*Geoarchaeology*

WILEY

Geoarchaeology An International Journal

RESEARCH ARTICLE OPEN ACCESS

# The Soil Erosion Paradox Re-Examined: Alluviation and Land Use History in a Small British Lowland River Catchment in the Late Holocene

Ben Pears[1] | Emily Forster[2] | Sam Hudson[1,3] | Jayne Carroll[4] | Richard Jones[5] | Antony G. Brown[1,6]

[1]Department of Geography and Environmental Science, University of Southampton, Southampton, UK | [2]Institute of Archaeology, University of Oxford, Oxford, UK | [3]Department of Archaeology, University of Reading, Reading, UK | [4]Institute for Name-Studies, University of Nottingham, Nottingham, UK | [5]Centre for English Local History, University of Leicester, Leicester, UK | [6]Tromsø Museum, UiT, Tromsø, Norway

**Correspondence:** Ben Pears (b.r.pears@soton.ac.uk)

**Received:** 13 January 2025 | **Revised:** 14 April 2025 | **Accepted:** 22 December 2025

**Scientific Editor:** Helen Mackay

**Keywords:** alluviation | chronostratigraphy | historic land use | medieval agriculture | pollen | soil erosion | tillage

## ABSTRACT

Modern studies show that soil erosion results in a loss of ecosystem function, particularly fertility, and is a cause of declining agricultural yields. However, despite the well-attested high rates of soil erosion across Roman and medieval Europe there appears to have been little or no soil-associated decline in agricultural production—the soil erosion paradox. Small low-slope erodible lowland catchments offer the opportunity to examine this question when sufficient historical information is available. Here, we show that, since its disconnection from the main River Severn (UK) floodplain in the mid-Holocene, the small Hatfield Brook catchment experienced high rates of soil erosion and alluviation (~2 mm year$^{-1}$) associated with extensive catchment-bound open-field system agrarianism. Scientific and historical data both indicate increases in activity during the early medieval and medieval periods, associated with landscape control by the Bishopric of Worcester (BoW). Agricultural expansion by the church from the late 11th to mid-13th centuries AD extended further into lower valley slopes and alluviated flatlands, tilled using the heavy plough, and catchment hinterlands were further cleared of woodland via assarting, all leading to greater soil erosion. After AD 1250, the power and influence of the Bishopric of Worcester declined with arable cultivation and a move towards pastoralism leading to a reduction in soil erosion, increased slope stability and floodplain deposition. This suggests that in the low-relief erodible lowlands of Europe *one* solution to the erosion paradox is that most of the sediment generated by open-field cultivation was trapped in the basin and created new, flat, and highly productive agricultural land producing both a sustainable farming system and a non-linearity in the relationship between population and soil erosion. Further modelling-based research is needed though to identify the relative role of the manipulation of fertility through manuring and new land-creation.

## 1 | Introduction

High rates of soil erosion stimulated by agriculture are known across Europe from the Bronze Age to post-medieval periods (Bork and Lang 2003; Hoffmann et al. 2011; Brown et al. 2013; Rapuc et al. 2024). Soil erosion is also known to reduce ecosystem services and particularly soil fertility (Boardman and Poesen 2007; Bakker et al. 2007; de Graaff et al. 2019) and this is the foundation of the soil erosion-induced societal collapse theory (Chew 2001; Montgomery 2007; Scholes and Scholes 2013). However, there is little reliable evidence to support this erosion-induced collapse model, especially in Europe, and environmental historians and archaeologists now focus on multiple stressors such as economics, disease, war and climatic sensitivity (Fraser 2011; Hoffmann 2014).

But this then begs the question, why did this apparently not happen? There are four principal ways in which agricultural production may not have been adversely affected by high rates of soil loss on soft lithologies. These include increased weathering rates that offset fertility loss (Brown and Walsh 2016), agricultural terracing to maintain soil depth (Wei et al. 2016; Brown, Walsh, et al. 2021; Pears et al. 2024), compensatory additions of manure or fertilizer (Arriaga and Lowery 2003; Goldberg et al. 2020), and the creation of new land within catchments that can be brought into agriculture (Jetten et al. 1999; Souchère et al. 2003). It is these two last mechanisms that are investigated here through the analysis of a low-elevation small catchment on erodible rocks which has a well-documented agricultural and societal history.

Geomorphological theory postulates a relationship between catchment slope and sediment retention, through the sediment delivery ratio (SDR), (Williams and Berndt 1972; Honek et al. 2020) which itself is related to catchment slope and area (Nguyen and Chen 2018). Additionally, small catchments that are tributaries of medium to large rivers also suffer from the backup-effect from floods in the main floodplain that may prevent free-drainage causing ponding and sedimentation in downstream areas. This is a common geomorphology across Europe within all the major river catchments on sedimentary rocks which have generally low hillside slopes, low river gradients and discharge into larger floodplains, particularly in areas influenced by glacial, periglacial and/or fluvioglacial processes.

The resultant fine-grained alluvial tracts can be crudely estimated by the area of clay-rich alluvial soils on chalk, sandstone, marl and loess substrates. With the development of the heavy plough and later the mould-board plough, from the Roman period onwards (Andersen et al. 2016; Hamerow et al. 2023), heavier but fertile clay-rich soils could be cultivated across alluvial plains, and across catchment slope-sides to a greater depth than before. In all, these technological developments and the development of the open-field agricultural system (Hall 2014) increased the potential land that could be brought under cultivation (extensification) and reduced the barriers to sediment conveyance.

This paper focuses upon an area of the largest riverine catchment of the United Kingdom, the River Severn. Its lowlands are characterised as low-slope, with thick superficial sediments, of largely periglacial origin, overlying soft sedimentary lithologies, and this has resulted in a history of high rates of potential soil erosion from agricultural land (Panagos et al. 2015). The low-relief study sub-catchment here, the Hatfield Brook, is typical of this lowland landscape, and using the Maner equation for the SDR (Nguyen and Chen 2018) yields a value close to 1 whereby the vast majority of sediment generated in the catchment is retained therein.

## 2 | Sedimentation and Palaeoenvironmental Conditions in the Severn Catchment

Evidence of sedimentation across the Severn catchment (Figure 1) suggested that extensive overbank alluviation started in later prehistory, ranging from the Middle to Late Neolithic in the Warwickshire Avon, and Late Bronze Age to Early Iron Age in the Worcestershire Arrow (Shotton 1978).

Pollen analysis from the Carrant Brook and River Arrow demonstrated the extent to which the open landscape and anthropogenic activity had driven the sedimentation in the Avon sub-catchment (Greig and Colledge 1988, 2005; Greig 1999, 2007). However, the presence of both wetland plants and wetland tree species indicated that although the wider landscape was predominantly open, it also contained managed floodplain woodland and wetland areas along the watercourses (Woodwards and Greig 1989). Sediment chronostratigraphy used with palynological evidence have shown how fluvial dynamics responded to prehistoric vegetation change in the Ripple Brook and Herefordshire Frome catchments. In both cases, Late Bronze and Early Iron Age (c. 3000–2500 years BP) basal silts and clays with organics, and the pollen and diatom records within these, indicate low-energy sedimentation derived from erosion caused by woodland clearance and increased catchment cultivation (Brown and Barber 1985; Brown et al. 2013). Additionally, the presence of progressively coarser deposits covering post-Iron Age archaeology (Miller et al. 2004) represented an increase in fluvial activity and discharge leading to a dryer floodplain surface. In the River Perry catchment, radiocarbon dating indicated the commencement of clastic-dominated overbank alluviation from the late Romano-British period onwards, with subsequent acceleration in the early medieval and medieval periods driven by the removal of floodplain woodland from the mid- 6th and mid- 8th centuries AD (Brown 1990).

In addition, palynological analyses from small lakes across the Severn catchment and the West Midlands region reveal predominantly open agricultural landscapes from the late Romano-British and early medieval periods, especially from the 7th and 8th centuries AD, coinciding with increases in alluviation within these small catchments (Beales 1980; Barber and Twigger 1987; Bartley and Morgan 1990; Twigger and Haslam 1991; Pittam 2006; Hamerow et al. 2020; Mighall et al. 2023). These studies also show the localised variability in the extent of arable cultivation and grazed grassland areas across the wider landscape.

More recent work using optically stimulated luminescence (OSL) dating of extensive deposits of clastic sandy silt sediments of the lower reaches of the Rivers Teme, Wye and Severn also reveals increased overbank alluviation from the Late Iron Age as a result of increased fluvial activity (Pears et al. 2020a; Pears, Brown, Carroll, et al. 2020; Pears et al. 2023), but the lack of suitable palaeoenvironmental material from these deposits did not enable land use to be determined. Here, we combine small-catchment alluvial stratigraphy, palynology and detailed documentary evidence to provide at least a partial solution to the soil erosion paradox.

## 3 | The Hatfield Brook Catchment, the Natural and Historic Landscape

The Hatfield Brook drains 12 $km^{-2}$ of the western side of the undulating Worcestershire lowlands (ca. 45–65 m above sea level asl) on the edge of the boundary of Jurassic/Triassic strata to the north, east and south and bounded by the Pleistocene gravel terrace to the west (Barclay et al. 1997). The catchment is linked to the main Severn floodplain by a narrow low-relief gorge section around which the village of Kempsey developed

