Some thoughts on the monitoring and preservation of waterlogged archaeological sites in eastern England

Charles French

McBurney Laboratory, Department of Archaeology and Anthropology,
University of Cambridge
caif2@cam.ac.uk

Abstract

This paper reviews five hydrological monitoring projects used on archaeological sites in the waterlogged landscapes of fenland East Anglia and east Yorkshire in England. The project design, recorded variables and implications of each is discussed. In particular, the importance of understanding the landscape context is paramount, and retrieving an appropriate dataset over a sufficiently lengthy period of time to obtain reliable results and predictability. Some of the lessons learnt and outstanding problems are explored. As former wetlands are fast disappearing around the world through dewatering and a host of wider development threats such as urbanisation and gravel extraction, the low intrusion suite of methods described here for measuring the degree and certainty of organic preservation is doubly important for establishing the viability of preservation *in situ* schemes for waterlogged archaeological sites. This is crucial to get right, as wetland archaeological records are an irreplaceable resource which offer extraordinarily full and diverse datasets of human lifeways which are all too often either poorly preserved or erroneously interpreted because of the skewed datasets recovered from dryland sites.

Keywords: hydrological monitoring, context, organic remains, groundwater, soil moisture, redox

INTRODUCTION

Over the past four decades I have been involved in a number of monitoring and analytical programmes of work on waterlogged archaeological sites, primarily in eastern England. This really began out of necessity, as I found myself working on sites that were actively disappearing before our eyes through dewatering processes, even without the threat of severe intervention such as gravel extraction.

Wetlands and their palaeo-environmental and archaeological records are fast disappearing. Whilst *c*. 4-6% of the earth's surface is covered by wetlands, there are a variety of estimates of wetland loss of about 90% disappearing in New Zealand to 60% in China for example (1), and almost all of East Anglia's former wetlands have become fully drained since the Second World War through the extensive advances of agricultural production, urbanisation, mineral extraction and associated dewatering. John Coles (2, 3) expounded the preservation virtues of the hugely better archaeological recovery obtained from wetland over dryland sites. The discovery of organic raw materials for tools and house construction, textiles, food remains and the organic 'debris of living' for example, takes potential archaeological interpretations to another level of certainty rarely ever enjoyed at a dryland site, to say nothing about the more detailed determination of palaeo-environmental context that is also possible. You only have to look at the complete archaeological record recovered from a site like Must Farm (see below) where the spatial distribution and arrangement of organic and inorganic artefacts allows one to talk sensibly about the use of internal space within the Late Bronze Age round houses.

The excavation and monitoring projects concerned were primarily located on the fen-edge of western Cambridgeshire in the lower Welland, Nene and Great Ouse valleys, and the Flag Fen/Bradley Fen basin just east of Peterborough (Fig. 1). Here there are series of landward fen basins which began to develop either wet riparian river valleys and/or first alder fen mires and then reed marsh from the 2nd millennium BC, which were then subsequently covered by with extensive alluviation of eroded soils, particularly from the later 1st millennium BC and Roman periods onwards (4).

The first site/landscape where a groundwater monitoring programme was designed, implemented and carried out from the start to final publication was at the Etton Neolithic causewayed enclosure site in the lower Welland valley just north of Peterborough (1, 2). This 4th millennium BC interrupted ditch enclosure located in a meander of a former river channel in what is now the floodplain of the River Welland produced a wealth of waterlogged material including worked wood and natural woven fibres as well as the whole spectrum of palaeo-environmental data including insect remains and inorganic artefacts. In this case the groundwater monitoring study was undertaken in direct response to the advancing gravel extraction programme of Maxey quarry immediately to the west of the site.

The second study area was at Flag Fen, the waterlogged Late Bronze Age platform and timber avenue (3). The Flag Fen basin on the eastern side of Peterborough, Cambridgeshire, gradually became a reed fen over the last two millennia BC as groundwater base levels rose. From about 1406 cal BC an oak timber avenue was constructed across this basin from the Fengate dryland to the west to the gravel island of Whittlesey to the east. This avenue, which was rebuilt and elaborated several times between then and about 937 cal BC, was aligned on and built over a substantial timber platform, whose use is not yet understood. Here the monitoring study has been more of a compendium of different studies in advance of various development threats rather than a coherent, designed research plan from the beginning.

