (*q.v.*). It is not always clear which of the mapped features pre-dated Inclosure, but the 'Commissioner's Rond' (or simply 'Rond') was clearly a product of the Commissioners for Drainage of the time, as was "Drain No. 2", dug along the internal side of the Rond and specified as being 4' deep and 10' wide at the top, and a 'Cross Drain' (Drain No. 4), a 12' drain which may correspond with the present 'Commissioner's Drain' along the western side of North and Middle Marshes. At least part of the Landspring Drain (another 10' drain), *viz.* the section along the northern margin of the fen, appears to have been initiated then.

Ordnance Survey Drawings (Budgen, 1816) and 1st edition 1” OS ‘Old Series’ map (1837)

The fens were surveyed in 1816 by C. Budgen at a scale of 2”: 1 mile and the surveyor’s drawing shows that many of the present-day features were then in place. The present-day rond is shown, as a doubled-ditched structure, extending *via* a large eastern loop from the upland margin at Fenside in the north-west to meet the Ant at Mud Point[13]. Budgen also mapped, joining with the Rond, another double-ditched feature (a rond or loke) connecting the old mill north to Fen Street, along what is now part of the western edge of the Catfield Hall Estate. The only other main feature shown by Budgen is a single, straight line, apparently a dyke, running south-south-east across the entire Catfield & Irstead fens, from near Fenside in the north to the Commisioner’s Rond a short distance east of Mud Point[14].

The Commissioner’s Rond can be traced readily on the 1st edition OS ‘Old Series’ map of 1837, which was based on Budgen’s mapping, but only the eastern section of this, *viz.* the stretch between the old mill and the north-east end of the Sharp Street Fens, is shown as being doubled-ditched, nor is there any indication of double-ditching between the mill and Fen Street. It is not clear what, if any, significance can be attached to this, as the Catfield Tithe Apportionment (TA) map of 1840 clearly shows the whole length of the rond to be doubled-ditched, though again with only a single ditch (and no obvious loke) from the mill northwards to Fen Street.

A significant feature of Budgen’s drawing and the subsequent 1” map of 1837 is that they both clearly mark the eastern fen compartments at Catfield (*i.e.* the current area of the Catfield Hall Estate) as ‘rough pasture’, in sharp contrast to the marsh symbols used for the rest of the Catfield & Irstead fens. The contiguous Sharp Street fens (also in Catfield parish) are also mapped as rough pasture, thereby contributing to a complete strip of better-drained land along all of the eastern margin of the fens. This swathe of drier ground is not, of course, coterminous with the split across the fens created by the Commissioner’s Rond, as the ‘internal’ compartments of Fenside and Sedge Marshes were still clearly mapped as ‘marsh’ on the 1837 map[15], possibly suggesting the existence of some sort of barrier to water exchange along what is now the eastern side of the Fenside compartment (see also Budgen’s drawing), which facilitated the drainage of the eastern strip. However, any notion that at this time the surface of what is now Fenside Marsh was then wet ‘marsh’ may be countered by the Tithe Apportionment map, which, like the Inclosure Map, shows more intensive compartmentalisation than is found on subsequent renditions.

Tithe Apportionment maps – Irstead parish (1838) and Catfield parish (1840)

Compared with the Catfield parish Tithe Apportionment map (1840), the TA map (1838) for Irstead parish shows a subdivision of the Irstead portion of the fens that is broadly similar to that of the present-day, though with somewhat fewer dykes. In the case of the Catfield apportionment, some features of the fens which are present today were also evident then, in particular the Commissioner’s Rond and, external to this, Great Fen and Little Fen. However, internal to the Rond the compartmentalisation was, in places, very different to that of the present. Sedge Marshes occupied their present position, but the area of Fenside Marsh was then subdivided into about nine small, rectilinear compartments[16], with an access loke from the vicinity of what is now Rose Cottage. North and Middle Marshes were broadly similar to

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13 The eastern loop in the southern part of the Rond accommodated the course of the Hundred Stream (the former Ant and the parish boundary) which is always to the west of the Rond and which, south of Little Fen, formed the external boundary dyke of the Rond. Thus in Catfield parish only Great Fen and Little Fen are external to the Rond, but all of the Irstead fens are external.

14 The dyke was apparently split by the northernmost west-east stretch of the Rond. A similar structure was also mapped by Bryant, though not in exactly the same location. It is not shown on the 1st edition ‘Old Series’ 1” map of 1837.

15 The symbols used for the Sedge Marshes / Fenside are obscure on the copy of Budgen’s drawing examined.

16 These distinctive compartments (along with some others) are identified on the Inclosure Award (1807) as being the “Copyhold of Sutton outsoaken”.

their present-day delimitation, but the area south of Middle Marsh was quite differently subdivided, by two orthogonal dykes, into three main, large compartments (see Figure 7).

The state of wetness of the fen compartments at the time is not really clear: the Catfield TA designates most of the fen compartments at Catfield as ‘pasture’, including the two areas allotted to the Poor of Catfield, *viz*, Great and Little Fens. The same largely applies also to the fen compartments of the Irstead TA, including those allotted to the Poor’s Trustees, both of Irstead and Neatishead parishes. By contrast some privately-owned fen parcels, elsewhere in Irstead parish, are not thus designated. For example, three compartments called ‘Turf Marsh’ supported “reed waters”, “rushes and water” and “mowing marsh” whilst ‘Turf Ground’ and many of the other fen compartments were designated as ‘pasture’. This evidence of habitat discrimination on the Irstead TA may suggest that ‘pasture’ was not being used by the surveyors – as might otherwise perhaps be suspected – as a generic descriptor for anything that was not ‘arable’ but as an indication of the actual state of use. If this is correct, then it is possible that at the time of the Tithe Apportionments even the external compartments of the Catfield & Irstead Fens were sufficiently ‘dry’ to provide ‘pasture’, whilst they were also being dug for peat (Figure 4).

Perhaps the main point to emerge from this description is that the eastern marginal fens seem to have been better drained than the rest of the site in the first half of the 19th century. The contemporary drainage status then of the other Internal Fens (*i.e.* Sedge Marshes and Fenside) is not really clear. If they were less well drained than the rest of the internal compartments, it is not obvious just why this was the case, though it could simply have been topographical coupled with any interception and drainage afforded by the dyke system. Another feature of these early maps is that they provide no obvious cartographic indication that peat was being removed extensively from the fens, but it would seem that, despite being mapped as ‘marsh’ by the 1st edition “Old Series” map of 1837, the surveyors of the Tithe Apportionment map of 1840 thought it appropriate to describe even the Exernal fens as “pasture”.

8.1.3 The “County Series” OS maps (late 19th – mid 20th century)

By the time the detailed 1st editions of the ‘County Series’ OS maps were produced, there was clear evidence of past turbary in the Catfield & Irstead fens, in the form of rectilinear compartments shown with reed (swamp) symbols (and coloured blue in some versions), on both the 25” (1881) and 6” (1890) mappings.

In the External System the Hundred Stream, the former course of the R. Ant, itself became subsumed with the excavations of the Great Fen turf pond and seems also to have been removed along part of the southern margin of Little Fen, so that only its former course remained marked by the parish (and Hundredal) boundary here (Figure 8). At this time, any former inflow from the Hundred Stream into Great Fen was presumably blocked, whilst outflow appears to have been along the dyke on the east side of Moore’s Head Marsh, which connects the south end of Great Fen to Shoals Dyke, and which appears subsequently to have persisted as the main course of a re-routed ‘Hundred Stream’ (Mr. P. Neave, *pers. comm.*). Thus, from this time on, the original Hundred Stream seems to have served as a drainage channel only alongside the Commissioner’s Rond for the reach south (and then west) from the old mill.

In the Internal System, only Sedge Marshes, North Marsh and Middle Marsh had retained more-or-less the outline and integrity shown on the TA of 1840. Almost all of Fenside Marsh was mapped as a large turf pond, and, south of Middle Marsh a turf pond occupied the present location of Mill Dyke Marsh, with another large and irregular flooded working in what is now the location of Goose Marsh (Long Marsh), Catfield Broad Marshes and Catfield Broad. Those parts of the eastern and Sharp Street fen compartments which were not marked as reeds (*i.e.* re-flooded turf ponds) were mostly shown as marsh. In consequence there were rather few areas of rough pasture residual from the 1837 mapped state of the eastern and southern strip of fen compartments. The only real exceptions to this were in the far south-east corner of the fen (near Fenside Farm) and in some small compartments along the southern edge of fen, where there was still rough pasture mapped that was ‘Liable to Floods’. This extended south-westwards along the upland margin of the Sharp Street Fens. Rough pasture symbols were also shown along the Commissioner’s Rond.

Something by way of a partial reversion to the 1837 condition is suggested by the 1st revision OS 25” plan of 1905, which mapped North Marsh once again as ‘rough pasture’, whilst the former ‘rough pasture’ in the small compartments along the southern edge of the fens had been replaced by an absence of symbols (*i.e.* the compartments were shown as ‘normal’ agricultural holdings). It is not known to what extent this represents evidence of real change in these compartments or changing perceptions amongst OS surveyors. The 1905 map also indicated that the old mill (drainage pump) was by then disused (it is uncertain if it can therefore be inferred that it was still in used at the time of the 1881 survey).

The old mill (drainage pump) was doubtless critical to pumping water away from the Internal System fens, both to enable the establishment of rough pasture and to facilitate the subsequent extraction of peat. Additional measures to help keep the eastern fens ‘dry’ were that water flows from the upland appear to have been intercepted by a marginal Landspring Drain. Flow from the drainage axis of the Church Wood valley is likely to have been diverted into this drain along the south side of the wood, whence it passed around the southern margin of the fen to Sharp Street. This marginal drain was separated from the excavations of the Catfield Broad Marshes–Long Marsh turf ponds by a narrow rond of undug peat, probably left *in situ* to help preserve the integrity and function of the Landspring Drain.

This drainage around the southern margin continued after the mill ceased to function, but otherwise the drainage arrangements, if any, for the Internal System compartments subsequent to the disuse of the mill are not at all clear from the cartographic evidence. Neither the 1881 nor the 1905 25” plans mark any sluices or other water control structures from the Internal Fens across the Rond into the External System, nor from the Internal System into the River Ant at Sharp Street. Nonetheless, some provision for drainage out from the Internal System must have been made, or else it occurred by default. It seems likely that a main axis of flow may have occurred along roughly the same drainage axis as was mapped by Faden, though the Commissioner’s Rond will have prevented any flow from the Internal Fens into the Hundred Stream, directing it instead into the dykes connecting with Sharp Street *via* the narrow gap where the south-eastern elbow of the Rond almost meets the upland near Fenside farm.

The 1881 and 1905 25” plans show free water connection between the re-flooded turf ponds and dykes of the Internal System. The turf ponds were, in effect and also in terms of compartment numbers, very large extensions of the dyke system, and in general dykes as such were short and sparse. Exceptions to this occurred in a few places, such as along the southern and western sides of Sedge Marshes, where dykes had been dug within ‘solid’ peat. A short dyke (which separated the Mill and the Rond from Middle Marsh) connected the large Fenside turf pond to the turf pond which is now Mill Dyke Marsh, and an even shorter one, more just a turf pond constriction between the Rond and South Marsh, connected Mill Dyke Marsh to the Long Marsh–Catfield Broad Marshes turf pond. Otherwise, in much of the fen area south of Middle Marsh, mapped dykes were conspicuous by their absence.

The condition of the fens and disposition of the dykes indicated on the 1905 1st revision is essentially repeated, with some minor changes, on both the 1938 and 1957 6” editions (Figure 8). The last shows some differences, but it is not clear what significance can be attached to them. The various ‘County Series’ editions, from 1881 up to the 6” edition of 1938 clearly show the fens south of Middle Marsh segregated into mostly ± rectilinear blocks of solid peat and turf ponds, clearly delineated, but mostly not obviously bounded, or separated, by dykes. On the 6” OS edition of 1957 the former turf ponds and areas of solid peat in the fens south of Middle Marsh are no longer differentiated as discrete units with boundaries, though variations in the density of the 'marsh' symbols[17] mapped roughly correspond with the former distribution of cut and uncut peat. This might suggest that, by this stage, the turf pond and solid peat.surfaces were losing their distinctive identities in consequence of terrestrialisation of the former. On the other hand, it could just reflect changes in cartographic approach. The 1957 6" OS edition examined is based on a pre-1930 revision, except for the southernmost part which was revised 1930-1945. "The entire sheet was revised for major changes only in 1952-53" but, although unspecified, these may well not include changes in the character of the marshland.