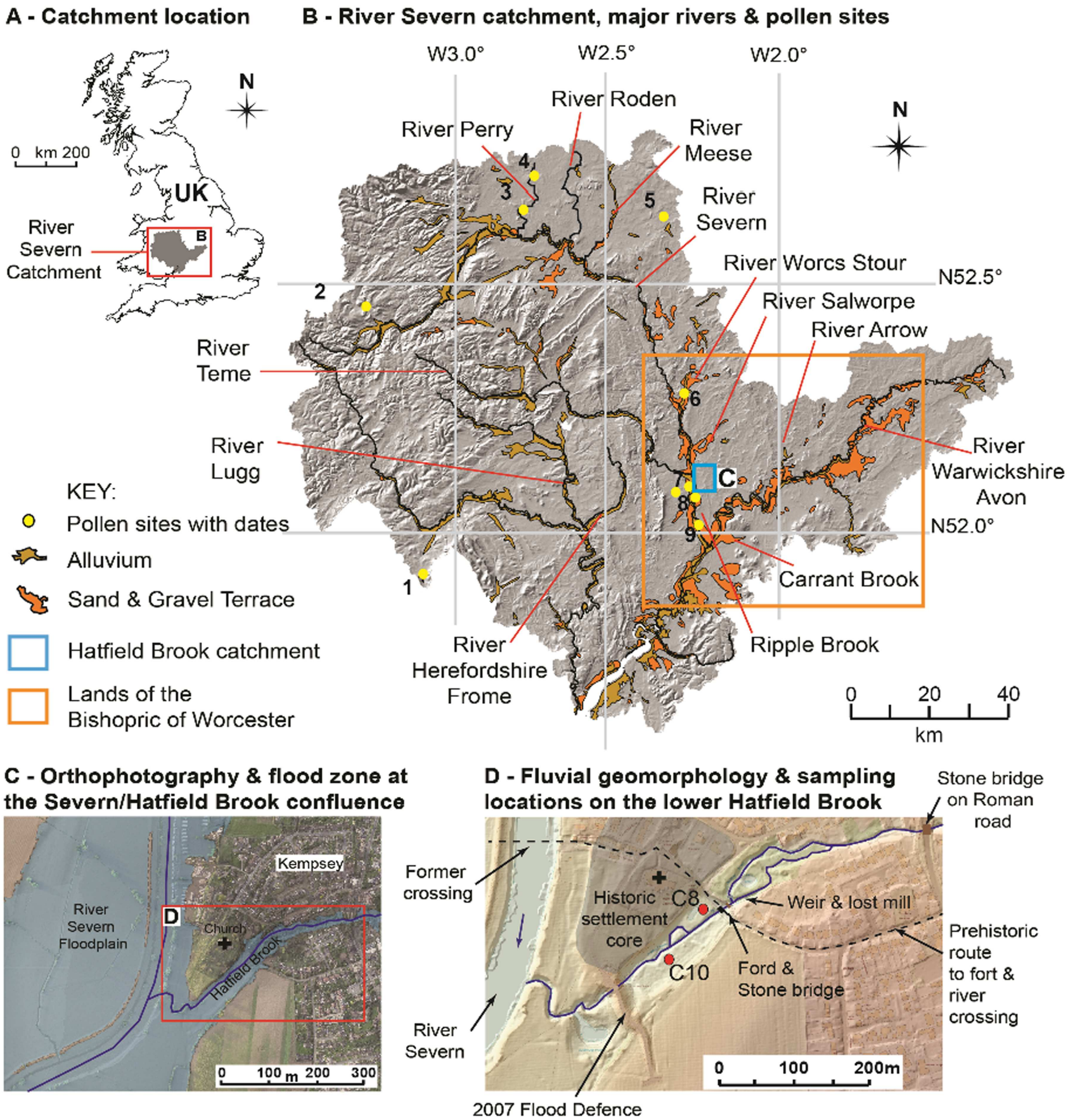


**FIGURE 1** | (A) River Severn catchment location; (B) major fluvial systems, palaeoenvironmental records including pollen sites (1–9) [1—Llangorse (Chambers 1999); 2—Carneddau (Walker 1993); 3—Crose Mere (Beales 1980); 4—Baschurch Pools (Twigger and Haslam 1991); 5—Aqualate Mere (Pittam 2006; Mighall et al. 2023); 6—Wilden Marsh (Brown 1988); 7—Callow End (Brown 1983); 8—Ashmoor Common (Brown 1983); 9—Ripple (Brown and Barber 1985) and location of Hatfield Brook case study area; (C) Orthophotography and flood zone at the Severn/Hatfield Brook confluence at Kempsey (Environment Agency 2007); (D) Fluvial geomorphology and sampling locations at the lower Hatfield Brook (1 m DTM Lidar, Environment Agency 2022).

(Figure 1). Critically although relatively soft and deeply weathered, these lithologies are also impermeable stimulating surface runoff, particle detachment and erosion. The lemniscate planform of the catchment follows the variable mudstone, siltstone and sandstone lithologies with subtle competencies which define three distinct axial reaches, including a relatively low gradient upper reach (0.014 $mm^{-1}$) from 45 to 27 m asl. with an incised narrow stream form, a lower-gradient middle reach (0.007 $mm^{-1}$) from 27 to 17 m asl. with an intermittent floodplain, and a low-lying extremely low-gradient lower reach (0.003 $mm^{-1}$) from 17 to 10 m asl., with a narrower floodplain where the watercourse dissects the gravel terrace and enters the River Severn at Kempsey (Figure 2; Figure S1).

Six small unnamed tributary streams form the Hatfield Brook catchment (Transects 1–4), and cross-sectional modelling shows that these valleys have dissected the soft basal mudstone and more competent terrace gravels, which were probably deposited in the late Pleistocene and allowed the Hatfield Brook to breach the glaciofluvial terraces of the main Severn valley (British Geological Survey 2020). As a result, the Hatfield Brook catchment is dominated by low-gradient hillslopes currently drained by extremely low-gradient ungauged streams (Figures 2 and S2). The Hatfield Brook has had a history of flooding that has impacted the village of Kempsey, parts of which have been flooded 23 times between 1977 and 2012 (Figure 1C) when a flood relief scheme was installed which included a flood barrier

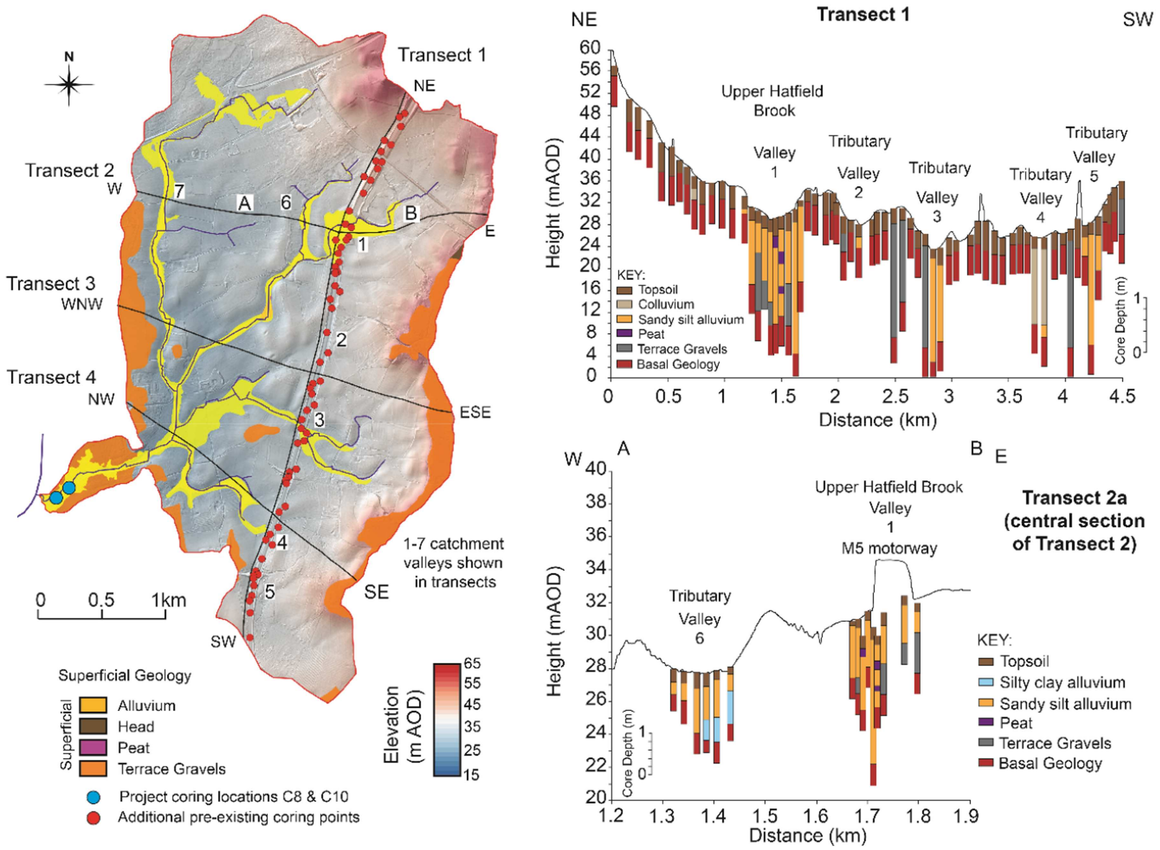


**FIGURE 2** | The geomorphology surface alluvium and terrace gravels with shallow subsurface stratigraphy of the Hatfield Brook catchment, Worcestershire (1 m DTM Lidar, Environment Agency 2022) with cross section sedimentology across Transects 1 and 2a (red dots). Additional topographic slope transects 2–4 in Figure S2.

(Environment Agency 2015). This was constructed due to the back-up of Severn floods into the lower Hatfield valley which frequently caused a flood-lock of high discharges from the catchment and increased the deposition of catchment-derived sediments.

Core samples across the catchment demonstrate the spatial extent of sediments within the Hatfield Brook catchments and the various tributaries. The cores show a maximum of 2.8 m (with a mean maximum depth of 1.1 m) of sandy silt alluvium in the upper and middle reaches of the Hatfield Brook and tributary streams alongside deep colluvial deposits (up to 2.4 m). In addition, the presence of repeated *in-situ* peaty clastic deposits and finer silty clay alluvium mark smaller areas of ponded drainage (Daffern and Webster 2013). The current climate of the catchment area has a mean annual temperature of 12°C, mean annual precipitation of 648 mm year$^{-1}$, a growing season of 209 days and 930°C cumulative growing degrees is well-suited to most temperate crops. This suggests that even with the magnitude of climate variation during the medieval period of around ±2°C mean annual temperature (Pribyl et al. 2012) most contemporary crops would have had no climatic limitation, although yields would have varied with annual synoptically-driven variability (Martínez-González 2025). The soils are predominantly slightly acid sandy-clayey loam Brown Earth soils (Cambisols) (LandIS 2024). The land in the catchment is classified as 60% Grade 1 and 2 (excellent and very good quality agricultural land), although there is localized impeded drainage, especially in the eastern part of the catchment, and in the west a greater susceptibility to drought (MAFF n.d). Overall, the soils are of moderate to high fertility, free draining and if manured maintain adequate structure and moisture and have no limitations for agriculture but are potentially vulnerable to surface capping and the erosion of the fine soil component (LandIS 2024) (Table 1).

The Hatfield Brook also has a long record of human activity and land use (Figure 3; Tables 2 and S1). The earliest activity in the catchment includes Neolithic and Bronze Age settlement and funerary activity (Lovett 2015), but by the Iron Age there is a more densely occupied catchment with farmsteads and field systems along the western gravel terrace and northeastern catchment edge (Pickering 1986a, 1986b; Goad et al. 2003; Parry 2010; Vaughan and Webster 2013). Kempsey was possibly the location of an Iron Age lowland promontory fort (O'Neill 1956) similar to other examples in fluvial contexts across the United Kingdom (Norton 2021). Within the catchment, increased land use and the onset of extensive sediment transfer is demonstrated by the presence of alluvial and colluvial sedimentation within the ditches of a late Iron Age to early Romano-British enclosure settlement around a northern tributary of the Hatfield Brook close to Newlands Farm (Webster et al. 2012, Figure 3).