The third study was at the waterlogged Late Bronze Age palisaded settlement site at Must Farm on the southern side of the Flag/Bradley Fen basin, adjacent to the Whittlesey clay for bricks quarry pit. Here there is an earlier oak timber causeway or avenue of timbers dated to *c*. 1280-1250 cal BC which was subsequently overlain by a short-lived palisaded settlement comprised of at least six, round wooden/thatched post-built structures, probably built around 1,000-900 BC (with its exact date yet to be confirmed by new dendrochronology and radiocarbon studies), all overlying a former silt-filled roddon or river channel (7). At the behest of the Cambridgeshire Mineral Planning Authority, the quarry operator provided funding and support for a initial five-year (extended to seven years) monitoring programme with the co-operation and involvement of the developer, in this case Hanson Building Products Ltd. (now Forterra) and their consultants SLR Consulting Ltd.

The fourth site was at Needingworth quarry north of Over where the lower Great Ouse valley spills out into the fenland of southern Cambridgeshire. This alluviated river valley landscape has revealed an extensive prehistoric landscape of Mesolithic, Neolithic, Bronze and Iron Age settlement as well a Bronze Age barrows and field systems, all as a result of planned sand/gravel extraction on a massive scale (8). Here a monitoring programme funded by English Heritage was custom designed and implemented during the first 10-year period of quarry life over a complete cycle of archaeological and gravel extraction works and land restoration.

Finally I played a small role in the English Heritage funded preservation assessment of the waterlogged Mesolithic site of Star Carr on the edge of the former Lake Flixton in the Vale of Pickering, East Yorkshire, using micromorphological characterisation techniques in addition to water quality and geo-chemical testing of the lake margin sediments. Star Carr was first excavated by Grahame Clark in the 1950s and significantly produced very early Mesolithic assemblages of *c*. 11,000-9,000 years old associated with some kind of timber platform structure on the edge of the palaeo-Flixton Lake (9, 10). New research on the dryland edge at this site has also revealed a structure with a sunken floor and surrounded by posts (11), and a number of apparently conflicting preservation trajectories (12, 13).

In each case, time-reliant information on the speed, timeframe and effects of dewatering on waterlogged prehistoric archaeological contexts, and especially organic deposits was required. This data has not just assisted preservation and/or excavation strategies but has crucially informed planning decisions for developer-funded work where mitigation strategies for preservation *in situ* or by record have not been straightforward.

In this paper, the aim is to draw attention to what worked and what did not, bearing in mind that each site has its own set of circumstances which may lead to different approaches as to how the study is conducted. Of course, these may not necessarily be the right choices with hindsight.