8.1.4 Land use in the 1930s

Figure 9 plots the marsh products harvested in parts of the Catfield & Irstead Fens, as recalled by Messrs P. and L. Neave and recorded by BDW (*c.* 1980). The use of most of the present Catfield Hall Estate at that time was not recorded (perhaps not known), except for North and Middle Marsh which were both apparently mown for 'hay'. This label stands in contradistinction to the 'litter' (or marsh hay) recorded from some other parts (such as Sedge Marshes) and is suggestive of a product more commensurate with normal agricultural 'hay'. This may suggest that both North and Middle Marshes were better-drained then than were other parts of fen, which is consonant with the mapping of 'rough pasture' in North Marsh on the OS 25" 1st revision of 1905.

Although outwith the Internal System, note may also be made of the harvesting of 'grass for packing melons' in the northern-most compartment of Great Fen. This refers to 'melon grass' or *Calamagrostis canescens*. This species, although nationally a rare plant of fens, is abundant in parts of Broadland, especially in relatively 'dry' situations. When examined by BDW in 1974 and 1986, *C. canescens* was present in the north part of Great Fen, but not in harvestable abundance. This may suggest that this part of the site was drier in the 1930s than in the 1970s and 80s but, if this was the case, the reason for it is not known.

8.2 PRESENT-DAY DRAINAGE

8.2.1 Development of the Present-day Dyke Network

Dykes have been shown across certain parts of the Catfield & Irstead since Faden's map of 1797, but their network has changed considerably between then and the present day (see above). For example, the network of dykes around the small compartments in the Fenside area that is revealed on the Tithe Apportionment map of 1840 mostly no longer exists, probably because it was largely obliterated by turbary and reflooding, though landward traces of some former dyke remnants can still be found in places along the upland margin. The same applies also to most of the large fen area south of Middle Marsh.

It is neither possible nor necessary here to describe the development of the dyke network in the Catfield Fens, but some general points can be made, based largely on cartographic evidence.

In the Internal System, on the 25" OS plans of 1881 and 1905, dykes were mostly associated with the residual areas of solid peat, where they presumably maintained a transport function. By contrast, the reflooded turf ponds were, at least initially, in effect large and shallow expansions of the dyke system; they were not usually bounded by dykes, nor subdivided by them. They were often directly juxtaposed against solid, uncut peat, without the separating dyke that is usually found at the present day.

[17] As well as being more sparsely plotted, the symbol used in the former turf ponds is also somewhat different to the standard 'marsh' symbol of the uncut surfaces, but it is not the conventional symbol specified for 'reeds' (swamp), or anything else.

As the turf ponds became wet reedbeds, water transport was maintained through cut strips of reed along ‘sloshways’ that were suitable for flat-bottomed boats (Mr. P. Neave, *pers. comm.*), but ongoing terrestrialisation and the coalescence of vegetation demanded a better-defined dyke system, and new dykes were eventually dug within the terrestrialising turf ponds and also, very often, along their boundaries with areas of solid peat. The time line of this process is not at all certain, nor is the reliability of the cartographic evidence. This is because on the one hand ‘cartographic inertia’ can lead to the perpetuation of some features between successive map ‘revisions’; or, on the other hand, different standards and surveyor perceptions associated with different revisions can suggest that more definite changes took place than actually occurred; both of these considerations are particularly pertinent to areas of marshland. Subject to these caveats, several observations can be made, with particular reference to the present area of the Catfield Hall Estate.

The large fen area south of Middle Marsh was largely devoid of mapped dykes at the time of the 1881 and 1905 25” editions. A continuous Landspring drain was mapped around the entire land margin of this area (as elsewhere), and two fairly short, blind dykes (one of which was a marginal remnant of a dyke shown in the 1840 TA map) extended from this to delimit partly an area of woodland immediately east of what is now South Marsh. Otherwise all of this large fen area is shown as a single, dykeless unit, nor had Catfield Broad been dug. Thus, from the perspective of dykes, the marshes of the present-day Catfield Hall Estate were then mapped essentially just as three separate compartments – North Marsh, Middle Marsh and ‘the rest’.

As terrestrialisation proceeded, the lack of dyke channels within this large southern area of fen is likely to have resulted in rather different hydrodynamics to those of the present day. In conjunction with the likely high water storage capacity of the embedded, terrestrialising turf ponds, it may well have resulted in generally wetter conditions away from the main drainage points than is presently the case[18], and perhaps a reduced responsiveness to catchment events. Drainage flow from this area is not certainly known, but it seems most likely to have been at the southern end, in what is now the south-western corner of Goose Marsh (Long Marsh), where there was a mapped connection to a dyke which ran south-westwards into the Sharp Street Fens. Such a drainage axis follows very roughly the same course as the watercourse mapped across this part of the fen in 1797 by Faden[19]

The mapped surface configuration of the marshes changed little between the 1905 survey and later editions of 1938 and 1957, through to 1976, probably mainly reflecting lack of cartographic revision, at least in the marshland areas, rather than lack of change. However, the 25” OS edition of 1978, and the 6” edition of 1981, which were based on a new survey, both essentially show the dyke arrangements of the present day.

It would therefore seem that much of the present-day dyke system of the Internal Fens was dug, along with Catfield Broad and the duck pond in Middle Marsh, sometime between 1905 and 1978. A more exact time-line for this cannot be determined from the cartographic evidence available, though it seems likely that some details could be supplied by local knowledge or records. It has been recorded (notes of Dr S C Shaw, source uncertain) that Catfield Broad was dug in the 1920s[20] and the duck pond is supposed to have been dug in 1947 (Mr. D.S.A. McDougall, *pers. comm.*). The date of the dyke system is not known to BDW, but it must be post-1905 and (parts) could be post-war. It may be noted that the ‘new’ dykes did not always respect the former boundaries between the turf ponds and ‘solid’ peat. This is well illustrated by the eastern boundary dyke of Mill Dyke Marsh (see 5.3).

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18 Mr P. Neave (*pers. comm.*) has pointed out that a lack of dyke cleaning made the marshes wetter, though this was probably partly context-dependent.

19 The ‘Church Wood’ stream may have flowed slightly further north, possibly making connection with the old Hundred Stream (former course of the River Ant) which is now in the External system on the other side of the Commissioner’s Rond.

20 Catfield Broad is not a deep medieval broad, but is a deepening within a shallow 19th-century turf pond.

Careful topographical survey is needed to establish better the relationship between dyke levels and fen surface levels in the Internal Fens. Mason (2012) has raised the possibility that the ground level in the east may be higher than that in the west. If this should be correct then, unless the water level in the dykes shows a comparable gradient, which in a well-managed, open, dyke system would seem unlikely, then the fen surface in the east will appear to stand more proud of the dyke water level than is the case further west. An open dyke system has not always been a feature of the fens south of Middle Marsh and the present fen surface may have, in part, developed independently on any current controls on the water tables of the fen compartments that are exerted by dyke water levels[18].

8.2.2 Drainage from the south end of the Catfield Hall Estate – the 'low bund'

Present-day drainage of the Internal Fens at Catfield is regulated partly by two sluices that connect to the External systems across the Commissioner's Rond (Mason, 2012). The date at which sluices were first installed in these locations is not known (to BDW) – they are mapped first on the 1978 25" OS plan. Mason (2012) has also drawn particular attention to a 'low bund' at the south-west end of Long Marsh, blocking part of the narrow gap between the rond and the upland margin at Sharp Street. Water can drain over this structure into the Sharp Street fen dykes.

The 'low bund' relates to drainage control in the south-west corner of the Catfield Hall Estate. At this point the Commissioner's Rond comes very close to the southern upland margin of the fens, separated from this by just by some small land compartments between the internal dyke of the west-trending, southern arm of the Rond and the Landspring Drain (Figure 8). These compartments were marked as 'rough pasture' on the 1881 25" plan and as 'normal' agricultural holdings on the 1905 revision. Nowadays they are very wet, peaty units that are difficult of access (Mr. A. Alston, *pers. comm.*). The internal dyke of the Rond at this point connected the northern side of the Sharp Street Fens with the south-western corner of Goose Marsh (Long Marsh) of the Catfield Hall Estate. All of the 6" and 25" Ordnance Survey editions examined, including the most recent, show open connection between this dyke and the Catfield Hall Fens, but this is not now the case. As Giller (1982) has perhaps mapped most clearly (Figure 1), the internal dyke of the Commissioner's Rond has here been diverted so that, at the south-west corner of the Catfield Hall Fens, instead of continuing south-west to Sharp Street, it turns east into a blind dyke along what was once the narrow southern end of the Goose Marsh (Long Marsh)–Catfield Broad Marsh turf pond (Figure 10). This dyke thus now forms a continuous 'boundary dyke' from the south-eastern upland margin near Fenside Farm to the northern margin by Great Fen at Fenside. Giller (1982) clearly showed that at the south-western corner of Goose Marsh the original run of the dyke internal to the Commissioner's Rond had been blocked, and this forms what Mason (2012) has referred to as the 'low bund'. This dyke arrangement thereby delimited the southern end of the Internal System and helped to isolate it from the Sharp Street Fens to the south west as well as from the External System fens

The antiquity of the arrangement recognised by Giller (1982) is not known (at least to BDW). However, the portion of the 'boundary dyke' across the southern end of Goose Marsh is clearly evident on an aerial photograph of 20th May 1975 (Figure 10) whereas only a thin line of bushes can be seen on an aerial photograph taken 10 years earlier (20th October 1965). The dyke has apparently been cleared out (or perhaps created) between these two surveys and it seems likely that the dam in the dyke to Sharp Street dates from this same time. The barrier to surface water exchange between the Catfield Hall marshes and the Sharp Street fens at this point seems to consist of two components: the 'natural' peat deposit immediately south of the boundary dyke; and, more specifically, a dam across the original dyke alongside, and internal to, the Commissioner's Rond. Mr A. Alston (*pers. comm.*) has indicated that outflow at this point, when water levels in the Internal System are high, is not confined to the dam across the dyke, which is presumably why it is referred to as a 'low bund'.

It has been suggested that the 'low bund' helps to regulate the maximum height of water within the adjoining Catfield Hall Fens. It is not clear (to BDW) what determined these levels before the bund was built and what the levels were. Dr T. Haines (in Mason, 2012) may, for all one knows, be correct in his assertion that "the bund was not originally designed to leak/flow at this point" but the cartographic evidence suggests that this location may long have been the focus of drainage from at the least the southern part of the eastern fen compartments, going back to the drainage axis marked on the 1797 map of Faden. The Tithe map of 1840 also shows a curious arrangement of dykes at this south-eastern elbow of the Rond, in which a linkage is mapped between the Landspring Drain and the internal dyke of the Rond, and *across* the Rond to join with the external Rond dyke (*i.e.* the Hundred Stream) (Figure 7). The significance and mechanism of this arrangement, and the concomitant water flows is not at all clear. The dykes concerned may well have been ensluiced.

The height of the 'low bund' may well be critical to water retention within the Internal Fens, though any such assessment requires better topographical data than are currently available. Mason (2012) has observed that substantial volumes of water may be lost across the bund on occasion, and made the reasonable suggestion that "since any breach in a soft embankment will tend to get larger over time, it may be that the amount of water lost from the Internal System has also increased over time". However, the magnitude of any outflow increase is not known, nor, in the absence of reliable topographical data and other information, is its likely effect upon the water table of the fen hinterland.

