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Catfield Renewals.

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Introduction.

This submission has been prepared by Dr Chris Bradley, Senior Lecturer in the School of Geography, Earth and Environmental Sciences at the University of Birmingham. Dr Bradley is a wetland hydrologist, a former member of the National Committee of the British Hydrological Society, whose research has been funded by NERC, EPSRC, the WMO, the Malaysian Government, and the US National Parks Service. A graduate of Cambridge University (BA MA), he completed a MA at Wilfrid Laurier University Canada (with distinction) and a PhD (funded by NERC) at Leicester University. He has >50 publications including:

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Context

This submission responds to a number of points raised in the documentation used to support the Environment Agency's 'minded-to' decision with respect to two licences to abstract groundwater from sites in the vicinity of the internationally-recognised Ant Broads and Marshes SSSI, Norfolk, UK. In doing so, it is noted that responses have been invited to consider: i. whether there is anything that is perceived to be inaccurate in the draft determination report; ii. has the EA failed to consider anything that it should have; and iii. has information become available in the time that has elapsed since the public consultation of October 2012?

Before commenting in detail on the draft determination report, it is important to review a selection of the information made available to underpin the decision. It is generally agreed that Catfield Fen (within the Ant Broads and Marshes SSSI) is a complex hydrological system (AMEC 2014; p. 24) with a complex geology (AMEC, 2014 p. 115). However, two points should be emphasised:

First, Catfield Fen is a groundwater dependent ecosystem. The inference is that Catfield Fen would be significantly affected, if not irreversibly degraded, were groundwater availability to vary beyond the normal range of fluctuation. As demonstrated later in this submission, there is evidence of marked spatial differences in the proportions of base-rich and base-poor waters in the rooting zone at Catfield Fen. This has implications for the ecology of the wetland, given the need to maintain a balance between the relative contributions of the principal water sources: precipitation and groundwater. The ecological significance of the balance between the relative contributions of precipitation and groundwater to the surficial (near-surface) of the fen is critical to assessing (and quantifying) the impact of groundwater abstraction on the fen. This was expressed in the document by Harding which forms part of a compendium of evidence prepared in conjunction with Natural England in 2011 (Natural England et al. 2011). Harding describes a mixed mire community at Catfield Fen where waters derived from recent precipitation overlie the groundwater table. In this situation, calcareous tall fen species may be rooted through the shallow rainwater table and into the minerotrophic water table below, whereas the surface bryophyte and shallow-rooted herbs may be supported by the perched rainwater table. As the two water types have contrasting hydrochemistries, an acid bog vegetation characterised by Sphagnum is found beneath a layer of rich-fen tall herbs. These are the prevailing conditions in *Dryopteris cristata* - *Sphagnum* fens found in the Norfolk Broads, for which Catfield is the type locality. As Harding highlights, their hydrochemistry is complex and susceptible to reductions in the upward flux (movement) of groundwater.

It is important to note that these points were agreed in 2012, and as Rushton (2014a) suggests, they highlight the need to focus on the hydrology of the wetland(s), rather than the hydrogeology (although it is generally agreed that the geology is complex). Fundamentally, it is essential to understand the impact of groundwater abstraction, not simply on wetland water levels, but on the balance between precipitation and groundwater within the rooting zone (i.e. in the specific area where the hydrology will influence the ecology). The hydrology of this rooting zone varies spatially and temporally and it is important to focus on any changes in those parameters that have ecological significance. For example, identifying any change in key hydrological thresholds (with respect to base richness / pH, summer water-tables; spring water-tables; frequency and duration of periods of saturation and/or water-table drawdown) in the relatively shallow rooting zone that impact the composition of local fen vegetation communities.