SOME DETAIL ON THE MONITORING SITES/PROGRAMMES

The Etton causewayed enclosure, Maxey Quarry

This groundwater study at Etton, funded by the Society of Antiquaries (London), was relatively uncomplicated as it was a greenfield, single period, buried archaeological site at the groundwater level in a floodplain margin location on the edge of an advancing gravel quarry at Maxey, Cambridgeshire. Essentially a series of dipwell tubes were placed at regular 20m intervals from south to north across the area occupied by the Neolithic causewayed enclosure prior to its full excavation through the *c*. 1.2m of silty clay alluvial overburden, *c*. 40cm thick buried soil and into the sand/gravel river terrace deposits beneath (Fig. 2) (14). This excavation was part of a long-term archaeological project investigating the alluvial floodplain of the lower Welland valley (5, 15, 16). The groundwater levels in the dipwells were read on a daily basis over a 14-month period (October, 1982 to September, 1983) with the daily local rainfall and evaporation figures retrieved from a nearby weather station. When the groundwater abstraction pumps were turned on in the adjacent quarry pit in late June of 1983, the groundwater exhibited an immediate and dramatic fall over the next four-week period (Fig. 3), lowering the groundwater table to more than a metre below the lowest primary fill deposit in the enclosure ditch, permanently. Low groundwater levels were sustained to enable dry gravel extraction until the causewayed enclosure was totally excavated and then destroyed through gravel extraction. The seasonally variable rainfall for the area appeared to have no re-charge effect on this situation. Almost immediately after this dramatic lowering of the groundwater table, there was an observable effect on the organic record. Marked vaccuoles (up to 2mm across) were recorded between the wood and ditch fill matrix, roundwood was often loose within its bark, roundwood ends were no longer crisp but soft and fragile, and deep cracks had appeared within the larger pieces of wood. In short there was a pronounced deterioration in the wooden remains as compared to the excellent preservation conditions for organic remains observed previously in 1982-3. Essentially the cell structure in once waterlogged wood was both drying out, shrinking and distorting, thus witnessing the immediacy of the detrimental effects on previously well preserved wooden archaeological material that varied from coppicing debris to axe hafts, bark matts and remains of bast fibre twine.

In this developmental study no account was taken of the groundwater quality and its chemistry in the dipwells nor the redox potential conditions. Given the known fast time-line of groundwater draw down at Etton, it would have been good to know if there had been similarly rapid changes in pH, conductivity, redox and dissolved oxygen which would have allowed modelling of these combined observed effects. This data would have dramatically improved this study of drastically changing preservation conditions that occurred inside and outside the causewayed enclosure, and potentially enabled modelling of similar circumstances at other gravel quarry sites in river valley terrace landscapes.

A multi-period prehistoric landscape at Over, Needingworth Quarry

The monitoring project at Over quarry demonstrated the importance of monitoring archaeological sites within their broader landscape context over a period of years. Most of the extraction area was buried by variable depths of silty clay alluvium and/or reed peat, and revealed an extensively developed prehistoric landscape of field systems, burial monuments and settlement features ranging in date from the Mesolithic to Iron Age periods (8). A multi-parameter monitoring programme was devised and instigated in July, 1994, and continued until March, 2005, funded by English Heritage (17, 18, 19). A series of 16 dipwells and 16 access tubes were placed around the area to be quarried as well as within the northern and southern Bronze Age barrow fields, as well as monthly rainfall, evaporation and soil moisture deficit data obtained from the local meteorological office. In addition, a digital buried terrain model was constructed using ARC (Central) Ltd.'s systematic borehole data. The aim was to observe and record the whole hydrological system before and during quarrying operations, and then for a period after restoration. Data for local rainfall, groundwater levels, pH, temperature, conductivity, redox potential, dissolved oxygen and soil moisture content were collected on a monthly basis from a series of access tubes placed around the quarry and within two known Bronze Age barrow groups in the southern and northern barrow areas of the quarry (Fig. 4).

A number of quite distinctive patterns were observed. Despite seasonally variable rainfall and control of the water levels in the drainage dykes by the local drainage board, groundwater levels fell by up to a three-fold factor (to more than 5m below the modern ground surface) with a draw-down 'halo' extending up to 500-600m beyond the quarry face, and up to 1,500m downstream. During quarrying, there was increased fluctuation in most parameters: especially higher levels of dissolved oxygen and positive redox values (Figs. 5-7), and a lowering of soil moisture levels throughout the floodplain and archaeological sequences. Moreover, the moisture regime reacted differently depending upon whether it was within the peat or the more moisture retentive silty clay alluvial overburden or well drained sandy loam palaeosols and feature fills, or the free-draining sand/gravel substrate.

The nature of the archaeological feature fills was very important in controlling water retention. For example, coarser grained primary fills (medium-fine sands, sandy loams and gravels) of the southern barrow ring-ditch suffered from the groundwater draw-down effect with a substantial and quick lowering of soil moisture, whereas the finer grained, silty clay alluvial secondary infills continued to inhibit and capture through flow moisture much better, inhibiting desiccation. Without these relatively localised non-porous, water-retentive, fine textured infill deposits (i.e. predominantly silt and clay), both in archaeological features and palaeo-channels, there would have been much more serious dewatering taking place within the archaeological features.