Evidence of an increase in density of settlement and agricultural activity during the Romano-British period includes an extensive 2nd to early 4th century AD rural settlement with numerous domestic, industrial and agricultural buildings identified near Crookbarrow Farm (Jackson et al. 1995, Figure 3). Downstream to the north of Kempsey, a 1st to early

**TABLE 1** | Summary of key historical events and survey data for Kempsey, Worcestershire and the Hatfield Brook catchment from prehistory to the post medieval period (full detailed table in Table S1).

| Period | Events | Sources |
|---|---|---|
| **Prehistoric (Pre-AD43)** | Neolithic & Bronze Age settlement and funerary activity across Hatfield Brook catchment.<br>Iron Age promontory fort at Kempsey.<br>Iron Age **field boundaries** within Hatfield Brook catchment. | Webster (1955),<br>O'Neill (1956),<br>Lovett (2015),<br>Norton (2021) |
| **Romano-British (AD43–410)** | Settlements, industrial sites, roads, **field systems**<br>Alluvial and colluvial infilling of boundary features. | Jackson et al. (1995), Parry (2010), Lovett (2015), Webster et al. (2012),<br>Daffern and Webster (2013), Vaughan and Webster (2013), Lovett and Hedge (2015) |
| **Early medieval (AD410–1066)** | Creation of the Bishopric of Worcester (680).<br>**Episcopal manor at Kempsey founded** (750).<br>Interchanging ecclesiastical and secular ownership (799–814).<br>Oratory (small church) dedicated to St Andrew built at Kempsey (868).<br>Formation of Oswaldslow Hundred centred around River Severn (964). | Herbermann (1913), Knowles and Hadcock (1971),<br>Finberg (1972), Dyer (1980), Hooke (1985), Bond (1988), Bassett (1989), McGurk (1995), Thompson (1998) |
| **Medieval (AD1066–1540)** | Domesday Record of Kempsey Manor—24 hides (2880 acres) of which 13 hides (1560 acres, 54%) were retained by the BoW (1086).<br>**Expansion in woodland clearance for cultivation** (assarting) across BoW land including Kempsey (mid- 12th to early 13th AD).<br>**Expansion in manorial settlements, demesne tenants and arable cultivation** (mid- 12th to late 13th AD).<br>Survey shows two-course arable rotation across BoW estate (1299).<br>Decline in manorial value, population, shift from arable to pastoralism alongside broad climate deterioration (early 14th to mid- 15th AD).<br>**Pastoralism dominant, enclosure of open field starts, increased meadowland** (from mid- 15th AD).<br>Almost all BoW assets were leased out—mills, demesnes, franchises, dovecots, fishing and hunting rights (early 15th AD).<br>Increased mortality in Kempsey manor, despite broader population rise (late 15th to early 16th AD). | Kempsey Court Rolls (1394–1537),<br>Denholm-Young (1937), Darlington (1962–1963),<br>Rahtz and Bullough (1977), Dyer (1980),<br>Hamshere (1980), Morris (1982), Jordan (1996), Williamson (2000),<br>Mullan (2007), Harding (2013),<br>Vaughan and Webster (2016), Pribyl (2017) |
| **Post-medieval (from AD1540)** | Dissolution of Worcester Priory but Kempsey remained in BoW hands (1540).<br>Kempsey Bishop's Palace confiscated and sold (1648) and demolished (1695). | Victoria County History (1913);<br>Thornton (2018) |

*Note:* Key historical processes in bold.

3rd century AD triple-ditched concentric Romano-British enclosure also contained a southeast orientated droveway leading from the settlement towards the stream (Lovett 2015). Ironworking waste, agricultural land divisions and ceramics suggests a largely open landscape with fields subject to manuring for arable cultivation (Lovett and Hedge 2015), but with areas of managed woodland providing fuel sources for domestic and smithing processes. Alongside the settlement evidence, at least three Roman roads of differing construction have been identified which cross the catchment linking the urban centres of Worcester and Gloucester, with the surrounding rural landscape (Bretherton and Jones 2000; Webster et al. 2012). These roads converge around Kempsey and may have crossed the Severn at the same location as the later medieval and post medieval crossing point. The orientation and alignment of the Roman roads and former field

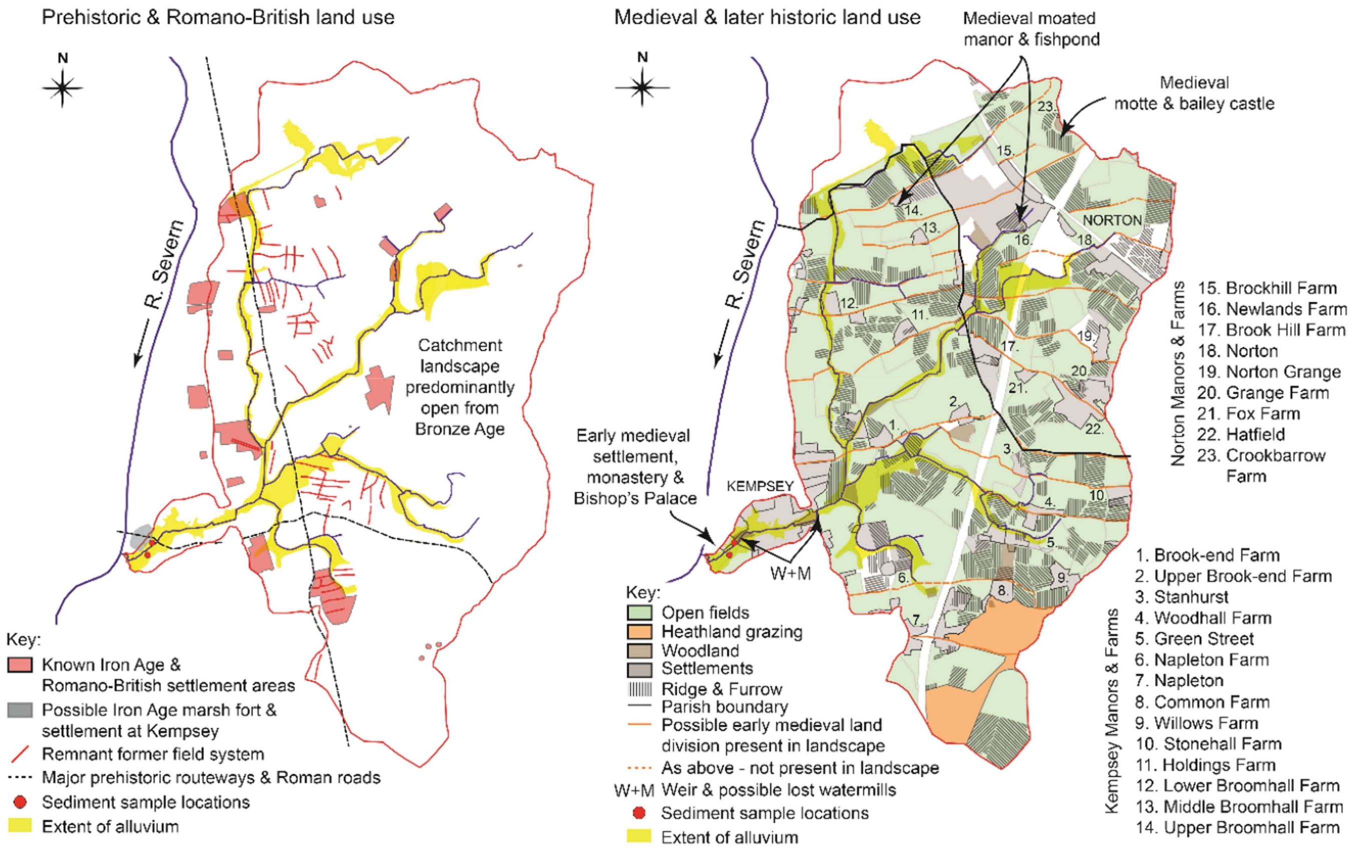


**FIGURE 3** | Archaeology with prehistoric and historic land use across the Hatfield Brook catchment from the Prehistoric to Romano-British periods (c. 500 BC–AD 400) and medieval to later historic period (c. AD 400–1750). Both depicted with the area of alluviation, agricultural landscape and settlements/manor farms mentioned in the text. Modern land use map provided in Figure S3.

boundaries, identified from crop marks, are similar and suggest a broader agricultural orientation and alignment of the Romano-British landscape across the Hatfield Brook catchment and which transfer in part into the early medieval and medieval fieldscape (Lewin 2010; Rippon et al. 2015).

Activity in the early medieval period is dominated by the founding of a settlement between the Hatfield Brook and River Severn and named 'Cemmi's/Cymi's Island' from which modern 'Kempsey' is derived (Sims-Williams 1990). The importance of Kempsey increased at the end of the 8th century AD when control passed from King Coenwulf to the Bishop of Worcester and a minster church was founded (Finberg 1972; Bassett 1989). In the 9th century AD expansion continued with the record of an episcopal manor (Bond 1988; Sims-Williams 1990), and a precursory church dedicated to St Andrew in AD 868 (McGurk 1995). From the 10th century AD, the Hatfield Brook catchment formed part of the wider demesne estate (land retained by the manor for its own use, as opposed to private rented tenancies) of Kempsey belonging to the Bishopric of Worcester (BoW) (Dyer 1980). This also included a regrouping of earlier Worcestershire hundreds (historic administrative land divisions, equivalent to 0.24–0.48 $km^2$) into one, Oswaldslow (Hooke 1985) which included other highly fertile fluvial landscape areas around the Rivers Severn and Avon.

By the late 11th century AD, the Domesday survey suggests the success of Kempsey was waning with a number of tax paying hides designated as 'waste' with a significant monetary devaluation from £16 to £8, although the manor still contained large areas of arable land, 16 ha (40 acres) of meadow and woodland (Morris 1982). Expansion of the original 11th to 12th century church of St Mary in the 13th century AD (Brooks and Pevsner 2007; Vaughan and Webster 2016) demonstrates economic expansion, albeit for the major demesne landowner. Excavations have also recovered evidence of a large medieval building overlying the medieval graveyard, which may have been part of the manorial complex that was demolished between ca. AD 1540 and 1695 (Vaughan and Webster 2016).

Across the wider Hatfield Brook catchment open-conditions prevailed throughout the medieval period with ridge and furrow cultivation, commonplace under the open field system, controlled by Kempsey through at least 23 smaller manors and farms including Broomhall, Napleton, Hatfield, Norton, Newlands and Woodhall, all documented by AD 1275 (Figure 3), and the nature of the medieval open field system has largely been preserved as ridge and furrow earthworks within the modern landscape despite subsequent enclosure.

At the beginning of the 20th century, the parishes of Kempsey and Norton-juxta-Kempsey, which comprise the majority of the Hatfield Brook catchment, had a combined record of 570 ha (1409 acres) of arable and 1202 ha (2971 acres) of permanent grasslands, but only 8 ha (20 acres) of woodland (Board of Agriculture 1905). The Tithe map of AD 1840 and 1st edition Ordnance Survey (OS) map (AD 1886) both illustrate a marked increase in orchards, which originated in the post-medieval period, as well as an expansion of suburban areas (Figures 3 and S3).