Second, to-date there has been a marked lack of integrative work that has succeeded in linking the hydrology and the ecology of the Fen. The lack of integration between hydrology and ecology presents a number of problems (and uncertainties) when considering the impact of local groundwater abstraction. Some of these problems include:

- How resilient are fen ecosystems to groundwater abstraction, the effects of which are likely to amplify ‘natural’ climate variability, particularly during periods of below average precipitation?
- What are the key hydrological thresholds (e.g. those referred to above in the rooting zone, that influence the fen ecology and which might account for change over time?

- More fundamentally, fen ecosystems are spatially diverse and characterised by significant local variability in their hydrology and ecology. Inevitably, model results are subject to considerable variability (both with respect to hydrology and their ecological significance), and the resulting uncertainties or error should be quantified.

Specific Comments:
Preliminary indications that the Environment Agency is minded not to renew the licences for groundwater abstraction are welcomed, given the importance of following the precautionary principle. In so doing, however, there should be more consideration to the uncertainty in our understanding of the impact of local groundwater abstraction on the hydrology and ecology of the Ant and Broads Marshes SSSI. It is important to note also, that groundwater models cannot be used on their own to licence groundwater abstraction, and that the ecological effects of specific abstraction regimes and totals should be established. The Yare North Norfolk model (YNN), and the revised North East Anglia Chalk (NEAC) model are regional groundwater models in which individual model cells are 200 × 200 m (40,000m^2 in area) while there is marked local variations (at the 1m^2 scale) in vegetation communities, and in the hydrochemistry of near-surface waters. The ability of the model to replicate local hydrological variability (whether with respect to water tables or hydrochemistry) has not been demonstrated and it is questionable whether an 'acceptable level of abstraction' can be identified by focusing on the 'hydrological functioning of the groundwater-surface water system in the vicinity of a groundwater-fed wetland' alone (implied by EA, 2014, Section 1.3).

It is instructive to consider whether the groundwater modelling process adopted has conformed with accepted practice. Rushton (2014b) notes that the EA have failed to follow their own recommendations in that data collation and conceptual modelling have not been undertaken prior to numerical modelling. This can be demonstrated in more detail with reference to Anderson & Woessner (1992) which purports to be a 'comprehensive reference to assist those wishing to develop proficiency in the art of groundwater modeling'.

Anderson & Woessner (1992) recommend that groundwater modelling results should be presented in a certain form. They suggest that *'one of the most insidious and nefarious properties of scientific models is their tendency to take over and sometimes supplant reality'*. For this reason, they consider it essential that modellers identify clearly **the purpose of the modelling project** including the questions to be addressed by the model, and **a statement of the error that is deemed acceptable**.

Anderson & Woessner (1992) suggest that a groundwater model should be '*only one component of a hydrogeological investigation'*, and extensive field information is required: both for input to the model and for calibration / verification. They indicate that in cases where the available data are inadequate to support the modelling work, *'professional ethics require that modelling results should not be used at all, or at least should be presented with the appropriate qualifiers'.*

Having identified the purpose of the model the investigation should proceed in a number of clear stages. These provide the *'ideal against which the completeness of a modeling study'* can be measured. It is suggested that all studies should include **calibration / sensitivity analysis**. The stages should include:

1. Formulation of a 'correct' conceptual model of the area to be modelled (the conceptual model is envisaged as a 'pictorial representation of the groundwater flow system'). Generally, the closer that the conceptual model approximates the field situation, then the more accurate the numerical model. For practical reasons, the goal is normally a parsimonious model (i.e. a model that uses relatively few parameters) which retains sufficient complexity so that it adequately reproduces system behaviour'.
2. Identification of parameter values to represent the properties of the geological units within the area to be modelled (vertical / horizontal hydraulic conductivity; specific storage etc.)
3. Model uncertainties should be identified at several stages (i.e. uncertainties / error in model parameters; uncertainty / error in model predictions).
4. Selection of model cell size is a critical step in model design. This should be influenced by the expected curvature of the water-table and the variability in aquifer properties.
5. Selection of model time step is also critical: the way in which the model represents space and time strongly influences the numerical results. '*Ideally, it is desirable to use small nodal spacing and small time steps*.'
6. Every modelling exercise should include water balance calculations, comprising the computation of water flows across boundaries, and water storage.
7. Groundwater levels reproduced by the model should be quoted together with estimates of the errors arising in a variety of ways. Those errors arising from temporal and spatial discretization should be assessed independently in the early stages of calibration.