Importantly, the clay bunding (using the underlying Oxford Clay geological substrate) of the former gravel extraction area and the subsequent creation of reed beds with a high maintained water level led to a recovery to pre-extraction levels of groundwater, soil moisture, redox and dissolved oxygen values (18). The 'sink effect' of the quarry area (21) was no longer affecting the acquifer as before and acting to lower the groundwater table beyond the quarry boundaries, but rather the original downstream aquifer flow (southwest to northeast) had resumed just as prior to gravel extraction. Nonetheless, there was a period of some two and a half years between the 28-month period of extraction/pumping and the maintained land/reedbed reinstatement with lowered soil moisture and groundwater levels, and higher positive redox and dissolved oxygen values. Although the manifestation of any changes in organic preservation has not been proven, there was sufficient time for the ingress of air and increased soil faunal bioturbation to have occurred, especially given a very active soil fauna normally present in such calcareous soil conditions. This situation corroborated the observation that there was minimal or no pollen survival in most of the prehistoric cut features and buried soils, with survival only in the deep earlier-mid-Holocene palaeo-channel, the occasional ghosts of wooden posts visible, and considerable zones of secondary amorphous iron staining in the buried soils and turves of the barrow mounds. Other studies of organic degradation in calcareous groundwater conditions (20) have demonstrated that remains such as textiles and pollen grains will disappear within a couple of years without air exclusion and/or waterlogging, and this is certainly the case at Over quarry.

The Late Bronze Age timber avenue and platform at Flag Fen

Hydrological monitoring at the Late Bronze Age timber avenue and platform site of Flag Fen over the past few decades has not been as systematic as would be ideally desirable, especially given its importance in terms of being one of the few waterlogged, wooden Late Bronze Age sites in Europe that is well preserved and open to the public (6). Nonetheless, there have been three important hydrological studies undertaken in the past 30 years since the site's discovery.

Discovered by systematic dyke survey in November, 1982 (22, 23, 24) (Fig. 8), investigations quickly showed that the managed drainage ditch, Mustdyke, which cut sinuously through the site, and maintained a low groundwater table for farming in the Flag Fen basin, was having a detrimental effect on the 3,000 year old wooden platform and avenue remains. In July 1987, a large artificial pond (the Large Mere) was deliberately constructed over what was believed at the time through a borehole survey to be the bulk of the platform site. It is now believed that leakage from this lake may in fact be assisting in maintaining locally high groundwater levels (25), at least on the western side of Mustdyke. Unfortunately this is not the case on the eastern side of the dyke.

The earliest hydrological monitoring studies were carried out in the late 1990s, funded by English Heritage (26). This first 10-day study indicated that the archaeological levels were moderately reducing and neutral in pH, despite the fact that there had been tertiary sewage settling beds located over this whole area for several decades before. Subsequently, Lillie and Cheetham (27) conducted a second water table monitoring study which indicated that either end of the post-alignment where it rises onto higher ground is seriously under threat of desiccation. As saturation levels never exceeded +0.55m OD, and the main platform levels are situated between *c*. -0.5 and +1m OD, at least the upper half of the wooden and other organic remains of the platform and avenue are compromised, and in particular the tops of all vertical posts of the timber avenue across the Flag Fen basin. Moreover, surface peat shrinkage of several metres over the past couple of centuries since drainage began has meant that the archaeological wood levels occur between as little as *c*. 0.5 and 1.25m below the modern ground surface (6), thus putting the whole complex at risk through on-going humification and bioturbation.