**TABLE 2** | AMS Radiocarbon dates from cores 8 and 10 within the Lower Hatfield Brook Kempsey, Worcestershire, UK.

| River | Core | Depth (cm) | Sample material | RC Age + error (cal. BP) | Laboratory code | cal. BC/AD date (σ2 95.4%) | cal. BC/AD date (σ1 68.2%) |
|---|---|---|---|---|---|---|---|
| Hatfield Brook | 8 | 136 | Plant macrofossils | 655 ± 36 | UB-36952 | cal.AD1266–1391 | cal.AD1275–1318 |
| | | 182 | Wood, plant macrofossils, seeds | 1100 ± 25 | UB-36948 | cal.AD898–1015 | cal.AD915–993 |
| | | 228 | Plant macrofossils, seeds | 1298 ± 36 | UB-36947 | cal.AD660–770 | cal.AD671–764 |
| | 10 | 140 | Wood, plant macrofossils, seeds | 701 ± 31 | UB-36949 | cal.AD1259–1387 | cal.AD1270–1298 |
| | | 210 | Charcoal | 2646 ± 35 | UB-36950 | 895–787 cal.BC | 831–796 cal.BC |
| | | 286 | Plant macrofossils, seeds | 3763 ± 28 | UB-36951 | 2286–2046 cal.BC | 2271–2137 cal.BC |

## 4 | Methods

### 4.1 | Sediment Sampling and Chronological Modelling

The analytical data in this paper derive from two percussion cores taken from the lower reach of the Hatfield Brook floodplain at Kempsey, Worcestershire. Core 8 (C8) was located at (Lat: 52.139388; Long: −2.2223577) on the northwestern side of the floodplain adjacent to the gravel terrace, whilst core 10 (C10) was positioned 78 m downstream in a central location (Lat: 52.138734; Long: −2.2228356). Both cores were located well away from potentially disturbed deposits created by the construction of the flood barrier, and both presented undisturbed sediment sequences extending 2.40 and 2.92 m, respectively. Chronological modelling of the alluvial sediments in C8 and C10 used six AMS radiocarbon dates extracted from suitable in-situ stable organic material (Table 2). The determination of $^{14}C$ dates then enabled detailed age-depth modelling of the sequences using suitable functions provided by both OxCal, v.4.3 with IntCal20 program (Ramsey 2008, 2009, 2017) and Bacon v2 3.5 (Blaauw and Christen 2011, 2013). To establish further confidence in the radiocarbon age-depth model of C10 and provide additional cryptostratigraphy *sensu* Staff et al. (2024) portable Optically Stimulated Luminescence (pOSL) was conducted (Supplemental Material S2). By extracting and analysing samples at 1 cm resolution the pOSL provided strong confirmation of the form of the radiocarbon age depth model along with minor variations, mostly small peaks caused by the influx of older sediment into the core profile (Pears et al. 2020a) These programs alongside additional support from pOSL data, which shows a generally smooth deposition history, and pollen, which shows that the uppermost sample pre-dates the reintroduction of pine (c. AD 1500–1600), enabled a clear improvement in the quality and resolution of sediment accumulation rate and enabled the more precise calculation of calendrical dates at 2σ (95.4%) and 1σ (68.2%) confidence.

### 4.2 | Sediment and Palaeoenvironmental Analysis

Both cores were subjected to a range of techniques to determine the depositional history of the sequences (Figures 4 and 5). Loss on ignition was carried out at 1 cm resolution to determine organic content (550° for 2 h) (Supplemental Material S3), and magnetic susceptibility (MS) for sediment characterisation (Supplemental Material S4). Laboratory based X-ray fluorescence was conducted on Core C10 using a Niton XL3t GOLDD+ portable XRF (pXRF) analyser at 2 cm resolution (Supplemental Material S5, Table S2). XRF on Core C8 was determined at 2 mm resolution using an ITRAX XRF housed at the British Ocean Sediment Core Research Facility (BOSCORF) at the National Oceanography Centre, Southampton (NOCS) (Supplemental Material S6). XRF was used to identify high-resolution variations in texture, and changes in depositional conditions including possible flooding events and sediment flux.

Further analysis of sediment texture was also conducted at 1–2 cm resolution using a Malvern Digisizer particle size analyser and dry sieving of coarse gravel and pebble deposits (Supplemental Material S7).

To determine palaeoenvironmental conditions around the lower Hatfield Brook catchment, pollen analysis was conducted on 15

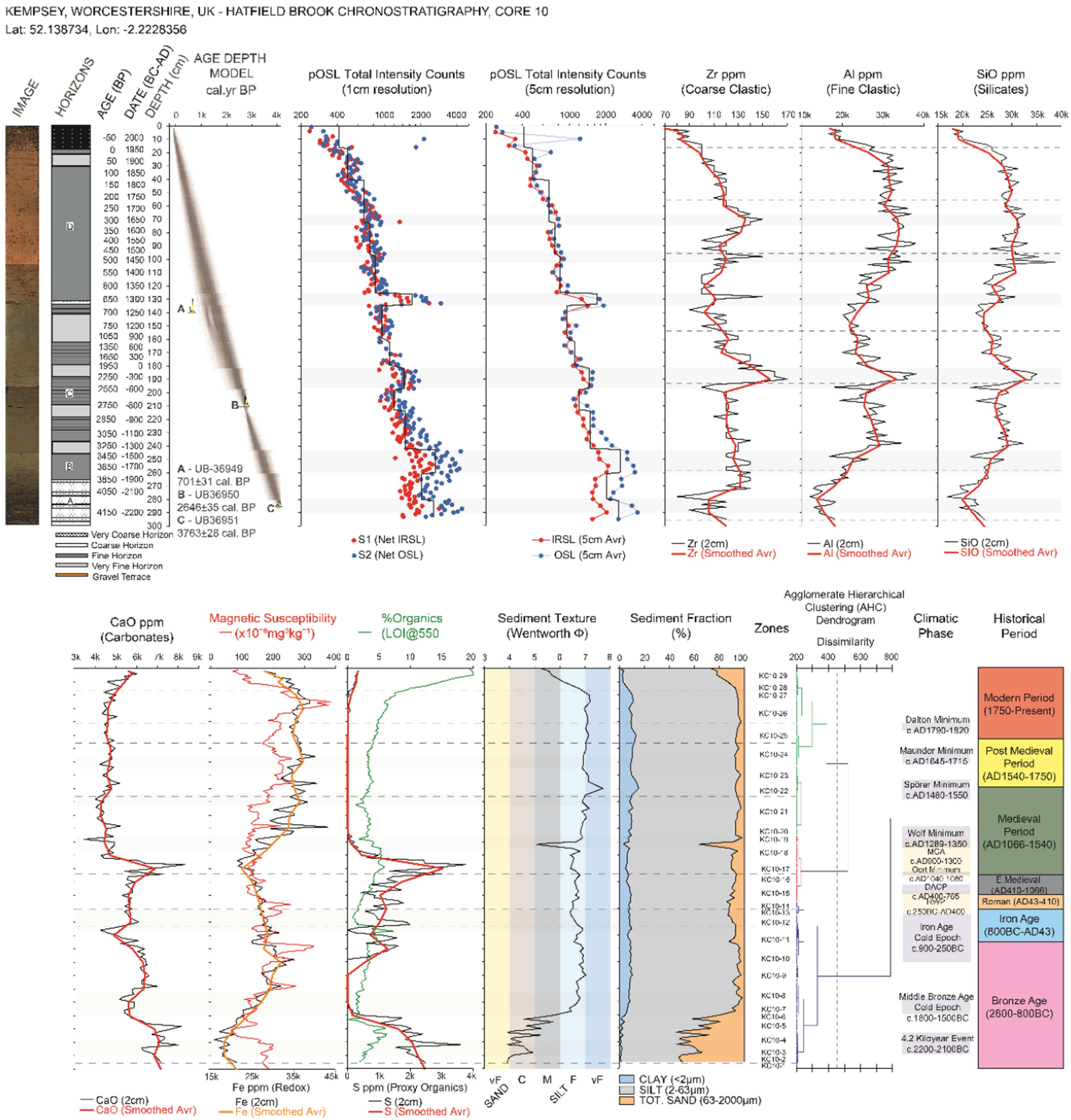


**FIGURE 4** | Chronostratigraphical model of the lower Hatfield Brook floodplain core C10.

subsamples, 4 from C8 and 11 from C10. The laboratory preparation process (Supplemental Material S8) identification and counting followed Andersen (1979), Moore et al. (1991), Bennett (1994) and Stace (2010), alongside reference to the collection held at the Institute for Archaeology, University of Oxford and the European Pollen Database (2024).

## 4.3 | Statistical Analysis

Following data collection and quality control, statistical analysis was conducted on Log-normalized sedimentological data. Sedimentological variations within the alluvial sequences from C8 and C10 were analysed using Agglomerative Hierarchical Clustering (AHC) using XLStat 2019.3.2 which enabled the zonation of horizons (Figures 4 and 5). Series dissimilarity was determined at 1 cm resolution using the Euclidean distance between six variables: percentage organics, carbonate content, magnetic susceptibility, fine particulate (ϕ) (Wentworth 1922), percentage sand and LogZr:Rb. Agglomeration was calculated using Ward's Method (Ward 1963). The results were presented in horizontal dendrograms demonstrating cophenetic distance between variables and horizons, with major classes defined by class colour variation and individual horizon zonation defined by changes at the most similar level.