The degree to which the YNN / NEAC has followed this protocol is questionable, and the documentation accompanying both models is of itself insufficient to identify key features of the model design. This is evidenced by some of the comments in Rushton (2014a) in which he comments (page 1) on the need for '*detailed models of the near surface conditions*'. More fundamentally, it is doubtful whether there is sufficient hydrological and hydrochemical data to inform model development. The lack of field data presents a significant obstacle for model verification and validation, particularly given the apparent lack of local determinations of key hydraulic parameters such as hydraulic conductivity and specific yield / storage.

Rushton (2014c; page 3) considers that the groundwater model, and especially the representation of conditions in the fens, does not warrant its use for detailed analyses of fen hydrology. He makes the point (made also by Mr Harris' advisors) that a cell of 200 m by 200 m cannot represent the detailed features and processes occurring within a wetland which determine the local variability in wetland vegetation communities. The importance of local variability has yet to be addressed by the EA and AMEC, and Rushton (2014c; page 9) notes the failure (by AMEC) in grasping '*the widespread concern that the complex hydrological and hydrogeological conditions of Catfield Fen cannot be represented by a model that assumes that only one set of conditions applies over each 200 m by 200 m plan area. The 200 m by 200 m grid does not allow the representation of individual drains, ponds, sluices etc.*' Rushton considers the Technical Note that seeks to address questions of model cell size fails to address the key questions, and the findings are of little value. These points are also not addressed by the later comment by van Wonderen (2014). Moreover, the fine-scale model apparently requires the use of unrealistic parameters (e.g. a specific yield of 0.8) to yield meaningful results.

With respect to the groundwater model itself, there are a number of uncertainties in model output which, it seems, have yet to be addressed. For example, the Ant and Bure Marshes; phase 3 project report on the Yare & N. Norfolk Groundwater Resource Investigation Area (June 2008), identified a number of key areas of concern which were not satisfactorily considered in the Groundwater Summary Report (EA, 2014):

- problems with elevation data; including LIDAR at low elevations;
- the lack of quantitative flow data in hydrometric area 34/09b (corresponding to Catfield) with the result that model water budgets cannot be verified by observed data. There are also uncertainties in the volume of water discharged by Internal Drainage Board (IDB) drainage schemes;
- hydraulic parameters have been estimated from sparse point measurements. There are no data, for example, on the hydraulic properties of recent and Quaternary deposits. Transmissivity (hydraulic conductivity x aquifer depth) data are also limited and mainly focussed along the river valleys;
- The definition of 'acceptability' of model performance (P. 139) is given as +/- 1m for riverside / riparian boreholes; +/- 3m for non-riverside wells; and +/- 5m for BGS archival groundwater levels.
- There is no quantitative measure of the 'goodness of fit' (e.g. root mean square error); and the report refers to the relatively shallow groundwater gradients in the vicinity of the Fen).
- Groundwater levels in the Crag do not appear to have been monitored over a period coinciding with an extended drought (e.g. as in 1995-97) which may have implications for model performance under drought conditions.
- The report acknowledges (P. 56) that 'abstraction is typically concentrated in the drier summer months and significant impacts can occur where concentrations of abstractions occur'.
- The report suggests (P. 78) that significant field-work is required for further quantification of the model.

A further area of concern, however, lies with respect to wider access to the model: the groundwater model (and the related code 4R) relies upon data-sets which are available to the EA (and AMEC) under licence. It is not possible to run the model without access to these data, and as a result, the model can only be operated by the EA / AMEC. Consequently, model sensitivity cannot be assessed by individuals from outside the EA / AMEC, and the degree to which the results are supported by '*adequate data and rigorous modelling'* cannot be considered.