The 2015 study (27) aimed to observe and model groundwater levels across the Flag Fen area. Chapman and Cheetham's (28) three-fold classification for groundwater was used: zone 1 is above the seasonal maximum water table; zone 2 is the band of seasonal water table fluctuation which is intermittently wet and dry; and zone 3 is the deeper zone of permanent saturation. The new study clearly indicates that much of the Flag Fen wooden structures are located within zone 2 (and even zone 1), and the hydrological conditions are not at all ideal for the long-term *in situ* preservation of the site and this part of the Flag Fen basin. Clearly this site and its wider importance to British and European prehistory is at risk. It has also exposed the fragility of the scheduled/protected status of the site and its immediate landscape, such that plans are now being formulated as to how to best re-wet the site and at least slow or arrest any further development, drainage and dewatering effects.

The Late Bronze Age timber settlement and avenue at Must Farm

The contemporary Late Bronze Age, once waterlogged site of Must Farm is located on the southern side of the same Flag Fen basin on the upper southern edge of an earlier silt-filled roddon or river channel (7). This site was first discovered at the southern edge of a 1960s clay pit by Martin Redding, and was then evaluated in 2006 and subsequently monitored (2008-15) and then fully excavated (2015-16) under the mineral planning process as applied to this active brick quarry site (Hanson Building Products Ltd., now Forterra).

Between 2008 and 2015, the site was subject to an hydrological monitoring programme and trial preservation *in situ* scheme implemented by SLR Consulting Ltd. in response to a planning requirement set by the Cambridgeshire Mineral Planning Authority and Archaeology section (29, 30, 31). This has provided a wealth of monitoring data and detail which was reviewed by Matthiesen and Gregory (32), and along with advice from Cambridgeshire County Council and English Heritage/Historic England impetus lead to the abandonment of the monitoring scheme as preservation of the wealth of organic remains could not be guaranteed in the longer term. This resulted in a programme of full excavation jointly funded by Forterra and Historic England.

The site in question had become sealed by some 2.5m of freshwater peat and alluvium from Late Bronze Age times onwards (7). It was situated in a small area of land between a late medieval dyke (King's Dyke) and the active brick clay quarry in former agricultural land that had been subject to drainage since the 17th century (Fig. 9). Quarrying in the 1960s had removed the northern part of the enclosed settlement when outfall pipe trenches were cut through the site to balance the water level in the pit with that in King's Dyke. The trenches and other areas on the pit edge were backfilled and consolidated with brick-bats and fen deposits taken from the area of the Bronze Age site. Following establishment of baseline conditions from archaeological, palaeo-environmental and geochemical tests (7, 29), fifteen access tubes for piezometer and water quality readings were installed across the site, as well three TDR (Time Domain Reflectometry) soil moisture readers. Data on effective rainfall, groundwater, groundwater flow, soil moisture, conductivity, redox potential (for 2008-11; thereafter discontinued) and some soil chemistry (nitrate, sulphide, sulphate, iron) was collected as part of the monitoring programme from sediments in the palaeo-channel sediments, occupation zone and the surface water on site (30, 31). Particular attention was paid to the occupation zone of archaeological material which was concentrated within the area of timbers at *c*. -1-1.4m OD. In addition, all classes of palaeo-environmental data sampled in the 2006 evaluation of the site had undergone a condition assessment (29), and most data categories were already witnessing different levels of preservation versus degradation. However, how much was a result of fen basin development over the last 3,000 years and more recent drainage especially since the 1960s and more recent quarrying operations remains open to question.