It is nonetheless the case that there appears at present to be a significant loss of water across the bund and it is possible that some of this could be kept on the fen by raising the level of the bund. Mr. P Riches (*pers. comm.*) has objected to this proposition on the grounds that raising the bund level would lead to excessive flooding of the adjoining fen. However: (a) it is difficult to see how the likely impact of bund elevation can predicted in the absence of reliable topographical data for the site; (b) the extent and depth of flooding could be controlled by the invert height of the bund; and (c) flooding would seem to be required to counteract concerns about the suspected drying and declining vigour of the reedbeds, and could be considered as a possible alternative to 'turfing out'. Professor D Gilvear has suggested (in Mason, 2012) that "it is too simplistic a management approach just to store or winter rainfall and groundwater inputs into the marsh and turn it into a lake…", but it is not clear what is so "simplistic" about this, nor how it differs materially from the original water management of some of the former turf ponds, when they were inundated to a depth of up to about 80 cm. It may be recalled that at Catfield, and elsewhere in Broadland, some of the 'best' wet reedbeds have been located over estuarine clays (Jennings, 1952; Giller & Wheeler, 1986) of the Breydon Formation (Arthurton *et al.*, 1994) where any significant supplementation of their water supply by groundwater outflow seems most unlikely. It also seems singularly curious simultaneously to raise concerns about supposed drying of the reedbeds whilst objecting to an elevation of their water level.

8.3 HISTORICAL SUMMARY

Probably the most significant hydro-ecological event as far as the Catfield Hall Fens are concerned was the construction of the Commissioner's Rond, as a consequence of the Inclosure of Catfield parish in 1807. This double-ditched feature extended south from Fenside, in the north-west of the fens, thence to loop eastwards around the eastern side of the Hundred Stream bight (the former course of the R. Ant) and then to follow this south to the present-day Ant at Mud Point. The purpose of the Rond was doubtless primarily to permit the drainage of the peatland on its upland (Internal) side, and this appears to have been achieved, especially along the eastern fen margin. Similar drainage initiatives took place at the time in various parts of Broadland. The Rond remains extant and largely effective, though the western end of its southern arm has now become wet and marshy and may no longer here provide an barrier to surface water flow.

In the Catfield & Irstead Fens, any agricultural development of the Internal System was superseded across much of the area by peat removal in the first half of the 19th century. In the Internal System this resulted in three main shallow turbaries: Fenside, Mill Dyke Marsh and the irregular and conjoined excavations of Goose Marsh (Long Marsh) and the Catfield Broad Marshes. By 1884 these turbaries had become flooded and largely colonised by 'reed'. Their subsequent infilling by terrestrialisation, and the development of less wet conditions, is not well charted after 1905 by the maps available, unless the mapping provided by the 1957 6" Provisional Edition (revision date uncertain for the fen area), in which the turf ponds and areas of undug peat are no longer mapped as discrete entities, is indicative of coalescing surfaces.

The original re-flooded turf ponds were connected by short dykes. Dykes were absent from the turbaries themselves, presumably because water transport could occur across the shallow water within them and it was necessary only to mow out of strip of reeds to permit boat traffic The large fen area south of Middle Marsh was for a period apparently largely dykeless (even the Internal edge of the Commissioner's Rond is shown only as a pecked line on the 1957 map (Figure 8)). As the turf ponds terrestrialised, this may have resulted in rather different hydrodynamics to those of the present day, possibly with wetter conditions away from the main drainage points than is presently the case, and perhaps a reduced responsiveness to catchment events.

Recorded details of the origin of the present dyke system in Fenside and south of Middle Marsh are not known to BDW, but may perhaps be available from local knowledge or records. It is difficult to infer more from the cartographic evidence than that many of the present dykes originated sometime after 1905. At some stage two sluices were installed across the Rond to regulate water exchange with the external system. Water exchange appears mostly to have been from the Internal System into the external system, though this was (and is) on occasion reversed. Thus the Rond has continued mostly to keep river water out of Internal Fens, and has made them largely dependent on direct precipitation and whatever land-drainage and groundwater inputs may occur. Any such inflows, however, probably feed largely into the dyke system and may show but limited penetration into the fens; and any penetration which does occur may well be accompanied by nutrient stripping near the fen edges with the dykes, as the reedbeds and fens act as large, semi-natural 'tertiary treatment' systems. Thus most of the internal *fens* appear to be largely isolated both from episodic inundation by river water *and* from marginal sources of nutrients and bases. Such circumstances can help explain chemical evidence of base depletion within the Internal System (Giller, 1982), and could also lead to reduced vigour of reed.

The 'low bund', at the south-east corner of the Catfield Hall Estate, helps to block a dyke planned and authorised by the Commissioners for Drainage at Inclosure (1807) and dug around the internal side of the Rond. All maps seen, including the most recent, show a free connection along this now-blocked dyke, between the Internal Systems fens and the Sharp Street Marshes. The age of the low bund is not certain, but it appears to be associated with a reconfiguration of the internal Rond dyke to form a 'boundary dyke' delimiting the Internal System fens, and this may have occurred between 1965 and 1975. The hydrological function of the low bund is not clear, but it must restrict water exchange between the Internal Fens and the Sharp Street fens, and presumably helps to retain water in the Internal System whilst also isolating it yet further from river water. Thus, whilst ostensibly part of the Ant floodplain, the Internal Fens seem largely separated from normal floodplain processes. This is likely to be reflected in their ecological characteristics.

9. CONCLUSIONS

1. Mill Dyke Marsh is terrestrialising turf pond. Here, in one sample examined, in a *Sphagnum* area near the north end of the marsh, there was some vegetational evidence for surface drying since 1977. This is compatible with an autogenic elevation of the surface that is characteristic of a terrestrialising turf pond.
2. Middle Marsh is not a terrestrialising turf pond. Here, in the samples examined, there was no vegetational evidence for drying since 1986 and some indication of a small but sustained *increase* in wetness. As Middle Marsh is almost continuous with Mill Dyke Marsh (separated just by a dyke) this may support the view that 'drying' changes in the latter are in consequence of an autogenic elevation of its surface rather than of a decline in the position of its water table.
3. Most of North Marsh was not examined other than superficially, because reported turf removal in the 1990s will have confounded any comparison with data available from the 1970s. The area of birch-Sphagnum woodland, which is thought not to have had turf removed recently, was also not examined in much detail because of the absence of locatable samples from the 1970s. However, it still contained good populations of the wet-fen / swamp species *Carex rostrata.*
4. The fens south of the northern part of Mill Dyke Marsh were not examined, because of lack of opportunity. There is a clear need for a 'before and now' comparison of the southern fens of the Catfield Hall Estate before any assessment of their present condition can be made, and evidence of vegetation change determined. It is believed that Rose Fen was subject to surface peat removal in the 1990s which, as with North Marsh, is likely to confound any assessment of change since the 1970s.
5. Whilst the fens of the Catfield Hall Estate (or at least those that were seen) seem subject to appropriate and effective vegetation management, this does not generally extend as far as the type of deep 'turfing-out' needed to provide suitably wet conditions for good reedbed regeneration. It is difficult to disagree with the view of Dr A.M. Holburn (*in litt.*) that "the most likely explanation for the present state of Catfield Hall marshes is persistent failure to apply traditional marsh management techniques", though this view should be tempered by the recognition that, in other regards, some good management work that has been carried out. It is considered that the reported lack of success of turfing-out in North Marsh and Rose Marsh may be because these compartments were not former turf ponds, or because an insufficient depth of peat was removed (or both).
6. As some of the vegetation of the more mature terrestrialising surfaces constitutes a rare habitat, which would probably not quickly be re-created in any attempted destructive rejuvenation of the hydrosere, there may be an understandable reluctance to adopt this as a conservation strategy. This applies particularly to some of the maturing *Sphagnum* surfaces (EC Habitats Directive Annex 1 habitat category of 'Transition Mire & Quaking Bog'). The long-term sustainability of these surfaces by mowing alone is not known, but mowing may perhaps provide an effective interim management solution for them until such time as more courageous conservation decisions can be taken.
7. There is evidence for significant water loss across the low bund at the southern end of Goose Marsh (Long Marsh) and consideration could be given to the retention of this within the Internal System fens, as a possible interim alternative to turfing out. Such an approach should be predicated upon an *accurate* topographical survey of the fens and on hydrometric data from the relevant dykes. The objection that any elevation of the bund is likely to cause some flooding of the internal fens can be countered on the grounds that this is its intended outcome, though it is recognised that there may be other constraints. Again, there may be a need for some difficult decisions. Long-term management of semi-natural, hydroseral fens often requires robust initiatives if it is to have effective outcomes.

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11. ANNEXE 1: INVOLVEMENT OF B D WHEELER IN THE CATFIELD & IRSTEAD FENS

Although they were undoubtedly known to some earlier botanists (perhaps most notably Mr G.H. Rocke), the Catfield & Irstead Fens were effectively ‘discovered’ for conservation by B.D. Wheeler in 1972. Wheeler observed in these fens the occurrence of a number of plant species that were rare both nationally and in Broadland, particularly, but not exclusively, in the area of Great Fen. The conservation organisations (Nature Conservancy, Norfolk Naturalists Trust) and some local naturalists (*e.g.* Dr. E.A. Ellis) were duly notified.

Because of its particular interest, the vegetation of the Catfield Fens was subsequently comprehensively surveyed and mapped, along with a wider, but less detailed, examination of fens elsewhere in the Ant valley (Wheeler, 1978). It became clear that the Catfield Fens provided a ‘microcosm’ of the variation in vegetational and ecological characteristics of the northern Broadland fens (*i.e.* the fens in the Ant, Bure and Thurne valleys) and that they provided a suitable site for an holistic investigation into the controls on the composition and distribution of the different vegetation types. The key features which informed this assessment were:

- The occurrence of almost all of the plant species and communities of the northern Broadland fens on the site
- The location of the site at the head of a Romano-British estuary, so that the fen surface straddled both continuous peat and peat intercalated with estuarine clays
- The existence of turf ponds and areas of undug peat in close juxtaposition
- The presence of areas actively mown for reed (*Phragmites australis*) and sedge (*Cladium mariscus*), alongside areas in which former mowing had been abandoned (for varying lengths of time).
- The subdivision of the fens by a rond into those alongside or in connection with the R Ant (‘external’ fens) and those internal to this (‘internal’ fens); these latter also had an apparent history of 19th century drainage.
- The opportunity of free and unfettered access to the entire fen system year-round, granted by Mr D.S.A. McDougal for the Catfield Hall estate (which then very largely equated with the Internal System) and by the various owner-occupiers of fen compartments in the external system.

A wide-ranging ecological study of the fens was carried out, with the aim of making a preliminary identification of the various environmental factors and vegetation processes that were important in controlling the composition and distribution of the main plant communities of the site (*e.g.* Giller, 1982; Wheeler & Giller, 1982; Wheeler, 1983; Giller & Wheeler, 1986, 1988).

Selected aspects of this were subsequently the subject of more detailed investigation, including examination of habitat conditions, palaeoecology and ecohydrology, as represented *inter alia* in studies by ECUS (1997), Wells & Wheeler (1999) and HSI (2002). In addition, parts of the fens were included within national studies on fens, *e.g.* Wheeler & Shaw (1987), Wheeler, Shaw & Tanner (2009) (See Annexe 3).

12. ANNEXE 2: FENSPEC

(Fen Species Prediction of Environmental Conditions and Change

FENSPEC is a trait-based data processing procedure that forms part of the FENBASE database developed by B.D. Wheeler and held at Sheffield. It is based on the measured environmental conditions that are associated with individual plant species, as recorded in a large number of samples from wetland sites throughout Britain, together with measured ‘functional’ biological traits of those species, derived from the FIBS database of the former Unit of Comparative Plant Ecology (UCPE) (University of Sheffield). The principal use of the procedure is to predict the environmental conditions associated with particular species assemblages and to identify likely causes of changes in vegetation composition with time. It is essentially a development of the FIBS methodology developed by UCPE, expanded and refined with specific regard to the species of wetlands and to utilise the environmental data available within FENBASE. Allied approaches have been used by other workers in Britain using Ellenberg values, but these values are just estimated categories within a ten or twelve-point scale and, with specific regard to indicating water conditions in wetlands, Ellenberg analyses are often effectively based on just a three point scale (as most wetland plant species are allocated to one of just three of the Ellenberg F-Values).