In this context it is difficult to evaluate some of the information presented by the Environment Agency in support of their decision, for example, their Appendix 12: the addendum to the appropriate assessment. Figure 3.3 in this appendix presents data for the model cell which approximates the location of Middle Marsh at Catfield Fen, however, the limited field data suggests that there were periods when the model water-table was >0.2m above the observed, field levels observed at TG32. At present, it is unclear whether these errors and uncertainties are seen more widely within the Ant Broads and marshes, yet a difference in water levels of this magnitude will have significant ecological implications.

In summary,

- It is questionable whether the catchment-scale groundwater model is able to yield data at an appropriate spatial and temporal resolution to quantify the degree to which changes in the hydrology will impact the ecology (in the context of the key thresholds noted above, and given the need to focus specifically on the hydrology of the 'rooting zone');
- It is important to emphasise the spatial variability in hydro-ecological processes across the wetland. It has been noted by Rushton (2014a) that the model results in the vicinity of Catfield Fen are constrained by spot elevations in the water courses. It is uncertain, however, whether the hydrology in the centre of individual fen compartments (distant from the water courses) can be modelled successfully);
- Related to the previous point, there seems to be an assumption that the spatially diverse wetland can be characterised using uniform parameters (for horizontal and vertical hydraulic conductivity; specific yield etc.) yet we know from recent stratigraphic surveys that the surficial sedimentary units are highly variable (with distinct variations across the SSSI, for example, in the distribution of the underlying clay layer; and in the extent of turbary). Moreover, it is questionable (from the information presented) whether: i. the model has taken recent fieldwork into account; and ii. if sufficient field-data are available to characterise sufficiently the hydrology of the wetland.
- It is significant that the draft determination report does not discuss errors and uncertainties in the model output. Similarly, a sensitivity analysis has not been completed (due to 'insufficient funds').
- In considering the significance of the results, it is unclear of the extent to which the draft determination report has drawn upon recent international research (particularly on accelerated succession in the Netherlands).

New Work:

Experience from work on comparable Dutch fen ecosystems, published in the internationally recognised peer-reviewed literature (and confirmed by Dutch experts) suggests that Catfield Fen is experiencing accelerated succession. A process which is very difficult to reverse, and which can be only be managed by a cessation of groundwater abstraction in the surrounding area.

The implications of this work have been summarised in papers (on the EA sharefile folder) by Dr Aat Barendregt (Utrecht University). The significance of this work, specifically for Catfield Fen, have been demonstrated by the work of a Postgraduate Student, Erin Payne, from Utrecht University over the summer of 2014. Some of her initial results (Fig 1 below) indicate that the presence of a number of rainwater lenses across transects at Catfield Fen. The vegetation is closely related to the hydrochemistry, and a mechanism has been advanced to explain the significant increase in the abundance of *Sphagnum fallax* at Catfield:

'The transition community with e.g. Sphagnum fallax appeared to be present in many locations at Catfield Fen. It is reported that this community expanded recently. It is characterized by accumulation of rainwater, but only represented in the top layer (10-20cm) the groundwater input at

surface is reduced. It seems that in recent years less buffered groundwater discharges and as a consequence acid rainwater can accumulate on top of the soil stimulating the presence of Sphagnum fallax. The balance in input with rainwater and groundwater changed at many locations in favour of acid rainwater and by this process it reduced the specific conditions for rich fen vegetation' (Payne and Barendregt, 2014)