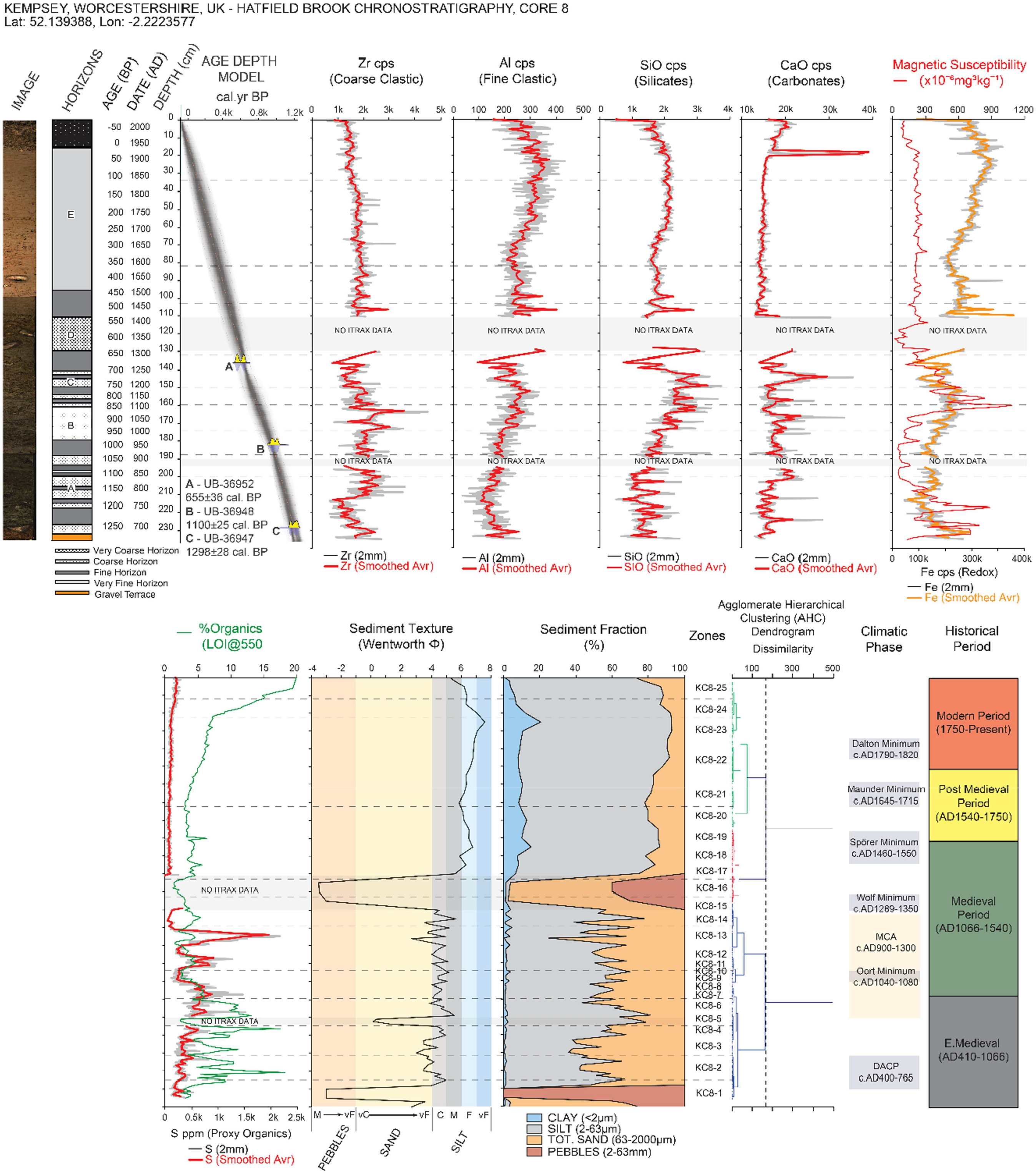


**FIGURE 5** | Chronostratigraphical model of core C8 from the edge of the lower Hatfield Brook floodplain.

## 5 | Results

The two cores analysed in detail here come from a narrow c. 50 m wide strip of floodplain on the eastern side of Kempsey (Figure 1) located mid-way between the channel, the valley-side and fully inundated at all out-of-bank flood magnitudes. The presence of an early medieval ford and later medieval stone bridge demonstrate that the Hatfield Brook channel has been in a fixed position for over a 1000 years and possibly since later prehistory as is the case of the lower River Teme to the north (Pears et al. 2020a).

### 5.1 | Sedimentology C10

The two sample locations within the lower Hatfield Brook floodplain at Kempsey reveal complex, yet similar sedimentological histories. Core C10 (Figure 4) reveals accumulation over the last 4000 years with the basal 35 cm (unit A, KC10.1–10.5) consisting of medium to coarse silts interbedded with at least seven laminated fine-sand lenses with raised pOSL intensities (c. 2k) and carbonate content (c. 7k ppm) but lower clastic (Zr [100 ppm], Al [12k ppm] and silicate [c. 20k ppm]) levels. These demonstrate clear yet intermittent phases of higher and lower energy deposition and indicate a time when the Hatfield Brook was a more active fluvial system in the Early Bronze Age (c. 2000–1500 BC).

After ca. 1900 BC there was a major change in sedimentation history. Between 265 and 220 cm (unit B, KC10.6–10.9) the C10 sequence is dominated by dark blueish-grey fine silts (c. 70%) with increased clay (c. 10%) and almost no coarse-grained inclusions. There is a distinctive increase in fine clastics (Al), silicates and Fe (c. 20–30k ppm). Additionally, carbonates reduce (c. 5k ppm) and S drops entirely. The pOSL readings remain high but fall slowly suggesting much more gradual deposition over time, indicating that the Hatfield Brook had become isolated from the main River Severn by the Middle Bronze Age (c. 1500–1000 BC).

After ca. 900 BC fine-grained silt sedimentation continued through the Late Bronze Age to Early Iron Age (unit C, KC10.10–10.11, 220–200 cm) with sustained low-energy depositional conditions. The presence of fine silts (70%) with clays (10%) alongside elevated S (1–2k ppm), high Al and silicates (both c. 30k ppm) and gradually reducing Fe, carbonates and pOSL values suggests wetter ground conditions and prolonged periods of slow or stationary water on the floodplain, although subtle variations in clastic elements Zr and silicates may indicate flood incursions bringing both finer and coarser sediment pulses.

From the Middle Iron Age to start of the Romano-British period c. 250 BC to AD 50 (unit C, KC10.12–10.13, 200–180 cm) a distinct change in deposition occurred in the Hatfield Brook. Distinctive increases in Zr (160 ppm), Al and silicates (both 35k ppm) and a higher proportion of percentage sand (15%) suggest an increase in depositional energy. At the same time, pOSL results also show raised intensities (c. 1k–2k) from the general background suggesting an influx of older material, deriving either from increased flood activity in the Severn or from increased soil erosion within the Hatfield Brook.

This phase of increased fluvial activity was relatively short-lived though as throughout the Romano-British, early medieval and start of the medieval period (KC10.14–10.17, 180–150 cm, c. AD 50–1200) there was a return to lower energy deposition with fine silt sediments with decreasing Zr (90 ppm), Al and silicates (both to c. 25k ppm) and decreasing pOSL intensities, alongside increased S levels (to 3k ppm) and carbonates (to 7.5k ppm). The lower part of the Hatfield Brook was therefore subject to a prolonged phase of wetter ground conditions and fine-grained sedimentation, possibly as a result of climatic and fluvial variability during the Medieval Climate Anomaly together with increased arable/pastoral land use.

After ca. AD 1200 (unit D, KC10.18–10.27, 150–20 cm) depositional and environmental conditions in the lower Hatfield Brook change again with a clear transition in sediment colour from blue-grey to dark yellowish light brown, although there is a continuation of fine to very fine silt texture. Broadly, there is a marked shift in sediment chemistry with major increase in Fe (> 35k ppm) and reductions in carbonates and S indicating prolonged phases of drying out across the floodplain. Within this period of fine sediment deposition are phases of coarser accretion between ca. AD 1250–1350 (140–120 cm), 1450–1500 (102–95 cm) and 1625–1675 (75–65 cm) marked by subtle changes in sand content (2%–5%) but more clearly by distinct increases in Zr (150 ppm), Al and silicates as well as pOSL intensities (1–2k) suggesting inclusion of older material.

## 5.2 | Sedimentology C8

Core C8 was located at the northwestern edge of the floodplain, closer to the eastern edge of the gravel terrace and to the south of the road and ford across the Lower Hatfield Brook (Figure 5). Despite a surface topography within 15 cm of C10 (both ca. 11.55–11.70 m asl) the age-depth model demonstrates a significantly younger sequence beginning in the 8th century AD.

At the base of the core, sitting unconformably upon coarse degraded gravel terrace geology (KC8.1), are a series of laminated deposits 2–5 cm thick (unit A, KC8.2–8.5, 230–185 cm) composed of dark grey medium to coarse silts with increased organic (+10%) and Fe content, interleaved with lighter grey horizons with higher sand content (c. 40%) and coarse-grained elemental indicators (Zr, SiO, CaO). These horizons suggest that from ca. AD 700–950, a former channel of the Hatfield Brook was active against the eastern edge of the gravel terrace. From ca. AD 950–1100 (unit B, KC8.6–8.11, 185–160 cm) sedimentation stabilised and was dominated by finer silts with less coarse material, suggesting deposition in reduced fluvial activity with lower flow energy.

Between ca. AD 1100 and 1300 (unit C, KC8.12–8.14, 160–130 cm), fine sedimentation continued but with evidence of occasional coarser sediment influx, suggesting largely continued low energy deposition with occasional higher energy channel reactivation, possibly during larger flood events. The presence of a prolonged period of much finer sedimentation shows a shift to lower energy deposition which corresponds to conditions widespread across the Hatfield Brook in the mid-13th century AD. Between ca. AD 1300–1400, there is evidence for a further increase in depositional energy (unit D, KC8.15–16, 130–110 cm). The 20 cm thick horizon was composed of very coarse sand and pebbles. ITRAX XRF was not possible from this layer but pXRF shows a dominance in coarse and fine clastic elements particularly SiO, Ti, Al, K alongside increased carbonate (CaO, Sr) and Fe redox (Table S2). This layer was not present in C10 but the close proximity of C8 to the gravel terrace at Kempsey may indicate that this horizon possibly derives from increased occupation activity and/or through the major redevelopment of the church in the 13th century AD (Brooks and Pevsner 2007), similar sedimentological signatures like this have also been determined on the western terrace edge bordering with the River Severn (Pears et al. 2023).

Following the period of coarse deposition, sedimentation in core C8 reverts to continual deposition of very fine silt alluvium (unit E, KC8.17–8.23, 110–20 cm) with greater proportions of clay (+10%) and silt (60%–80%) and prolonged drier ground conditions, indicated by higher Fe levels and change from dark grey to light yellowish-brown colouration (also identified in C10), suggesting that low energy fluvial deposition was occurring across the narrow Lower Hatfield Brook floodplain from the 15th century AD onwards.

## 5.3 | Palaeoenvironmental Analysis

Pollen samples from core C10 were extracted from c. 98–181 cm and spanned the period from ca. AD 0 to 1500 (Figures 6 and S4). Overall, pollen concentrations were generally high, though variable, ranging from c. 16k $g^{-1}$ to almost 90k $g^{-1}$, and only one sample from 164 cm proved too poorly preserved for analysis. The degraded pollen and spores are 20%–30% of the Total Land Pollen (TLP) in most samples, though in the uppermost sample 98 cm this increases to almost 50% caused by the progressive drying out of the floodplain surface towards the top of the sediment sequence.

Overall, the pollen results demonstrate a very open landscape, with herbaceous plants dominating the assemblage whilst trees and shrubs make up less than 15% TLP throughout the core. The main trees are oak (*Quercus*), hazel (*Corylus avellana*-type) and alder (*Alnus glutinosa*), with birch (*Betula*) and willow (*Salix*) being less common. Oak, hazel and birch are typical trees of mixed deciduous woodland, patches of which are recorded on historic land use maps, while willow and alder are wetland trees likely to have been growing on the floodplain and streambanks. Additionally, species including holly (*Ilex aquifolium*), rowan/whitebeam (*Sorbus*) and blackcurrants (*Ribes* sp.) are present but rarer and would have occurred within boundary hedgerows and on the edges of woodlands.