Various other ‘models’ have been developed, especially in the Netherlands, to help predict environmental conditions in vegetation from the species composition of samples (e.g. the MOVE model; Latour et al., 1993). FENSPEC has a broadly similar objective to these, but offers the following advantages over some other known approaches:

1. developed specifically for wetland species and habitats
2. based on a large (UK-wide) environmental data set for wetland plant species (rather than estimates)
3. species ranges and ‘preferences’ can be analysed for specific regions of the UK
4. represents a unique combination of species environmental and trait data
5. based on measured environmental and trait values, not on ‘expert assessment’
6. based on continuous variables and thus permits more sensitive and accurate analyses to be made than is possible with 10 or 12 point scales (*e.g.* Ellenberg numbers)
7. can take account of the response curves of individual species to environmental conditions (*i.e.* is not necessarily just based on a single value for each species).

Various indices can be calculated using FENSPEC, of which perhaps the most generally useful are Indexes of Water Level, Substratum Fertility and Base-Status. These are useful when these variables cannot be, or have not been, measured directly, or where (as with water level) they are labile, so that FENSPEC index provides an integrated assessment of conditions as experienced by the vegetation year-round. For this reason, the ‘water-level index’ does not relate back to actual water levels, but can only be used to indicate the ‘wetness’ of samples relative to each other. A ‘dereliction index’ has also been formulated, but has yet to be evaluated.

13. ANNEXE 3: ECOHYDROLOGICAL ACCOUNT FOR THE CATFIELD & IRSTEAD FENS

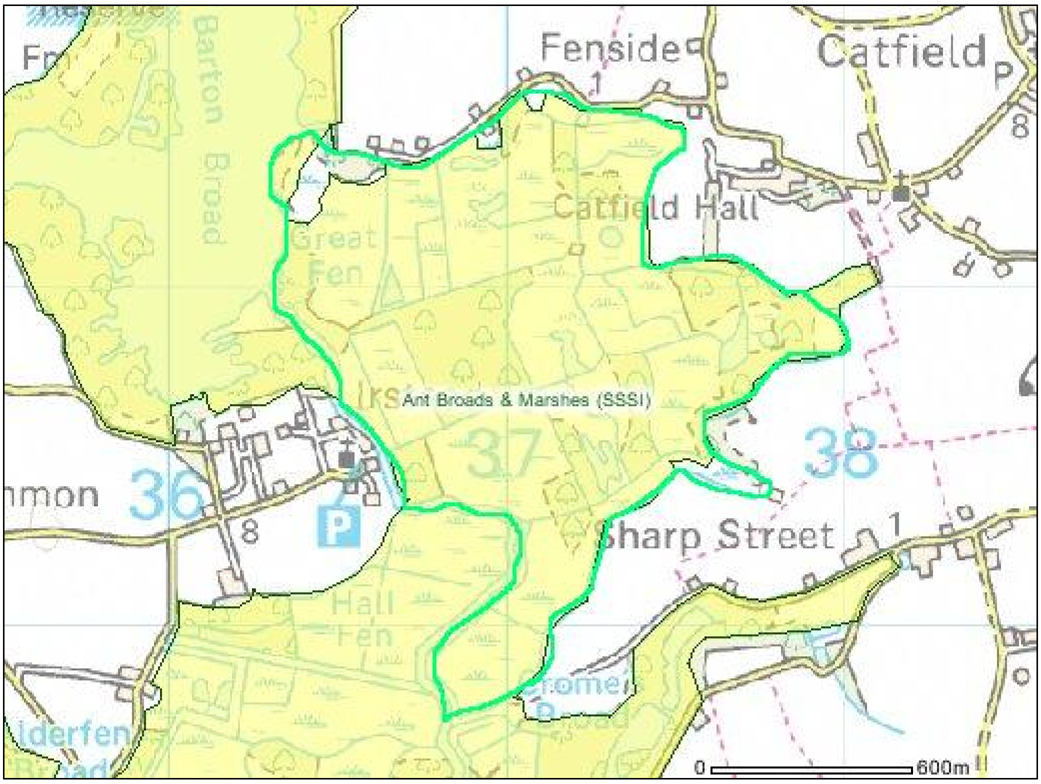
(Extract from Wheeler, Shaw & Tanner, 2009)

CATFIELD AND IRSTEAD FENS

NORFOLK: TG3620

***Status*:** SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

***Wetmecs*:** WETMEC 3b: Bog-Transition Quag (± Open Basin), WETMEC 5c: Winter-Flooded Floodplain, WETMEC 5d: Floodplain Sump, WETMEC 6b: Grounded SW Percolation Quag, WETMEC 6c: SW Percolation 'Boils', WETMEC 6d: Swamped SW Percolation Surface, WETMEC 6e: 'Wet' SW Percolation Quag, WETMEC 6f: SW Percolation Water Fringe, WETMEC 11b: Slowly Permeable Partial Seepage.



Description: A large site, located on the west side of the Barton Broad and the R. Ant, which has been the subject of quite a lot of ecohydrological research (see Box, below). Any ecohydrological assessment of this site is complicated by the disposition of the R. Ant (which originally flowed through the fens rather than along their western margin, as now) and by the Commissioner's Rond, a bank of solid peat which divides the fen into two hydrological systems, an 'internal' system, which lacks direct connection with the river but receives some land drainage and groundwater inputs, and an 'external' system which has direct river connection. It is thought that the Commissioner's Rond was constructed to permit drainage of the internal fens, but only partial conversion of a small number of them (those directly along land eastern upland margin) seems to have been attempted. However, both the internal and external fens were subject to considerable 19th century peat extraction, and much of the surface these fens consists of shallow turf ponds in varying states of terrestrialisation. The alluvial infill is some 4–6 m deep across much of the fens. A thick layer (*c.* 4 m) of dense brushwood peat lines the entire site, but over much of the southern area this is covered by estuarine clays. These are thickest (*c.* 2m), shallowest (*c.* 0.5–1 m subsurface) and purest in the south of the site, in association with the former course of the R. Ant. Northwards they thin and become represented as *Phragmites*-clay and in the most northern compartments they are absent (but are represented by a layer of organic muds which extends laterally northwards).

Vegetation: The site has a rather complex vegetation pattern, but in essence the solid peats support various types of tall mixed fen vegetation, dominated by *Cladium mariscus*, *Juncus subnodulosus* and *Phragmites australis* (mostly some version of S24) and are very prone to scrub invasion when not managed. Turf ponds in the south of the complex (over clay) are mostly 'reedbeds' (*Phragmites australis* and/or *Typha angustifolia*) whereas those near the northern margin are mostly 'sedge beds' (*Cladium mariscus*). Some of these latter are referable to the *Peucedano-Phragmitetum caricetosum* community and support nationally rare plant species. However, on-going terrestrialisation has the consequence that the vegetation of many of the turf ponds is becoming increasingly like that of the uncut surfaces and, as well as becoming more prone to scrub invasion, it is also losing some of its speciality species. In some places, areas of *Sphagnum*-dominated vegetation have established in the turf ponds.

Substratum: The site is underlain by Crag (some 35–40 m thick), which is separated from the Chalk by a fairly thin (< 5 m) layer of London Clay. The Crag also outcrops on much of the adjoining upland, though the higher ground is capped by the Corton Formation. The peat infill of the fens is separated from the Crag by a thin layer of clay, though the full extent of this is not known.

Water Supply: The 'internal' fens lack direct connection with the river and appear to receive river inundation rarely (if ever). They appear to be fed predominantly by precipitation. Land-drainage inputs are directed into the dyke system. A consequence of this is that the surfaces of some of the fens – especially, but not exclusively, undug surfaces – seem to receive little input of bases or nutrients[21] and may become quite dry during the summer. Gilvear *et al.* (1989) suggest that groundwater inputs may occur into the internal fens, through clay windows, but the magnitude of this effect is not really known – though it is clear that, if it occurs at all, it has no obvious impact upon the ecology of the fens. It is likely that some groundwater discharges into the dyke system, around the perimeter and in some of deeper marginal dykes, but the ecohydrological significance of this is not known. Various workers have reported more base-rich conditions in the marginal dykes than in most of the Internal System dykes, but these seem to be largely confined to locations where the Crag is exposed in the dykes, with a rather abrupt lateral change to the dystrophic conditions of most of the internal dykes off the Crag (the significance of this is discussed further below). Connection with the external system is regulated by a sluice.

The 'external' system is connected to the river and is partly irrigated by this, by episodic flooding and, in the case of turf ponds closely attached to the dyke system, probably by subsurface flow during the summer. Much of the southern part has thick accumulations of estuarine clay, which are likely to prevent upward water movement in this area, but these clays thin and disappear towards the N margin, where communities with 'seepage indicator species' occur. However, piezometric investigations close to the N margin provide no reason to suspect groundwater inputs. This area is, however, in (tortuous) connection with Barton Broad *via* an overgrown dyke, though the degree (and direction) of flow is not well

[21]Note that this process of base-depletion does *not* correspond with the process of *Sphagnum* invasion, which is observed in various parts of the fens, including locations quite close to the river. *Sphagnum* colonisation is a more localised process, associated with acidification of buoyant fen mats over terrestrialising turf ponds. The base depletion in the internal fens is a much more pervasive process and is not associated with *Sphagnum* establishment.

established. The external fens also receive some water inputs from the internal fens, mainly through a sluice cut through the Commissioner's Rond between Sedge Marshes and Great Fen.

***Conclusion*:** Precipitation appears to be the main water source for much of the fen, supplemented by some land-drainage in the Internal System and important river inputs in the external system. Groundwater inputs into the fen compartments *per se* appear to be small – inputs into the marginal dykes may be more significant, but this needs to be established.

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Ecohydrological Investigations at Catfield Fens

The Catfield fens have been the focus of a number of 'ecohydrological' investigations, more so than any other site in Broadland. Studies in which a significant number of field measurements have been made include the following:

- Jennings (1951) published some peat stratigraphical sections from across the fens.
- Wheeler (1975) made numerous vegetation records. Giller (1982) and Wheeler & Giller (1982a) produced a vegetation map, recorded a number of stratigraphical sections, examined aspects of the plant ecology and made some simple water level measurements. Aspects of the work have been published (Wheeler & Giller, 1982b; Giller & Wheeler, 1986a, 1986b, 1988).
- The University of Birmingham made some detailed hydrological and hydrochemical investigations, including measurements of topography, hydraulic conductivity and piezometric head. This has been reported by Collins (1988) and Gilvear et al. (1989) and aspects of the work were subsequently published (Gilvear et al. 1994, 1997).
- Parmenter (1995) made a comprehensive vegetation survey and map (herbaceous communities only) as part of the Broadland Fen Resource Study.
- Environment Agency installed 5 piezometers and 3 gauge boards (HSI, 1996). Data from these have been collated and interpreted by Montgomery Watson (1999).
- van Wirdum et al. (1997) reported some preliminary hydrological investigations in part of the fens, with particular reference to the peat layers (mainly determinations of hydraulic conductivity, piezometric head and thermal-conductivity profiles).
- Wells & Wheeler (1999) analysed the developmental history of the fens over the last 2000 years, based on detailed macrofossil analyses of peat cores. This showed inter alia the changing importance of river flooding to the wetland.

Despite these studies, some aspects of the ecohydrology of the Catfield fens remain inconclusive. This is partly because sufficiently detailed studies have not been made of salient issues, but it is also because of errors in recording and inconsistencies in reporting.

Main Water Sources

Wheeler & Giller (1986b), Gilvear *et al.* (1989) and Williams *et al.* (1995) all concluded that precipitation is the dominant component determining the hydrodynamics of this site. However, as with all broad generalisations, consideration needs to be given to the detail. There are some hydrochemical differences between adjoining parts of the external and Internal System, which may possibly reflect differences in water sources. The University of

Birmingham study was particularly concerned with the Internal System, and it seems quite possible that these studies may have underestimated surface water inputs from the R Ant into the external system. This is not least because the relationship between water levels in the external system and the river does not yet seem to have been established consistently or conclusively (see below).

Topographical Relationships

It is important to know the topographical relationships and water level differences between the Internal System, the external system and Barton Broad. However, the evidence available is more a source of confusion than clarification.

Wheeler & Giller (1982) presented water levels for the internal and external dykes on either side of the Sedge Marshes / Great Fen sluice for a 10-year period. This indicated that for much of the year flow was normally outwards, from the internal to the external system but that in some summers flow was inwards.