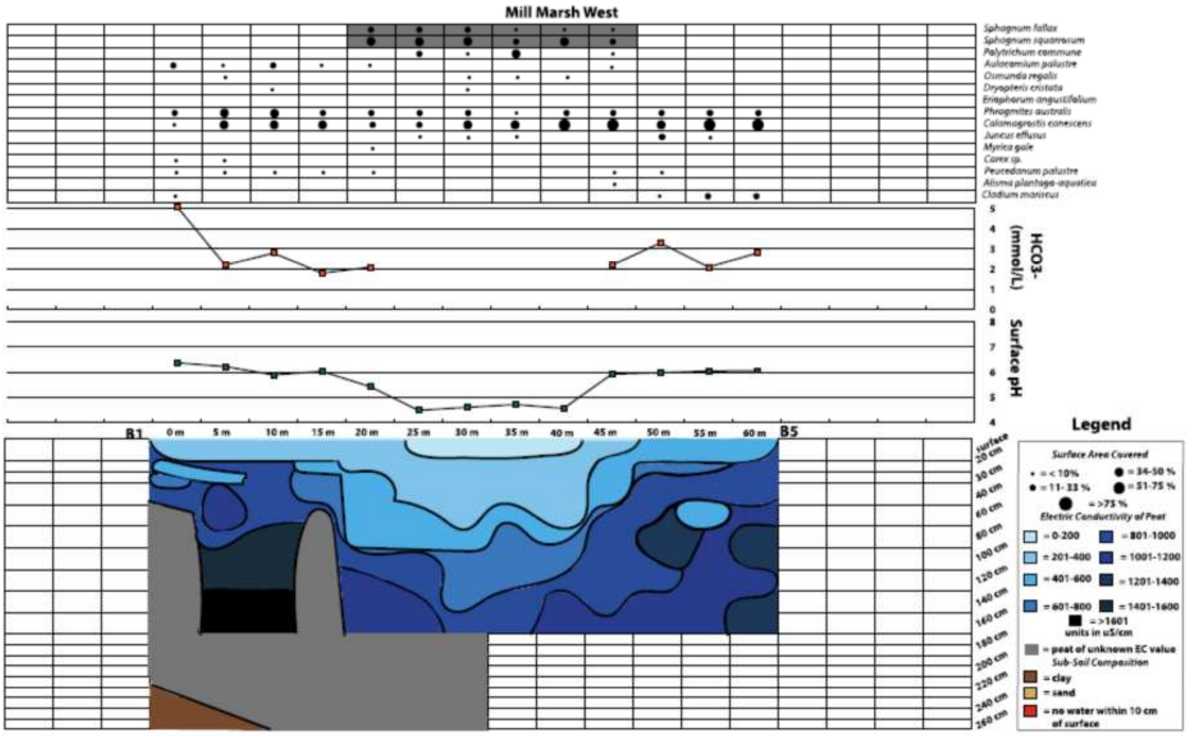

Figure 1: Transect of Mill Marsh West

Drawing upon Dutch experience, Dr Barendregt emphasises that this process can only be controlled by maintaining a continued upward groundwater flux to the surface of the wetland. Importantly also, the recent study by Payne and Barendregt indicates that there are marked vertical and horizontal differences in the hydrochemistry. At the moment, however, the degree to which the distribution of waters of differing composition may change over time is uncertain, and this is one of a number of uncertainties in the hydroecology of the wetland which should be taken into account when considering the effect of local groundwater abstraction.

Conclusions.

Catfield Fen in a site of acknowledged global significance: it forms part of an internationally recognised RAMSAR wetland, and has been described as the finest undrained floodplain fen ecosystem in Europe. The available data indicate that groundwater contributes to the water-budget of the site, and the variability in the local water-budget (including a groundwater contribution) undoubtedly account for the ecological diversity of the site.

At present there are considerable uncertainties about the impacts of hydrological change on the wetland. New research has demonstrated marked vertical and horizontal gradients across the fen which are important in determining the vegetation composition of the site. While the quantitative effects of individual abstractions can be estimated using a regional groundwater model, the potential error in model outputs is not known. Moreover small changes in the water-table may lead to significant change in the predominant water source at key depths immediately below the surface (i.e. within the area where plants extract water), leading to increased mineralization of the near-surface organic deposits (releasing nutrients and CO_2 to the atmosphere).

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