Without going into the detail of individual readings on an annual/monthly basis, a few trends of key data types are mentioned here (30). Despite a bentonite clay wall installed around the 1960s quarry face by the quarry operator in 2008, overall there was clearly considerable fluctuation in the groundwater and soil moisture levels over the lengthy period of monitoring, which responded to rainfall and surface re-charge. The groundwater level was at or below the Late Bronze Age occupation deposits for the majority of the monitoring period, and there was a general downwards water flow and across/away from the site to the southwest. Nonetheless, the position of the palaeo-channel below part of the site with its perched groundwater table and capillary fringe effect helped to counteract this trend. For some periods, the occupation zone was not saturated, at other times it was, such as in 2012-13, but this was coincident with a period of higher winter rainfall, with the air filled pore space often in the range of 20-50%. As there was no specific calibration of the TDR moisture probe equipment to the varied sediment type at Must Farm, caution needed to be exercised about how the absolute moisture values should be interpreted. Redox values were highly variable in the first five years of monitoring (30), ranging between -200 and +700mV with a tendency to positive values (above +100mV) which are considered to be unsatisfactory for indicating a good reducing burial environment. In the limited geo-chemical assessment that was undertaken in 2009 and 2010, samples taken from palaeo-channel sediments were indicative of sulphate reduction or anoxic conditions (30: Report 3 (2009), 12; 33), whereas the few samples taken from the occupation zone exhibited high concentrations of nitrate (20-450ppm) and sulphate (1100-1600ppm), and low concentrations of sulphide (<30ppm) (30: Report 5 (2010), 14). A pond of standing water that had developed in the last couple of years of the monitoring programme above the site also showed a high sulphate content, but no systematic analyses of surface or groundwater quality were undertaken over a period of time to demonstrate whether this was a consistent trend or not.

Even considering all the data reports, an independent review of the scheme and its results (32) and the different interpretative views of the monitoring advisory board, it still remained difficult to prove what was the actual rate of degradation of the organic deposits and artefacts on site and whether the plan of *in situ* preservation through re-wetting would be viable and preferable in the short- and/or long-term. In the end, the large variety of risks was seen as much too great to take given the archaeological significance of the site, and with funding assistance from Historic England and Forterra the decision was taken for full excavation. This has now been successfully undertaken, thus satisfying the planning and preservation requirements.

The early Mesolithic site of Star Carr

It is crucial to include a brief mention of Star Carr in the Vale of Pickering, East Yorkshire, as it bears many similarities to the East Anglian fenland sites considered above. The site at Star Carr is an early Mesolithic occupation site located on the northern edge of the palaeo-Lake Flixton and which is part of a much wider Mesolithic exploitation of the lake margin (9, 10, 11). Subsequent peat formation has preserved a ‘brushwood and timber platform’ with fantastic artefact assemblages of wood, bone and antler, with hints of contemporary settlement on the immediately adjacent dryland. As there had been at least 2m of peat shrinkage between the early 1950s excavation and initial evaluation in 2002-3, during which Mesolithic artefacts emerged in the ploughsoil, a programme of research excavations was undertaken between 2004 and 2015. In advance of the recent excavations, Boreham *et al*. (13) conducted groundwater, surface water, pH, electrical conductivity and redox potential analyses in 2008-9. Despite the circum-neutral pH of the underlying glacial sediments, most of the Mesolithic organic horizons have suffered almost complete chemical oxidation of sulphide to sulphate under very acidic pH conditions (26). Only the basal peats and detrital mud in proximity to the groundwater table have not yet become fully sulphated but are nonetheless already acidifying. Bone and antler preservation is often ‘on its last legs’ as it has de-mineralised *in situ* to become ‘jelly-bone’ as most of the mineral hydroxyapatite has been removed by the acidic groundwater (12). Wood preservation is apparently better, but its cellulose content has severely degraded leaving only a lignin-rich outer skeleton. Similar decay mechanisms involving hydrolysis and acid-induced digestion combined with oxidation and bio-degradation are responsible.

There is also a disturbance 'halo' effect of better preservation up to about 1-2m laterally beyond the backfilled earlier excavations (13). Against the back-drop of widespread and intensifying drainage of this area, especially since the construction of the Hertford River cut in the 1820s and a change from pasture to arable in 2001 coincident with intensified tile drainage, it is suggested that a low summer groundwater level led to the oxidation of the upper sediments, resulting in the concentration of iron, manganese and iron sulphides. In the wetter winter months with a higher groundwater table, soluble residues such as sulphates concentrate in the lower part of the profile. Thus different preservation states unusually appear to reside side by side and up/down the lake's edge profile: where there is upwelling calcareous spring water feeding the adjacent Hertford River there is better preservation in small areas, and in the peats above the clay-filled channel there is on-going acidification and a possible source of the sulphur which is so detrimental to continuing organic preservation.