Gilvear *et al*. (1989) and Gilvear *et al.* (1997) both present data for water levels in Barton Broad and on either side of the sluice, but they are inconsistent, making interpretation difficult. For example, in Gilvear *et al.* (1997) hourly data for water levels at the sluice are in a higher range than weekly data calculated for the same period. Likewise, Broad water levels reported by Gilvear *et al*. (1989) are higher than levels reported for the same period by Gilvear *et al.* (1997). In this last paper, dyke water levels in both the external and Internal Systems are predominantly higher than those in the Broad, suggesting a gradient towards the Broad, but Gilvear *et al*. (1989) indicate that there is often potential for water flow from the Broad into Great Fen (external system).

The Agency gauge boards G1 (in an external system dyke), G2 and G3 (both in Internal System dykes and in free hydraulic connection with each other) might be expected to resolve the issue of the direction of water flow between the internal and external systems, but they do not because they indicate about a 10 cm water level difference between G2 and G3 which almost certainly does not exist. This appears to be a consequence of a levelling error (probably of G2).

Thus, despite the work reported it is difficult to know what conclusions to draw about directions of water flow. The simple data collated by Wheeler & Giller (1982a) appear to be reliable, and indicate that flow is mainly from the internal to the external system (this is corroborated by casual observations at the sluice). However, the relationship between water levels in the external system (Great Fen) and Barton Broad does not seem to be known with confidence.

Hydraulic conductivity

There is considerable inconsistency between the peat *K* values reported by the Gilvear *et al*. (1989) study and that of van Wirdum *et al.* (1997). The former workers report mean and range values that are much higher than those recorded in the latter study. The reason for this discrepancy is not known, though it may be noted that van Wirdum *et al.* carefully located piezometer tips within well-defined and ‘uniform’ peat strata. It is not known to what extent Gilvear *et al*. (1989) specifically sampled a range of contrasting and ‘uniform’ peat strata.

Hydraulic gradients

The University of Birmingham studies show considerable inconsistency in their reporting of hydraulic gradients, especially between reports and published papers, so that the conclusions reached by Gilvear *et al.* (1994, 1997) do not appear to take account of the full complexity of the results presented in earlier reports. For example:

- Gilvear *et al*. (1989) report, for some parts of the fen, lower heads at greater depth, giving the potential for downward movement of water.

- Collins (1988) suggests a steep downward gradient between the peat and the Crag, but these values do not seem to be used or documented by Gilvear *et al.* (1989).

- Gilvear *et al*. (1989) show a downward gradient over the clay in 1988 and a predominantly upward gradient in 1989, but neither is as steep as those recorded by Collins (1988).

- Gilvear *et al*. (1989) report small gradients within the peat, sometimes upward and sometimes downwards, yet Gilvear *et al.* (1994) only make reference to the upward gradients. Likewise, the piezometric data reported by Gilvear *et al.* (1997) suggests a complex system of upward and downward flows, which provides little convincing evidence of the predominantly upward trend subsequently emphasised by these authors in the conclusions of their 1997 paper.

The reasons for these discrepancies are not known to us.

Groundwater Supply

Gilvear *et al.* (1997) suggests a clear over-pressure in the Crag. This agrees with other piezometric observations. Gilvear *et al.* also conclude that groundwater forms only a minor component of the water balance of the fen, but may be important in providing a saturated base to the system. van Wirdum *et al.* (1997) broadly concur with this conclusion (insofar as they found little evidence for upwelling water feeding the fen). However, Gilvear *et al.* (1997) go further and, on the basis of hydrological modelling, conclude that a drop in the Crag water level would cause drying of the fen. This conclusion, however, is open to some challenge:

- The contribution made by the Crag appears to have been overestimated (and needs to be better determined by further research).

- Vertical drainage of water from the peat into the Crag depends not just on head values, but also on *K* values of the peat and clay. In the model used, the *K* values used are high (compared with those measured by van Wirdum *et al*) and may overestimate rates of vertical water transfer.

- Little account is taken of the potential for replenishment of water from surface water sources (particularly relevant to the external system).

Groundwater and Fen Ecology

The *Peucedano-Phragmitetum caricetosum* community that occurs in Great Fen is characterised by a number of species that are also found in soligenous fens. The occurrence of these so-called ‘seepage indicator species’ has led to the recurrent suggestion that the distinctive compositional characteristics of Great Fen occur because this area receives groundwater inputs. There is, in fact, no evidence for this. Neither Giller (1982), using simple thermal measurements, nor van Wirdum *et al.* (1997), using a combination of thermal-conductivity profiles and piezometry, were able to find indications of groundwater inputs.

One feature that distinguishes Great Fen from the Internal System fens is that it is slightly more base-rich (see Fig 5.4 in the main document). The origin of this is not known – it could reflect ‘fossil’ bases deposited when the R Ant formerly flowed close to this part of the fen and probably periodically flooded it, or it could be due to modern inputs from Barton Broad – though the uncertainties about the topography and water levels across the site (discussed above) leave an open question as to the extent to which broad water is likely to penetrate into Great Fen. It does, however, seem unlikely that the base-enrichment reflects localised groundwater input as the pH of the groundwaters in the nearby piezometers P1 and P2 is *less* than that measured in Great Fen. (Table CF_1).

Table CF_1. Water chemical data from samples from piezometers and dykes by gauge boards (9 April 2000)

	P1	P2	P3	P3[1]	GB3	GB2	P4	P5
pH	5.9	6.3	6.3		7.5		6.1	6.7
Conductivity (µS cm–1)	1050	486	1672	640	679	675	964	975

[1]: sample from flooded surface water alongside P3

For more pH data from the fens near piezometers P1–3, see Figure 5.4 in the main document

In general, there has been a tendency to assume that groundwater inputs are likely to be more base rich than the fens and dykes into which they discharge (because Crag groundwaters elsewhere are often base-rich (*e.g.* Upton Fen) and because of the tendency towards acidification within most peatlands in the absence of base-rich inputs). The apparently rather low base-status of the groundwater in the Catfield piezometers is therefore of considerable interest and may have some intriguing implications. Much of the fen (and dyke) water of the Internal System is rather base poor (Giller & Wheeler, 1982a, 1982b; Collins, 1988) and some of the water is little different to rainwater. van Wirdum *et al.* (1997) suggested that this reflects the present predominance of precipitation inputs coupled with the absence of the former episodic inundation by river floodwater, consequent on the construction of the Commissioner's Rond. This may still be a sufficient explanation for the base-poor conditions, but it now appears that if any inputs of base-poor groundwater do occur, they could contribute to the low base status of the fens, especially in the absence of inputs of bases from river flooding. If correct, this may suggest that any such groundwater inputs could be seen as ecologically and conservationally *undesirable*, because in general acidic fens have considerably smaller biodiversities than do base rich examples.

Groundwater and Dyke Ecology

As the dykes are cut into the Crag around the margins of the Catfield fens, it seems likely that they will have some exchange of water with the Crag aquifer. The general water flow from the internal dykes to the external system is also indicative of a water source within the Internal System, though the proportion attributable to rainfall, land drainage and groundwater inputs is not known.

There has also been a suggestion that groundwater inputs may be responsible for determining the distribution of aquatic vegetation within the dykes. In particular, it has been suggested (C. Doarks, *pers. comm.*) that this might account for the localisation of the valued *Stratiotes*-dominated community and, moreover, that the observed decrease in extent of this community (in recent years it has become increasingly confined to the very land margins of the dykes) could reflect a diminution of groundwater inputs. This interesting suggestion merits consideration.

Wheeler & Giller (1982b) demonstrated that the *Stratiotes* community is indeed confined to the marginal dykes, and that it (then) was a good indicator of stretches of dykes cut into the Crag (as opposed to peat) (since then, the community has contracted its range so that not all Crag-based dykes support this vegetation). They also found that the waters in which it occurred were both base rich and more nutrient rich than the central dykes without *Stratiotes*[22]. They suggested that this was probably due to the influence of land-drainage

[22] The central dykes supported only a sparse macrophyte flora, dominated mainly by *Utricularia* spp.

inputs. This view was subsequently supported by the (independent) observations of Collins (1988) as all of the dykes which supported the former ‘best’ *Stratiotes* stands correspond exactly to her Type 3 Groundwater category, which she suggests includes water which “originates dominantly in surface run-off from the adjoining highly fertilized uplands”. Although only provisional the water chemical data from the Agency piezometers suggest that the groundwater is *less* base rich than that recorded from many of the dykes, and especially lower than the water in the *Stratiotes* dykes[23]. On this analysis (which requires further investigation), far from being the explanation of the occurrence of *Stratiotes* vegetation in base rich conditions, it could be suggested that any groundwater inputs at Catfield may in fact *decrease* the base status of the dykes and thus be detrimental to their aquatic macrophyte vegetation.

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[For citations not included in the ‘References’ section (above), see Wheeler, Shaw & Tanner (2009).]

[23] The piezometers sampled are located some distance from the ‘best’ current *Stratiotes* dykes, though in the 1970s *Stratiotes* occurred in the dyke immediately adjoining the piezometers

14. LIST OF FIGURES

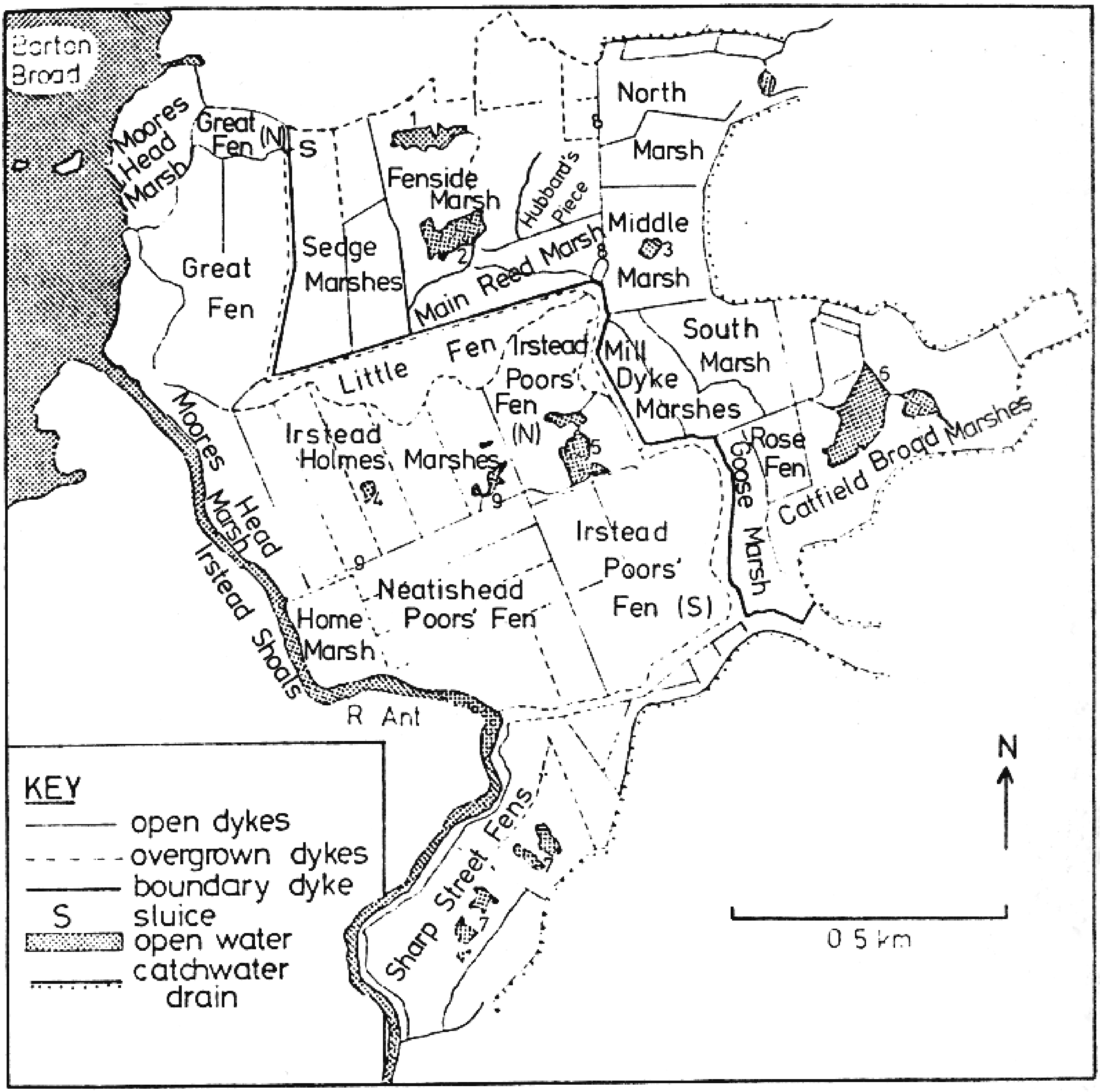

Fig. 1. Names of fen compartments in the study area (1, Fenside Outer Broad; 2, Fenside Inner Broad; 3, Middle Marsh decoy; 4, Monsey's Decoy; 5, Irstead Holmes Broad; 6, Catfield Broad; 7, Sharp Street turf ponds; 8, Commissioners Drain; 9, East-West dyke).