The pollen catchment area for this sample is likely to be quite small, but with pollen carried from areas upstream and possibly eroded out from soils and sediments. This fluvial input probably also explains the high percentages of degraded and robust

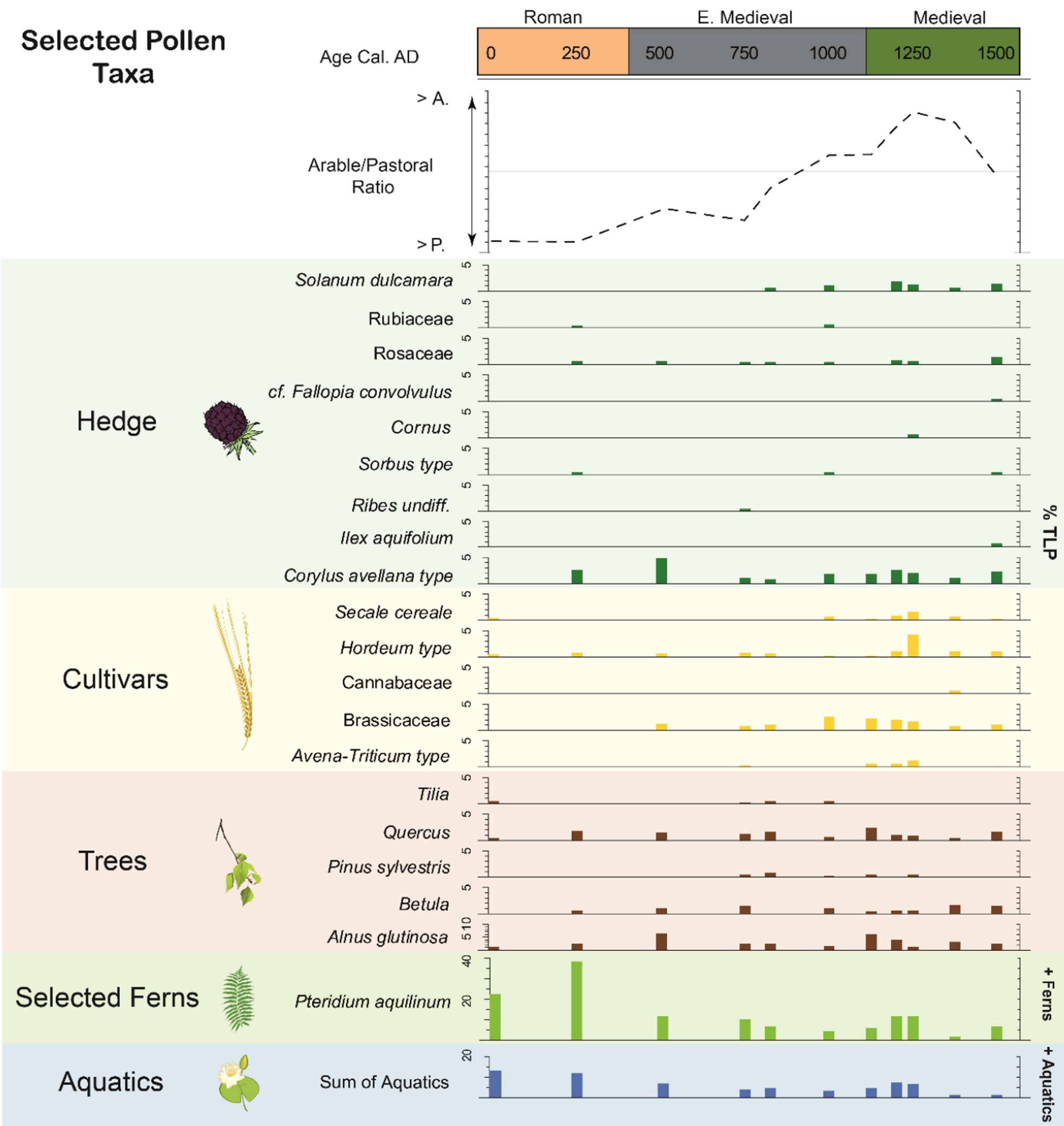


**FIGURE 6** | Selected pollen types and land use ratios from sample core C10 from the lower Hatfield Brook floodplain. Full pollen diagram provided in Figure S4.

pollen such as Lactuceae. Aquatics are present throughout much of the core, namely waterlilies (*Nuphar* and *Nymphaea alba*) at 173 cm (ca. AD 250), and water plantain (*Alisma* type) from 155 to 165 cm (ca. AD 500–1125). These taxa indicate slow-flowing or stationary water upstream from the Romano-British to medieval periods. The absence of these taxa from later periods might relate to the changes in sediment accumulation and floodplain drainage infilling shallow areas of open water.

Heaths make up only c. 1% of the TLP; most were undifferentiated Ericaceae (heather/heath family), with a very small number of other heathland pollen types from 163 cm onwards (from ca. AD 750). As the percentages are so low, heath pollen could originate from areas of grazed heathland in the wider catchment rather than from near the sampling site (Figure 3). Grasses (Poaceae), however, constitute 30%–67% of the TLP throughout the sequence. Pastoral taxa such as plantains (*Plantago* spp.), knapweed (*Centaurea nigra*), dock/sorrel (*Rumex*) and clovers (*Trifolium*-type) are common, while cereals and probable arable weeds (e.g., *Achillea*-type, *Solidago virgaurea*-type, and *Polygonum*) are rarer, yet all three common cereal types are present. Barley (Hordeum-type) in most subsamples, while oats/wheat (*Avena-Triticum*-type) first appear at 163 cm (ca. AD 750), and again from 140 to 155 cm (ca. AD 1125–1250). A single pollen grain of rye (*Secale cereale*) was identified at 181 cm (ca. AD 0), but in increased amounts from 98 to 157 cm (ca. AD 1000–1500).

Overall, cereals and arable indicators occur in greater quantities and with more diversity over time, beginning in the early medieval period around ca. AD 500, but more notably by ca. AD 1000, with a peak in the medieval period ca. AD 1250, before gradually declining in the later medieval period (to ca. AD 1500). In contrast, peaks of bracken (*Pteridium aquilinum*) and common polypody (*Polypodium*), do not correspond to reductions in pollen concentration, as might be expected if due to pollen destruction (Figure S4). This suggests several phases of reduced arable activity, reduction in animal grazing and possible land abandonment in the local landscape during the Romano-British period (ca. AD 0–250).

## 6 | Documentary Evidence of Land Use and Landscape Change

In addition to the palaeoenvironmental record additional landscape information can be ascertained from the records of the Bishopric of Worcester (BoW). Historical research by Dyer (1980) and Hamshere (1980) has increased our understanding of this major ecclesiastical centre from its founding in AD 680 to the dissolution in AD 1540 (Figures 7 and 8). Critically, the creation and management of the bishopric enabled the control of large areas of land within the Severn catchment as large episcopal manors, including Kempsey, Hartlebury, Wick and Ripple (Severn), as well as Bredon and Hampton (Warks Avon) and Tredington (Warks Stour). The development of these centres likely followed on from the typology of settlement and agrarian patterns present in the prehistoric and Romano-British periods and they largely observe a similar distribution of productive free draining alluvial and colluvial soils (c.f. Brown 2009).

In contrast, manors on the heavier clay soils of the headwaters of the Arrow and Salworpe valleys and steeper valleys of the catchment margin on the Cotswold edge had more woodland, associated with more pastoral and arboreal economies.

By the early 11th century AD, the BoW estate was organised into manors with land divided between demesne and tenant

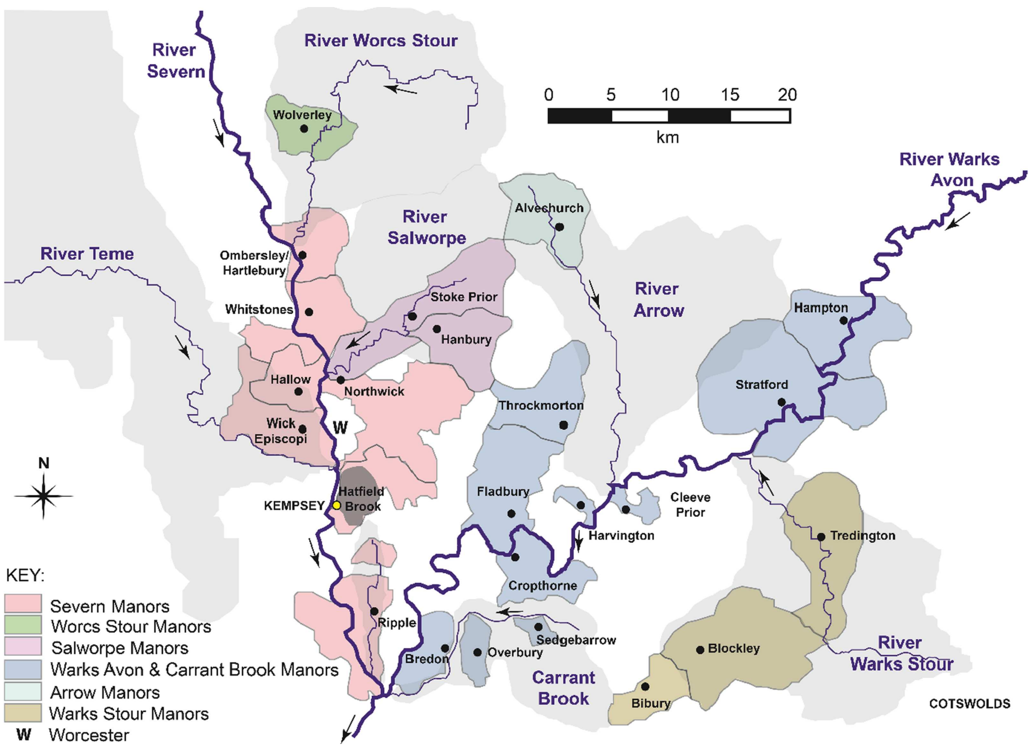


**FIGURE 7** | Map of the lands of the Bishopric of Worcester in proximity to fluvial catchments of the Rivers Severn and Avon including small systems the Hatfield Brook and Ripple Brook.