LESSONS LEARNT AND OUTSTANDING ISSUES

As other authors have stated before (34-37), understanding each site's context is of paramount importance and is crucial in the design and execution of any hydrological monitoring programme. The case studies presented here have demonstrated the importance of monitoring archaeological sites within their broader landscape context over a period of years. This includes the macro- to micro-scale, ranging from how the hydrology and geomorphology of each catchment works to the deposit sequences and even individual feature fills or deposit horizons at each site needing to be fully investigated at the microscopic level to prevent making the wrong assumptions about the suite of mechanisms controlling the present and past preservation environment. A good case in point is the Star Carr study as it demonstrates that there can be very different preservation states occurring over a few metres of spatial difference and different categories of data surviving dependent on distinct differences in localised and individual contexts on the site, and these have changed dramatically since the 1950s. Without the preservation assessments by Boreham and Milner *et al*. (12, 13) and the subsequent ground-truthing excavations, the wrong conclusions could have been easily drawn at opposite ends of the spectrum, and therefore inappropriate courses of action taken. Similarly in the excavations at Must Farm, organic preservation varied over very short lateral and vertical distances within the occupation horizon depending on the proximity to the former palaeo-channel and the adjacent quarry pit. There was also variation depending on the type of organic material itself, seemingly irrespective of their ages, with the oak posts of the earlier timber avenue and later alder palisade surviving better than many of the oak structural elements of the later Bronze Age houses. Thus, there is a very strong case for including monitoring schemes as part of applied planning policy with respect to wetland archaeological sites (38, 39), which must include condition assessments of different archaeological and palaeo-environmental datasets (29).

What is often harder to get at is the time dimension of change in the preservation environment. This requires years of accumulated data at all scales of recovery, such as in the Over case study, and this is rarely possible to achieve, especially in a commercial archaeological environment. It is easy to say it, but it is the case that more and better datasets on the rates of decay of different types of organic remains in different preservational contexts is certainly required. For example it would be good future practice to assess and monitor various classes of palaeo-environmental data such as uncharred plant remains, pollen and insect remains, as well as the extent of microbial activity on the destruction of organic evidence over time under set conditions of preservation environment (i.e. wet/calcareous; wet/acidic; variable waterlogging/calcareous; variable waterlogging/acidic; in peat; in clay; in soils; etc.). Essentially the vulnerability of the site and all categories of organic remains to degradation must be thoroughly evaluated as was done for example in the initial studies of a broad suite of palaeo-environmental remains at Must Farm (29).

Sites compromised by multi-various factors should not be targeted for *in situ* preservation schemes, whereas green-field sites possibly can be as these may be contained in an extensive area around the site in question by some kind of non-permeable geomembrane and the surrounding site environs and any development threats better controlled. The task of actually isolating a waterlogged archaeological site within a larger catchment is a significant engineering problem and would certainly exceed realistic funding costs. For example at Must Farm, its location between the King's Dyke embanked river channel to the south and the quarry pit to the north provided difficult challenges to isolating the site. In addition, as it was still an active clay quarry with access road and drainage requirements for its continuing operation, this made any chance of absolutely sealing the site off from all interventions in the surrounding drained landscape almost impossible, effectively making any attempt for a contained re-wetting strategy an unviable option. In addition, much thought should be given as to whether such a scheme is sustainable in the longer-term – who will take responsibility for management and continued monitoring?, who will pay for this in perpetuity?, and what are the trigger factors for determining whether the scheme is working properly or not and the site is continuing to decay? Moreover, does the value of the archaeology outweigh the expensive possibilities of trying to encapsulate the site with all its long-term locational, drainage and logistical problems.