Fig 2. Site visit to Catfield Fen 16/05/2013. Field notes on locations examined. (R. Tratt)

Mature birch and willow with some alder over patchy *Sphagnum* (including *Sphagnum squarrosum* and *S. palustre)* with frequent *Carex rostrata*; patchy *Juncus effusus* and *Carex nigra*. [pH 4.3; µS 488]

Area where mature scrub has been removed. *Betula* and *Myrica* regenerating. Abundant *Sphagnum* (including *Sphagnum squarrosum* and *S. palustre)* with scattered *Drosera rotundifolia* beneath a tall, patchy sward of *Phragmites australis* with tussocks of *Carex elata.* Ferns are prominent with *Osmunda regalis, Dryopteris cristata* and *Dryopteris carthusiana* scattered throughout. Other associates are *Comarum palustre*, *Rumex hydrolapahum, Iris pseudacorus*, *Lysimachia vulgaris*, *Peucadanum palustre* and *Ranunculus lingua*. (BDc vegetation).

Tall *Phragmites* fen with frequent *Cladium mariscus, Carex elata, Eupatiorium cannabinum* and *Peucedanum palustre*. *Rumex hydrolapatum* and *Ranunculus lingua* occasional. *Cicuta virosa* has been found in this area in past surveys and a likely plant was found, but it was rather too early in the season to identify it with certainty.

Marker locations are approximate.

[Satellite image from Google Earth (http://earth.google.co.uk/), copyright Google, Tele Atlas, Getmapping plc, Europa Technologies]. http://www.google.com/permissions/geoguidelines.html

Area of *Phragmites* fen which was turf stripped approximately 8 years ago. *Comarum palustre, Carex paniculata, Mentha aquatica, Thelypteris thelypteroides* and *Calliergonella cuspidata* noted. [pH 6.2; µS 778]

S27 area in the rough location of 1986 quadrat. Similar species list, but marked increase in cover of *Sphagnum* in the whole area (no *Sphagnum* recorded in 1986). Ground layer dominated by *Sphagnum* (*including S. fallax, S. fimbriatum, S. palustre, S. subnitens*). Relatively low sward of *Agrostis stolonifera, Carex rostrata, Eriophorum angustifolium, Phragmites australis* accompanied by a range of herbs including scattered *Comarum palustre* and *Hydrocotyle vulgaris*. *Menyanthes trifoliata* occurs locally with *Calliergon cordifolium*. [pH 4.7; µS 209]

Molinia caerulea – Juncus acutiflorus area at edge of compartment (location of 1986 quadrat). Ground layer dominated by *Sphagnum* (including *S. fallax, S. fimbriatum, S. palustre, S. subnitens*) mixed with *Aulacomnium palustre* and *Polytrichum commune*. *Cirsium dissectum* and *Succisa pratensis* locally abundant, *Eriophorum angustifolium, Hydrocotyle vulgaris* locally frequent. *Drosera rotundifolia* and *Dactylorhiza maculata* seen in this area (several plants). Species list similar to 1986, but *Sphagnum* spp. have colonised and become dominant (now up to 90% cover).

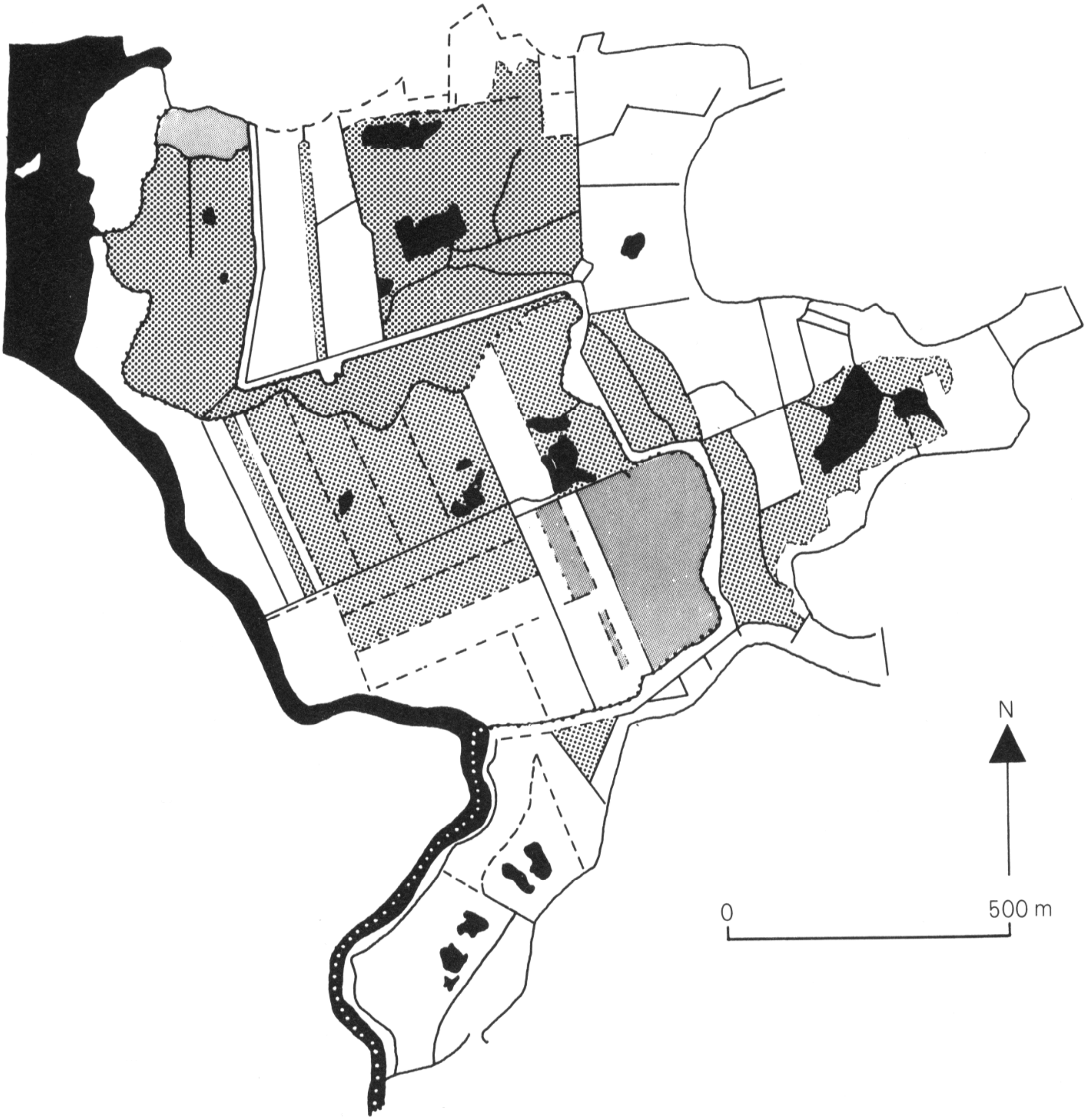

FIG. 3. Distribution of turf ponds (shallow 19th-Century peat excavations) in the Catfield and Irstead fens, Norfolk. Stippled areas represent total extent of turf ponds as extrapolated from stratigraphical data, coarse stippling, turf ponds which are also shown (as blue areas) on 1st Edition (1885) 1:10 560 Ordnance Survey plan.

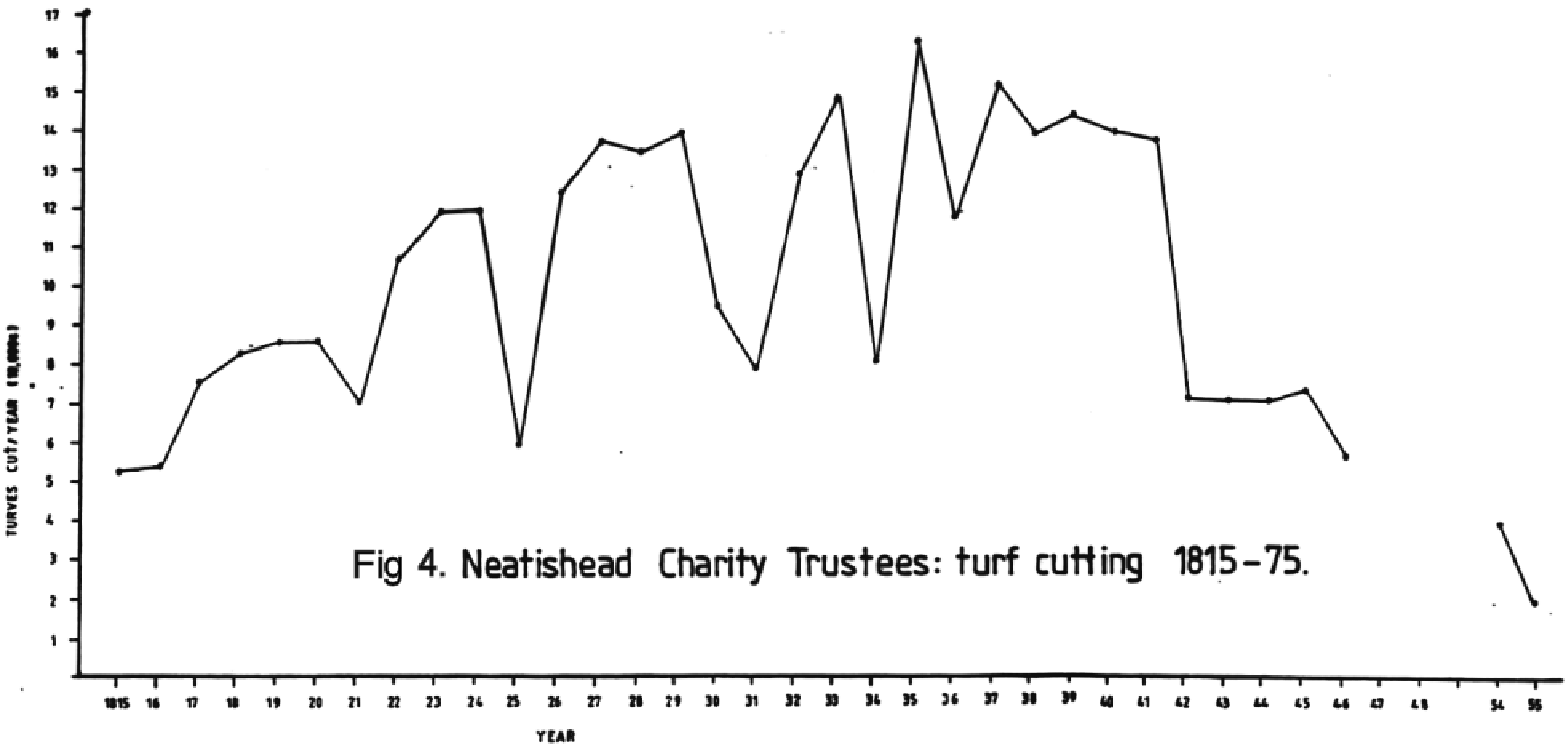

Fig 4. Neatishead Charity Trustees: turf cutting 1815–75.