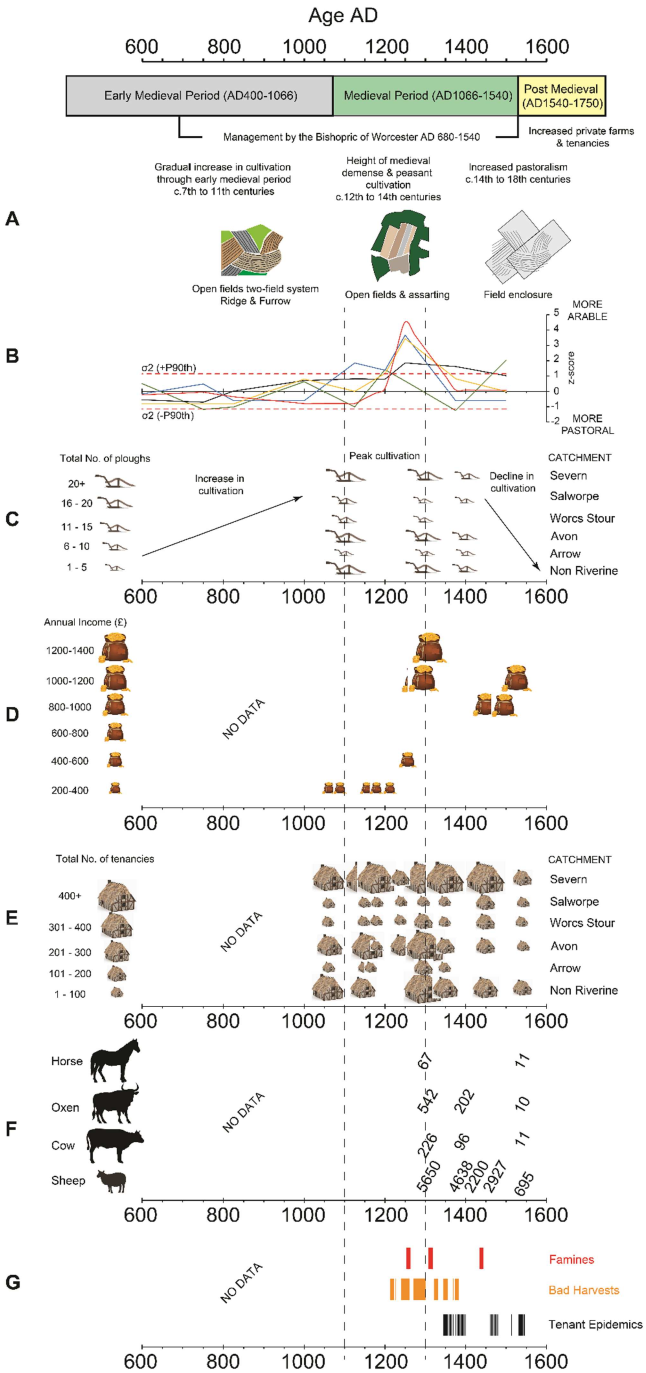


**FIGURE 8** | Summary models of historic land use, palaeoenvironmental and economic history data from the Hatfield Brook and neighbouring manorial areas between AD 600–1600 including (A) Hatfield Brook catchment historic land use; (B) Hatfield Brook arable:pastoral ratio with Herbs; Hordeum, Secale; Avena/Triticum; (C) Total demesne ploughs at manors by major river valley from AD 1086–1389 (Dyer 1980; Hamshere 1980); (D) Annual income (E) of the Bishopric of Worcester AD 1066–1540 (Dyer 1980); (E) Total tenancies at manors by major river valley from AD 1086–1544 (Dyer 1980; Hamshere 1980); (F) Number of recorded domestic farm animals on the Bishopric of Worcester estate AD 1292–1539 (Dyer 1980); (G) Recorded famines, bad harvests and tenant epidemics.

holdings. In terms of tenant numbers, there is no direct evidence that the population of the villages on the estate increased in the 12th and 13th centuries AD, but such an increase must lie behind the growth in number of recorded tenants, from 950 in 1086, to 1289 in AD 1170, and again to 1853 in AD 1299 (Dyer 1980; Hamshere 1980) (Figure 8). The initial rise in tenant numbers between AD 1170–1299 have been attributed to the intensification of previously occupied areas, rather than due to a major rise in the amount of arable cultivation (Dyer 1980, 96–97). In contrast to this, with the decrease in the profitability of arable cultivation and rise in pastoralism from the late 13th century AD, the BoW could make more money from rents and sheep farming rather than crop cultivation.

Further division of lands came in the mid-11th century AD when the estate of the cathedral monastery was separated from that of the bishopric. The bishops were therefore faced with the long-term reduction in the size of their estate. One reaction was to seek better land for themselves. When Bishop Oswald leased out land at Wolverton at Stoulton, Worcestershire in AD 977, he reserved 60 acres (24 ha) of 'wheat land' presumably for his demesne at Kempsey (Robertson 1956, 114–115). Similarly, on a number of other estates such as Fladbury (Avon), the best arable land was retained in the episcopal demesne manor, while lessees received inferior clay lands across the Cotswold Margin.

By the late 12th century AD, the estate expanded its revenues by taking direct control of demesne lands and increasing the development of agriculture. As a result, the incomes of individual landlords often more than doubled in the 13th century AD, though expansion ceased during the early 14th century AD (Figure 8). In addition, the bishops of Worcester were able to maintain the estate value after the 13th century AD peak by purchasing assarted land (forest converted to arable land) in the woodland manors of Hanbury (Salworpe) and Alvechurch (Arrow), although the main focus of assarting in the Severn Valley had already occurred in the 12th century AD (e.g., 86 ha at Whitstones and 85 ha at Kempsey, Dyer 1980, 91). The peak of arable growth across the demesnes was in the 13th century AD, with large areas of floodplain demesne set out for extensive arable cultivation for example, Cleeve Prior (Avon) (Dyer 2022, fig. 6.4, 186), and particularly between AD 1290–1299 arable cultivation appears to have been practiced on a large scale throughout the estate, which accords well with the pollen results from Kempsey. Throughout the BoW estate agricultural management was conducted at a more local level with two-field system (fields under crop then fallowed for 1 year) manors at Hampton, Stratford (Avon Valley), Kempsey (Severn Valley), Blickley in Hanbury (Salworpe Valley), Bibury, Paxford, Tredington, Withington (Cotswold Margin), and multiple field divisions at Alvechurch (Arrow Valley), Aston, Whitstones, Wick (Severn Valley), Hanbury (Salworpe Valley), Hartlebury (Worcs Stour Valley) (Dyer 1980, 68).

Across many of the floodplain dominated manors including Bredon, Hampton (Avon), Kempsey, Northwick/Whitstones (Severn) and Hanbury (Salworpe) there are records of the number of ploughs, demonstrating the advantage of lowland arable and the reflection on overall value and profitability, which were often double that of the Cotswold and North Worcestershire manors (Dyer 1980; Hamshere 1980). However, between AD 1086 and 1290 there is a large fall in ploughs in the Avon and Severn manors as a result of the reduction in arable profitability and the beginning of the move towards pastoralism which increased in the 14th century AD alongside the deterioration in climatic conditions (Jordan 1996; Pribyl 2017) and population stagnation.

From the 14th century AD onwards records suggest a widespread reduction in arable cultivation across the lands of the church of Worcester. In AD 1306, the demesne manors of Alvechurch (Arrow), Hanbury (Salworpe), Kempsey and Wick (Severn) were said to lie in a 'barren district' (*de debili territorio*) and Bishop Reynolds commented on the barrenness of the demesnes 'so that it does not seem useful to till them' (Denholm-Young 1937).

By the late 1300s, the amount of demesne arable agriculture was further reduced. A comparison between the number of demesne ploughs reveals a decline from 61 ploughs in AD 1302–03 to 20 by AD 1389. Half of the fall was the result of the total leasing of eight demesnes, but on the manors where direct management continued, except for Alvechurch (Arrow), the demesne ploughs had usually halved in number, due to sub-divisional demesne leasing, less intensive cultivation and deteriorations in climatic conditions and arable markets. In common with other demesnes at this time though, spring-sown crops (barley, drage [Dyer 2022, 158–160], oats, pulses, legumes and vetch) predominated on all of the manors, particularly Kempsey and Whitstones (Severn).

The reduction in the area under cultivation allowed flexibility in crop rotations and land use. Convertible husbandry, with land being used alternatively as pasture and arable, was practised. The major factor in reducing the area under crops, and perhaps discouragement in developing agricultural techniques, was the downwards trend in prices. As the demesne area shrank because of leasing, the pastoral resources of the estate were also inevitably diminished, although the reduction was much less than for arable land. On the demesne kept in direct management, arable was converted to pasture. A comparison of stock lists compiled in AD 1290 and AD 1389 shows a marked reduction in the number of oxen at Kempsey, because fewer plough-teams were employed, and the numbers of cows fell from 226 to 96, but sheep declined only by 18% from 5650 to 4638 (Dyer 1980, 134). This demonstrates the relative importance of sheep farming in the estate economy in the 14th century AD. Pastoral farming, and particularly sheep, was maintained at a higher level than cereal production because it enjoyed the two-fold advantages of a favourable market and lower costs. So although both grain and wool prices declined in the late AD 1370s, wool remained profitable. As a result, by the early 15th century AD, the largest flocks were kept on the Cotswold manors but increasingly larger numbers of sheep were also being pastured at the riverside manors of Bibury, Hampton and Kempsey. After AD 1458 the only vestige of direct management by the church was the continued use of meadows to supply the household with hay, although demesne meadows were still kept in hand at Kempsey and Hartlebury in the early 16th century AD, with records from Kempsey from 1505–06; 1508–09; 1514–15; 1520–21 and 1525–26 (Dyer 1980, 152), again highlighting the importance of maintaining superior quality grazing lands within the floodplain landscapes around the Hatfield Brook and River Severn.

Tenant numbers recorded across all the manors between AD 1299–1349 show an overall reduction from 1346 to 781 (42%), and this is unlikely to be solely as a result of the Black Death, as the records also show recovery after the epidemic, and by the end of AD 1349 the worst of the plague was over (Dyer 1980, 237). For the later medieval period, population change at Kempsey has been determined using mortality records in court rolls from AD 1432–1539. This highlights the worst years for tenant deaths as AD 1455–56; 1464–65; 1471–72; 1488; 1499–1500; 1524–25; 1526–27; 1528–29 and 1536 (Dyer 1980, 223). In short, high mortality spikes occurred in almost every decade recorded and was caused by famines, bad harvests and pestilence (Figure 8).

## 7 | Discussion

The two sediment cores from the lower Hatfield Brook reveal sediment accumulation rates (SARs) of up to 2 mm $year^{-1}$. The complex morphology of the valley makes exact volumetric calculations difficult, but from the 4% alluviated area and the mean alluvial depth (1.2 m), the Hatfield Brook has been estimated at holding approximately 76,800 tons $km^2$ of sediment (using an average bulk density of 1.6 tons $m^3$) the vast majority of which is post-Roman in age. This corresponds to an annual mean rate of 38.4 tons $km^2$ $year^{-1}$ or between 26.2 and 50.6 tons $km^2$ $year^{-1}$ using 1 $\sigma$ of the mean depth, which is the equivalent to a mean denudation rate of $0.6 \pm 0.2$ mm $year^{-1}$ but when similar estimates from other small catchments are compared a greater degree of contextualization can be made (Figure 9; Table S3).

Unsurprisingly, given the Hatfield Brook catchment size the average mean accumulation rate is comparable with a number of other small local catchments, the Worcestershire Stour, Carrant Brook and River Lugg (c. 27–45 tons $km^2$ $year^{-1}$). In contrast, this value is signifyingly lower than the Rivers Perry, Teme, Arrow and Herefordshire Frome, (c. 90–129 tons $km^2$ $year^{-1}$), where the most extensive clastic alluviation has traditionally been identified (Shotton 1978; Brown 1990; Brown et al. 2013; Pears, Brown, Toms, et al. 2020; Pears, Brown, Carroll, et al. 2020). In contrast though, the Ripple Brook demonstrates a major outlier in this pattern as a result of its lower topographic extent, downstream position, extensive fluvial influence from the River Severn and prolonged history of human activity (Brown and Barber 1985; Miller et al. 2004). Comparisons of the mean denudation rates suggest that most of the smaller catchments, including the Ripple, have similar erosion rates over time (0.5–0.9 mm $year^{-1}$), with only the Rivers Perry, Teme having rates in excess of 1 mm $year^{-1}$.

Across many of these catchments alluviation has been shown to begin in late prehistory, but in many cases accelerated sedimentation also increased again in the early medieval, medieval and post medieval periods (Macklin et al. 2014). A good example of this can be seen in the River Lugg (1.4 mm $year^{-1}$) where the majority of overbank sedimentation occurred from the early medieval period onwards (Macklin et al. 2007, 64).