Understanding the redox conditions is absolutely key, along with groundwater level, soil moisture, dissolved oxygen and groundwater chemistry/water quality monitoring for any waterlogged site under threat of development or destruction. It should be noted that installing and taking readings using redox probes is a relatively cheap and easy exercise with probes lasting at least five years as long as they are completely sealed into the sediments (34, 38, 39). Importantly it should be noted that high groundwater/soil moisture values indicative of saturation does not always imply oxygen exclusion and highly reducing environments as specific site conditions will control this aspect (39). Several authors have questioned the use of redox potential as a reliable method for assessing reducing/oxidising environments (40, 41), but in my view and others (39) it is the one technique that will always portray what is really happening in the burial environment and whether a reducing environment actually exists. For example, with hindsight through the full excavation just undertaken at Must Farm in 2015-16, the varying redox, groundwater and soil moisture values in the monitoring points in what has turned out to be the central area of the wooden round building structures were reflecting the actual alternating and variable states of preservation, both vertically and spatially. This is nowhere seen more visibly than the creeping 'amoeboid-like halo' zone of amorphous iron oxidation across the upper surface and through a depth of *c.* 10-60cm of the occupation/collapsed wood zone that was observed extending southwards from the quarry pit and palaeo-channel area in the initial phase of excavation at Must Farm immediately after exposure (Fig. 10). Moreover, a combination of simple and efficient methods of monitoring can be employed such as the use of redox clusters and piezometers in the field (27, 39-42), with GIS modelling of hydraulic flow and groundwater saturation levels (28), and lysimeters in the laboratory to measure decay vectors in simulated burial environments using oak wood as a biomarker (43).

For each study described here there has been the additional benefit of a programme of thin section micromorphological analysis of the buried soils and/or the deposit sequence. At sites like Must Farm and Star Carr, where most of the deposit sequence is organic material of some form or another, it has been possible not just to identify the components but also examine the nature of degradation of the organic remains as well as how and by what it is being replaced with, and the area/frequency/occurrence of pore space in the matrix at the micro-scale (29, 44, 45). This identifies the actual processes at work within the soil/sediment matrix, and in what order of occurrence, and demonstrably shows how the organic components are either being preserved, degraded and/or replaced.

There is a very compelling case to be made for requiring a combination of predictive modelling and extensive and systematic monitoring of any landscape and/or archaeological sites that are under threat of dewatering from any development scheme, or land drainage, or through long-term landscape/climate change. Importantly, this means instigating the monitoring scheme prior to any major ground interventions and thus at a very early stage in the planning process for the development and/or stewardship protection of a particular site. Only by understanding how a particular burial landscape works using a combination of methodologies can one begin to predict whether preservation *in situ* schemes will work effectively or not (13, 46-49), and whether similar schemes may be applied elsewhere with a reasonable expectation of success. In the end analysis, the risks of degradation and destruction must be removed by the monitoring scheme being implemented. If there is an element of risk remaining, especially to nationally and internationally significant archaeology, a different strategy for the preservation of the site and its information must be swiftly implemented.

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Figures

1. Location map of the monitoring sites in the lower Welland, Nene and Great Ouse valleys and the Cambridgeshire fens (V. Herring after C. Begg)

2. Location map of the Etton study and monitoring points (V. Herring after C. French)

3. The June-September, 1983, monitoring results showing the dramatic groundwater table fall when the quarry water abstraction began at Etton (V. Herring after C. French)

4. Location map of the Over quarry study area and monitoring points (C. Begg/D. Redhouse)

5. The groundwater levels for the reinstatement period between March, 2004 and March, 2005, compared to pre-extraction (top) and extraction levels (middle) (D. Redhouse)

6. The redox potential values (mV) for the reinstatement period between March, 2004 and March, 2005, compared to pre-extraction (top) and extraction levels (middle) (D. Redhouse)

7. The dissolved oxygen values (mg/l) for the reinstatement period between March, 2004 and March, 2005, compared to pre-extraction (top) and extraction levels (middle) (D. Redhouse)

8. Flag Fen location map and known archaeology (V. Herring after C. French)

9. Must Farm location map and plan of monitoring points (CAU/SLR/Hanson, 2009)

10. The reddened oxidation ‘halo’ creeping variable through the settlement zone deposits as first exposed (01/09/2015) in the recent excavations at Must Farm (C. French)