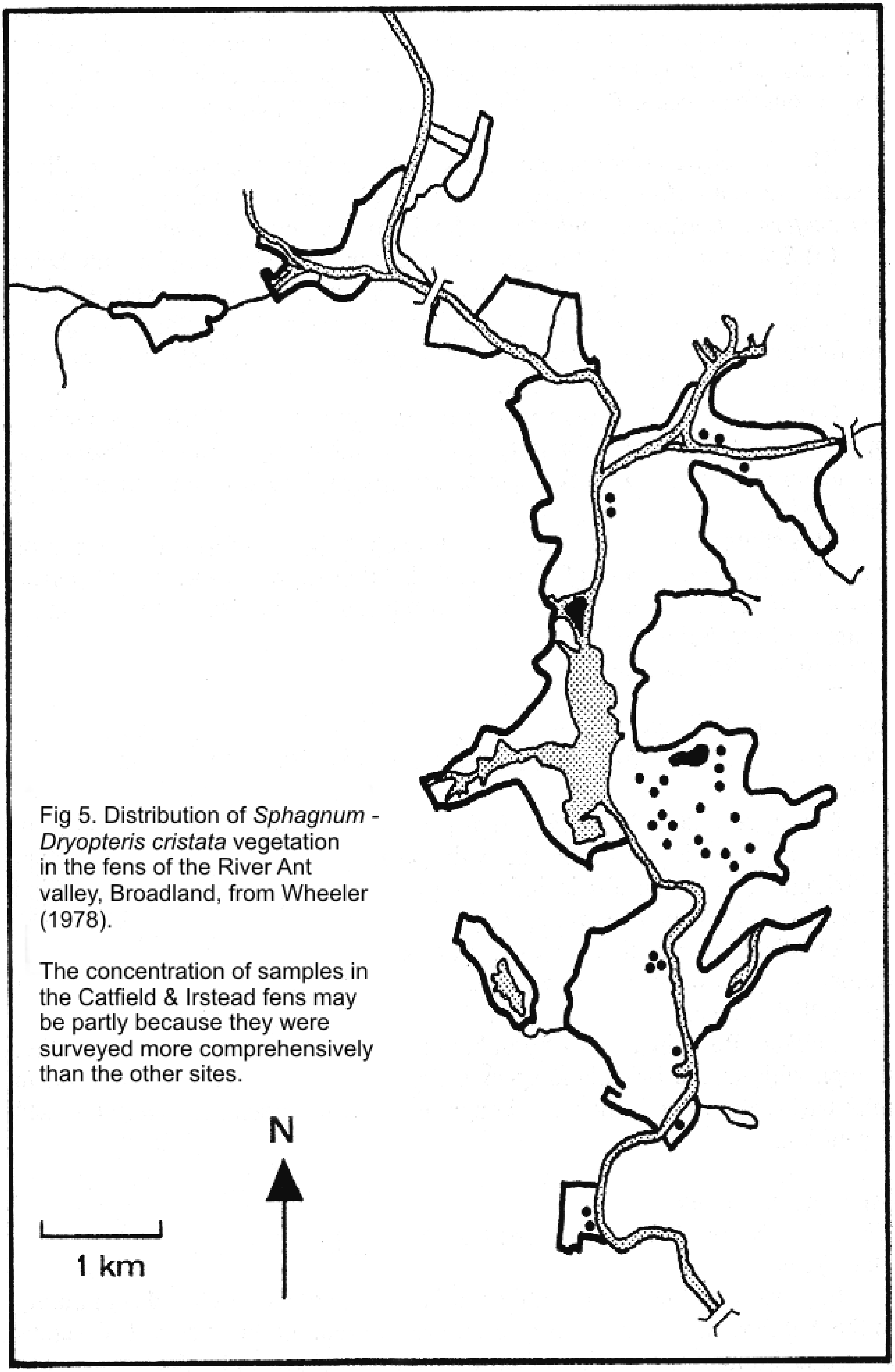

Fig 5. Distribution of *Sphagnum* - *Dryopteris cristata* vegetation in the fens of the River Ant valley, Broadland, from Wheeler (1978).

The concentration of samples in the Catfield & Irstead fens may be partly because they were surveyed more comprehensively than the other sites.

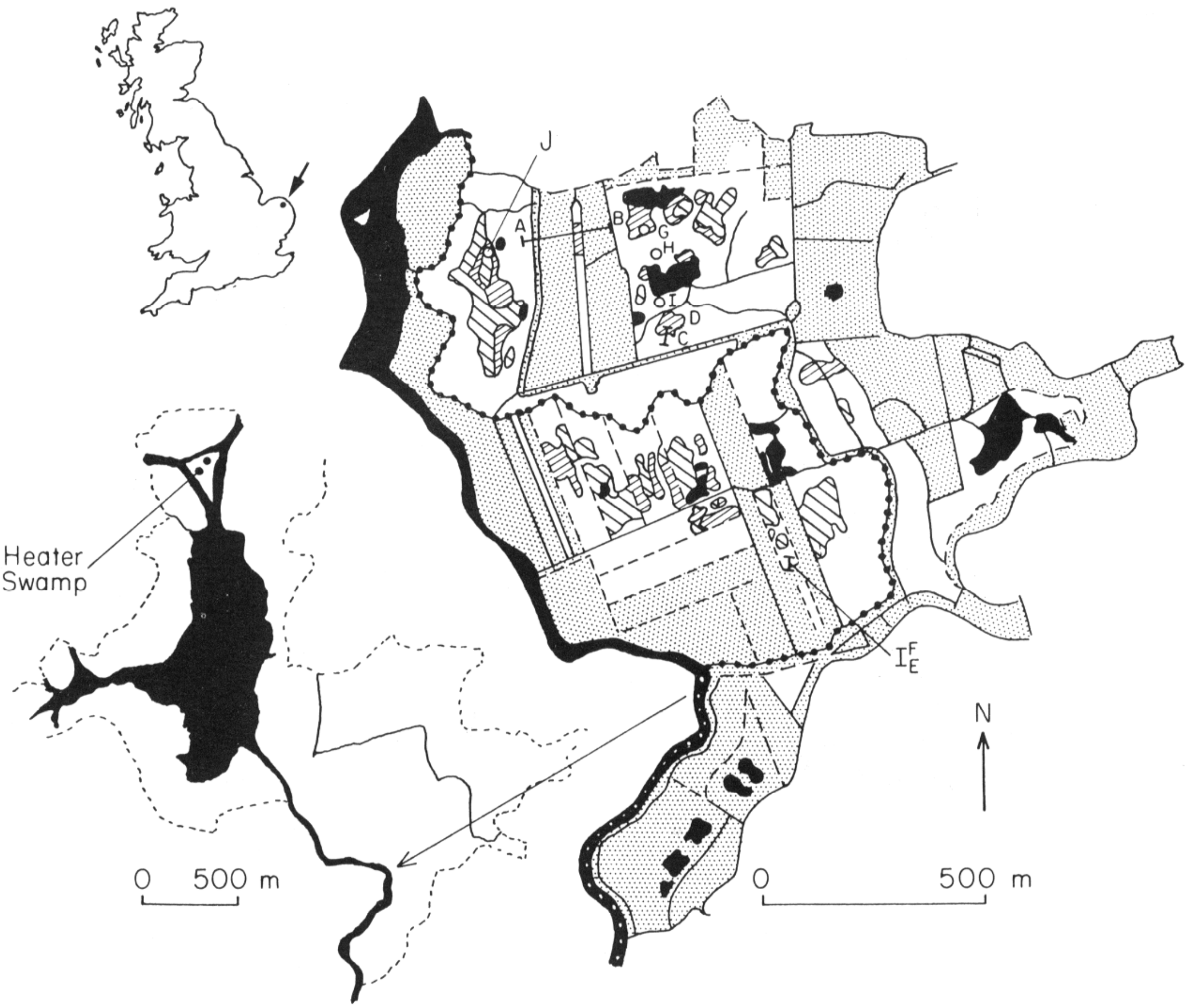

FIG. 6. Map of the Catfield and Irstead Fens. Black areas and lines represent open water and dykes. Dashed lines represent overgrown dykes. Stippled areas mark solid (i.e. uncut) peat surfaces; other portions are former turf ponds (Giller & Wheeler 1986a). Hatching shows distribution of *Sphagnum* stands: ▨, *Betulo–Dryopteridetum cristatae*, ▧, *Betulo–Myricetum gale Sphagnum* variant. Letters mark location of transects and sampling sites investigated. Black dots show the position of the parish boundary (the former course of the River Ant) through the fens. Inset shows location of the fens alongside Barton Broad and position of Heater Swamp.

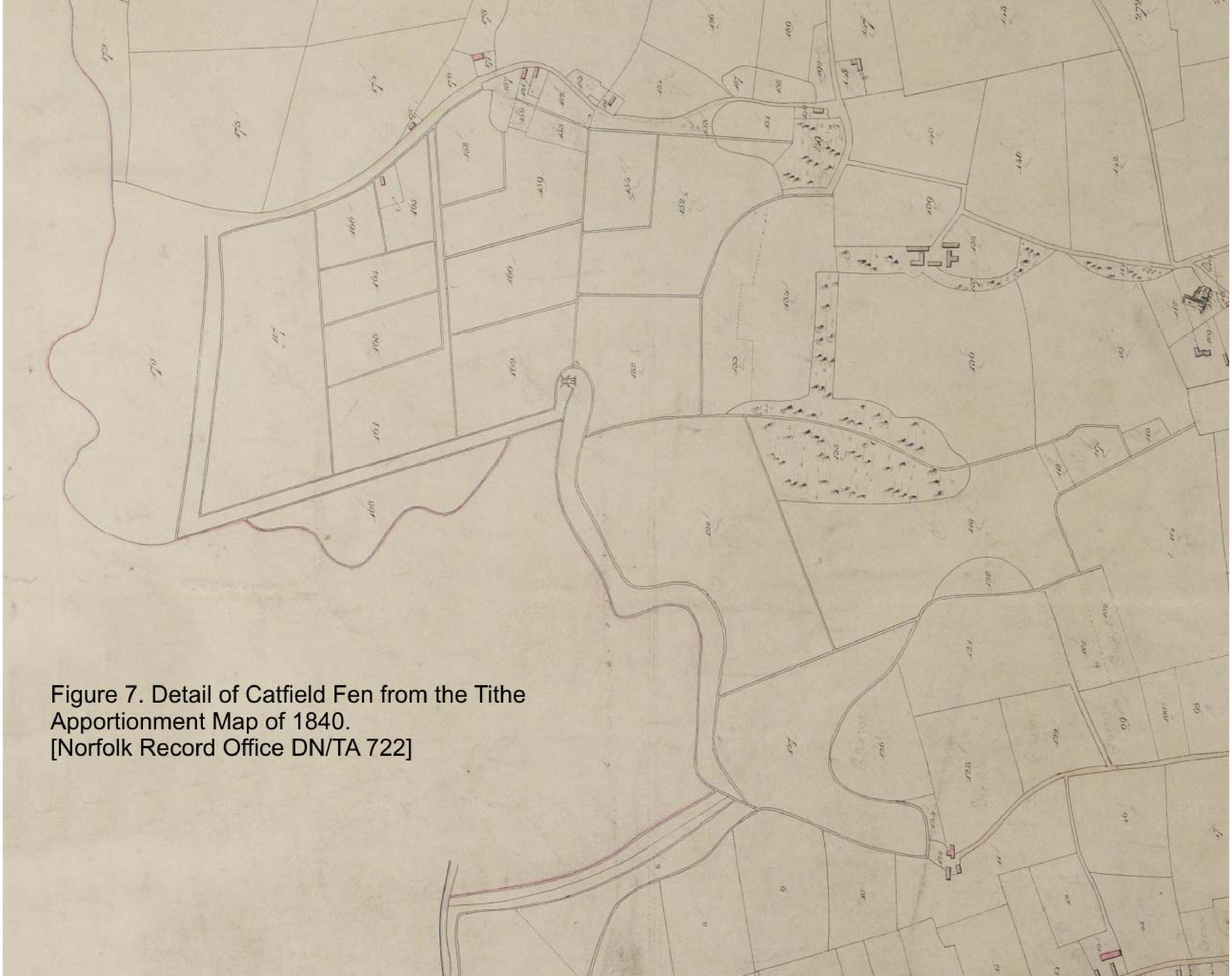

Figure 7. Detail of Catfield Fen from the Tithe Apportionment Map of 1840.
[Norfolk Record Office DN/TA 722]

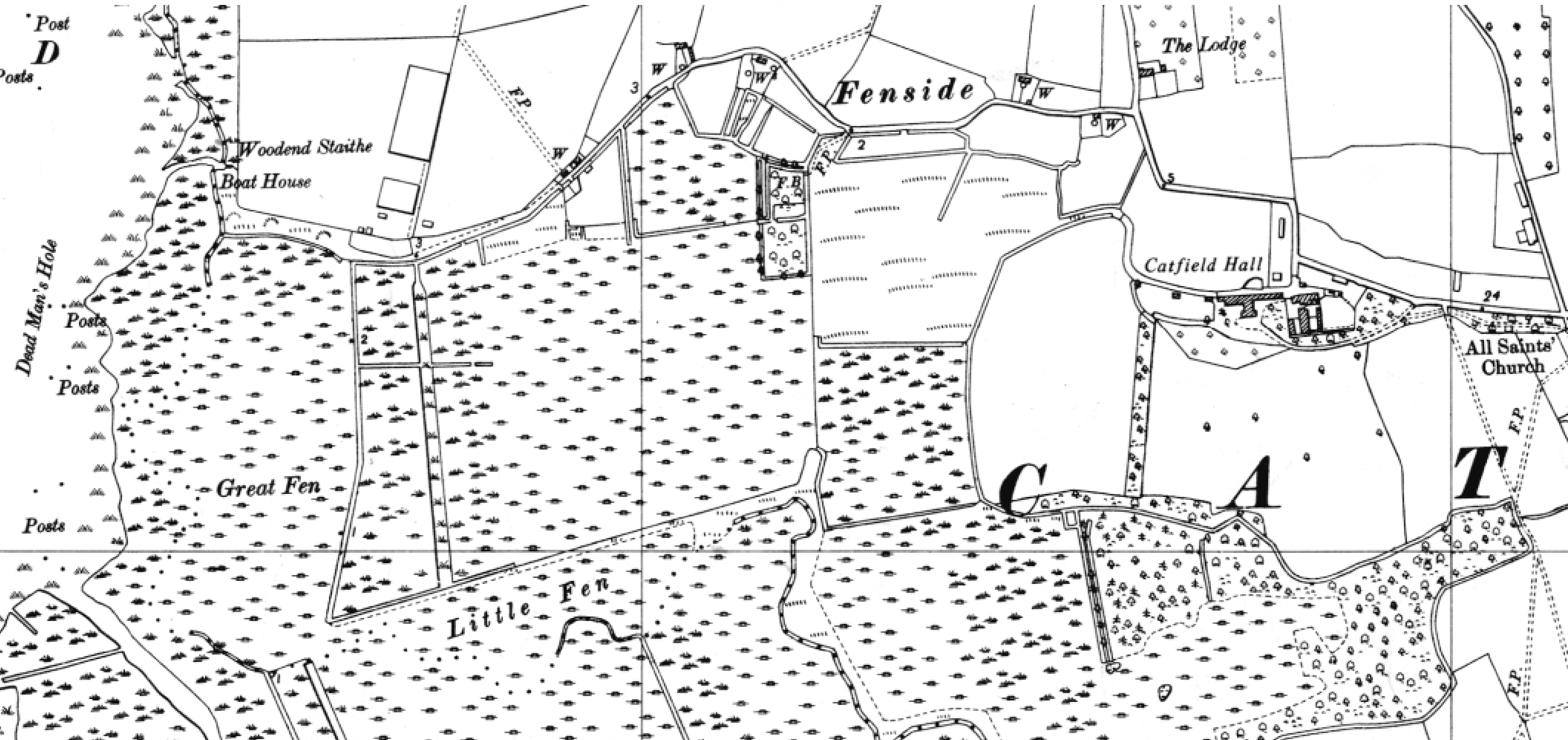

Figure 8. Extract from 1:10 560 Provisional Edition Ordnance Survey Sheet TG 32 SE (1957)

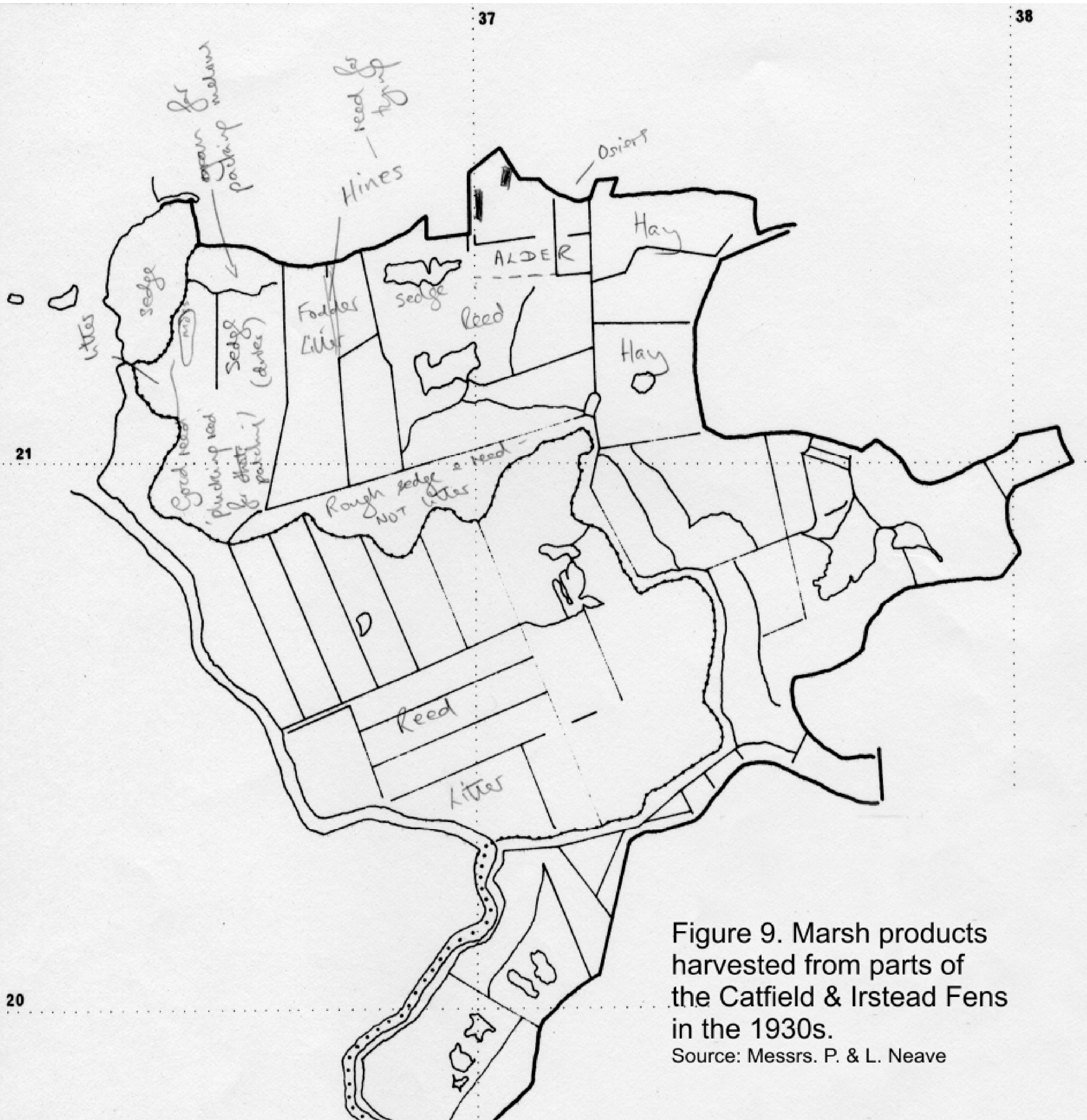

Figure 9. Marsh products harvested from parts of the Catfield & Irstead Fens in the 1930s.
Source: Messrs. P. & L. Neave

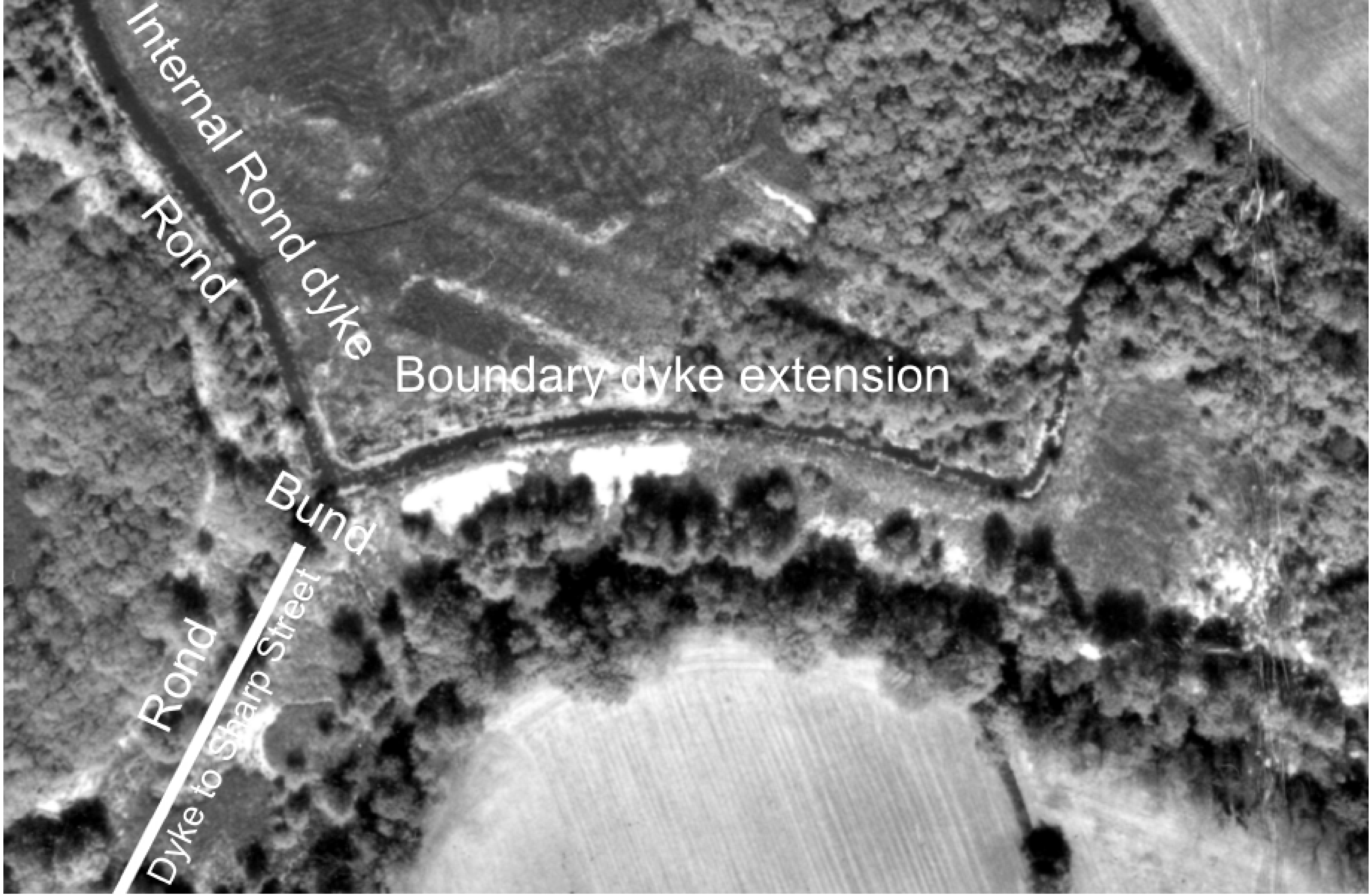

Figure 10. Detail from aerial photograph (25th May 1975) of the southern end of the Catfield Hall Estate marshes