Alluviation across all these catchments is therefore likely to vary somewhat as a result of localized geomorphological and topographical traits resulting in differences in catchment characteristics and fluvial gradients, and the extent and magnitude of anthropogenic factors are likely to have played a significant part alongside climatic variability especially during the later Holocene.

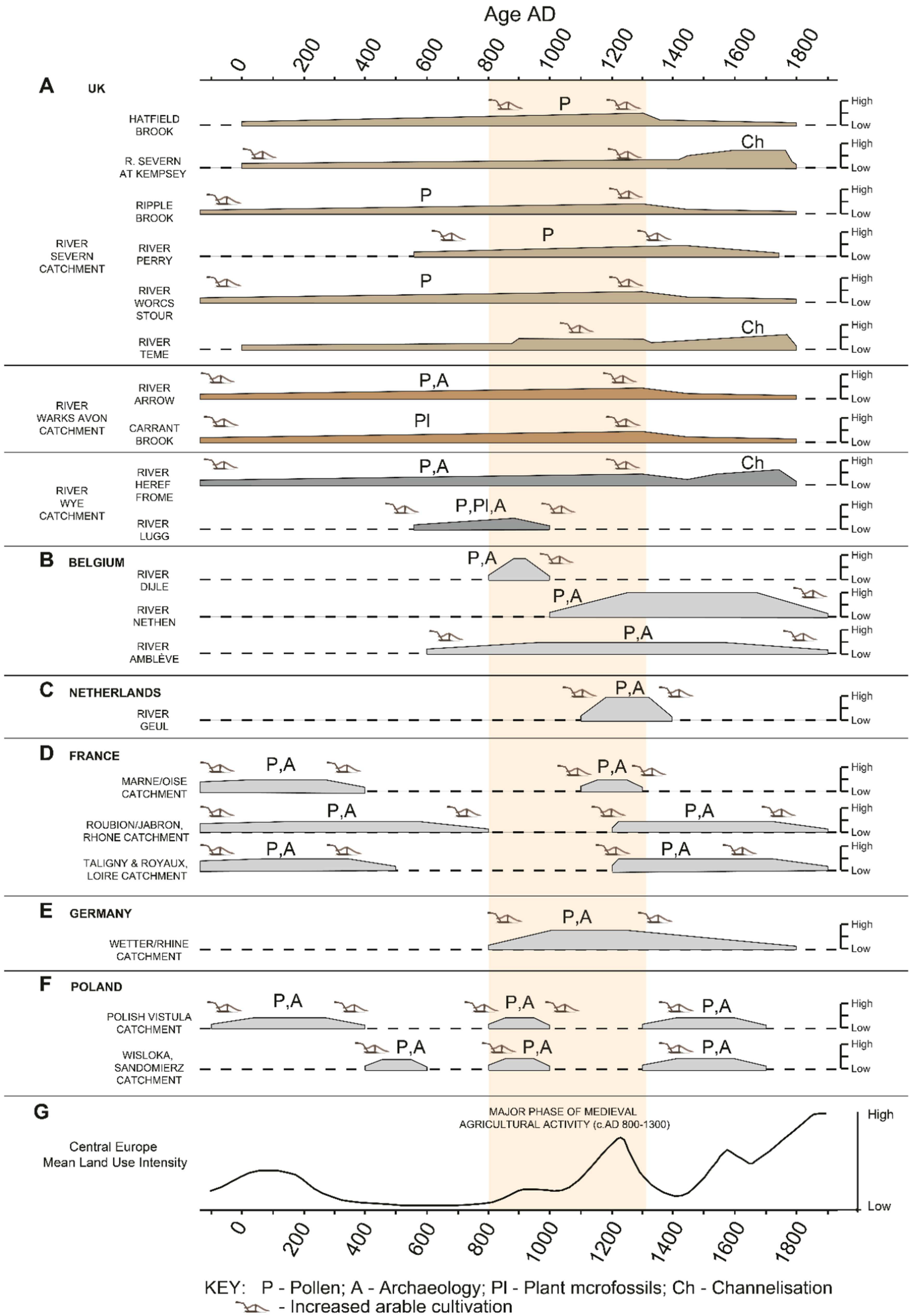


**FIGURE 9** | Modelled historic alluviation, environment and land use in the Hatfield Brook and comparative catchments from mainland Europe between AD 0–1800. (A) (this paper; Pears et al. 2023; Brown and Barber 1985; Brown 1990; Brown 1988; Pears et al. 2020a; Shotton 1978; Palmer 1999; Greig and Colledge 1988, 2005; Brown et al. 2013; Macklin et al. 2007; Carey et al. 2017). (B) (Notebaert et al. 2009, 2011; Broothaerts et al. 2014; Rommens et al. 2006; Verstraeten et al. 2009; Notebaert et al. 2013). (C) (De Moor et al. 2008; De Moor and Verstraeten 2008). (D) (Pastre et al. 2003; Larue et al. 1996; Macaire et al. 2006; Notebaert et al. 2014; Lespez et al. 2008). (E) (Hoffmann et al. 2008, 2009; Houben et al. 2007, 2013 Dotterweich 2008). (F) (Klimek 2002; Starkel et al. 1996, 2006; Szmanda et al. 2004). (G) Central Europe mean land use intensity from Dotterweich (2008). Additional information on the United Kingdom, Belgian and Netherlands examples are also presented in Table S3.

At a broader scale across mainland Europe, a selective survey of a number of comparably sized lowland fluvial systems within geologically similar catchments (Figure 9, Table S3) provide additional information as to the nature of sediment erosion, transfer and deposition during the historical period across Belgium, the Netherlands, France, Germany and Poland.

Across Belgium and the Netherlands, increased alluviation in the medieval period occurred regularly, especially across the loessic central belt with readily erodible, yet highly fertile soils (Notebaert and Verstraeten 2010). Calculations of three of the catchments indicate annual mean accumulation rates which align with that for the Hatfield Brook. The Nethen, Amblève and Geul have figures ranging from 5 to 81 tons km$^2$ year$^{-1}$. In contrast, the Dijle catchment has a considerably higher figure of 90–210 tons km$^2$ year$^{-1}$ possibly reflecting the catchment size, but in each of these cases the denudation rates are considerably higher than all the UK examples (between 2 and 15 mm year$^{-1}$) due to the majority of deposition occurring over a more condensed period of time between the early medieval and medieval periods.

Alluviation across other areas of Europe also demonstrate increases at the same time. In the Loire (Larue et al. 1996; Macaire et al. 2006), Marne/Oise catchment (Pastre et al. 2003), and the Roubion and Jabron catchments of the Rhone, France (Notebaert et al. 2014) accelerated deposition occurred between AD 1100–1300 associated with an increase in anthropogenic land use (Lespez et al. 2008) and major colluviation (Notebaert et al. 2014).

Across German river catchments, particularly the Rhine (Hoffmann et al. 2008, 2009) increased alluviation has been shown to have occurred since the 8th and 9th centuries AD, driven by increased human activity (Houben 2007; Dotterweich 2008). In the upper Wetter valley increased alluviation started at the same time as the start of the three-field crop rotation, akin to the Hatfield Brook. The development of this agricultural revolution in the later medieval period and the utilization of the oxen-powered mouldboard plough drastically increased slope-sediment transfer as cultivated areas were left exposed to soil erosion for longer periods (Houben et al. 2013).

Similarly, increased medieval alluviation, coinciding with increased agricultural land use and exacerbated by climatic variability has also been demonstrated across the Polish Vistula (Klimek 2002; Starkel et al. 1996, 2006; Szmanda et al. 2004).

### 7.1 | Evidence of Fallowing/Rotation and Manuring

The presence of both scientific datasets and historical sources for Kempsey has enabled a greater discussion of the vegetational, alluvial and land use history within the Hatfield Brook. The fact that the catchment lies completely within the area of the Kempsey demesne manor (Figure 7), means that soil erosion is effectively an effect of land use activity promulgated by the Bishop of Worcester. Ultimately, soil erosion is largely controlled by cultivation and crop types, but we can also identify the particular fields that received the soil lost from the slopes. These are often long-thin fields that bound the streams but also include several broader confluence zones. Although now mostly under grazing, a range of ridge and furrow types provides a broad chronological base (Upex 2004) indicating phases of erosion and stability. Ridge and furrow cultivation with the classic reverse 's' morphology are typical of oxen driven cultivation through the medieval period (11th to 15th centuries). In contrast, more regular, straighter earthworks tend to date to the post medieval and modern periods (16th to 19th centuries) typical of machine-driven steam ploughing (Figure 10).

The documented medieval two-field arable system used at Kempsey, across the Hatfield Brook catchment and other ecclesiastical demesne was common practice across the West Midlands (Dyer 1980, 68). Whilst this system enabled the land to rest and recuperate between winter and spring crops and had the advantage of reducing the total period of bare-earth exposure, it did involve ploughing-up greater areas of fallow pasture offered in comparison to the three-field system.

We have no direct information on the specific plough-types utilised in the Hatfield Brook catchment, but evidence of swivel-type ploughs has been identified in England from as early as the 8th century AD (Thomas et al. 2016) and that heavy oxen-driven wheeled ploughs were in common use after the Norman Conquest (Andersen et al. 2016). Indeed, at Kempsey the heavy plough may well have been in use from the medieval period given the wealth and influence of the Bishopric of Worcester, which is likely to have rapidly adopted new agricultural technologies, particularly from mainland Europe. On wider context a greater systematic use of the mouldboard plough in two- and three-field systems across central England has also been suggested in the 12th century AD onwards (Hamerow 2022, 21).

Additionally, the medieval cultivar species identified in both the pollen analysis and the documentary evidence consist predominantly of cereals including barley, oats, wheat, rye, fodder crops (Brassicaceae) and by the 15th century AD flax. The increase in cultivation from c. AD 750–1300 is also reflected in the land use pattern across the Severn catchment (Beales 1980; Barber and Twigger 1987; Bartley and Morgan 1990; Twigger and Haslam 1991; Pittam 2006; Hamerow et al. 2020; Mighall et al. 2023) and over the wider landscape of central and southern England (Rippon et al. 2015; Forster and Charles 2022) albeit with discrete localised topographic variations.

There is also indirect evidence of significant manuring with organic and inorganic components common to the Midlands of England in the medieval period (Jones and Lewis 2012; Jones 2016) akin to central England in the 12th and 13th centuries (McKerracher and Hamerow 2022). To the north of Kempsey and the Hatfield Brook systematic fieldwalking has identified over 2000 finds from prehistory to the post medieval period, with distribution analysis suggesting a correlation of manured artefacts with historic field boundaries and entrances (Loney and Hoaen 2018). To the south at Pendock, extensive ceramic evidence found by fieldwalking contemporary fields suggests extensive periods of cultivation in both the Romano-British and mid-12th century AD (Dyer 1990, 104).

A potentially complicating factor in this study is the role of watermills at Kempsey. Domesday does not mention a mill at Kempsey, and this may have been due to an insufficient or unreliable flow, resulting in the construction of windmills

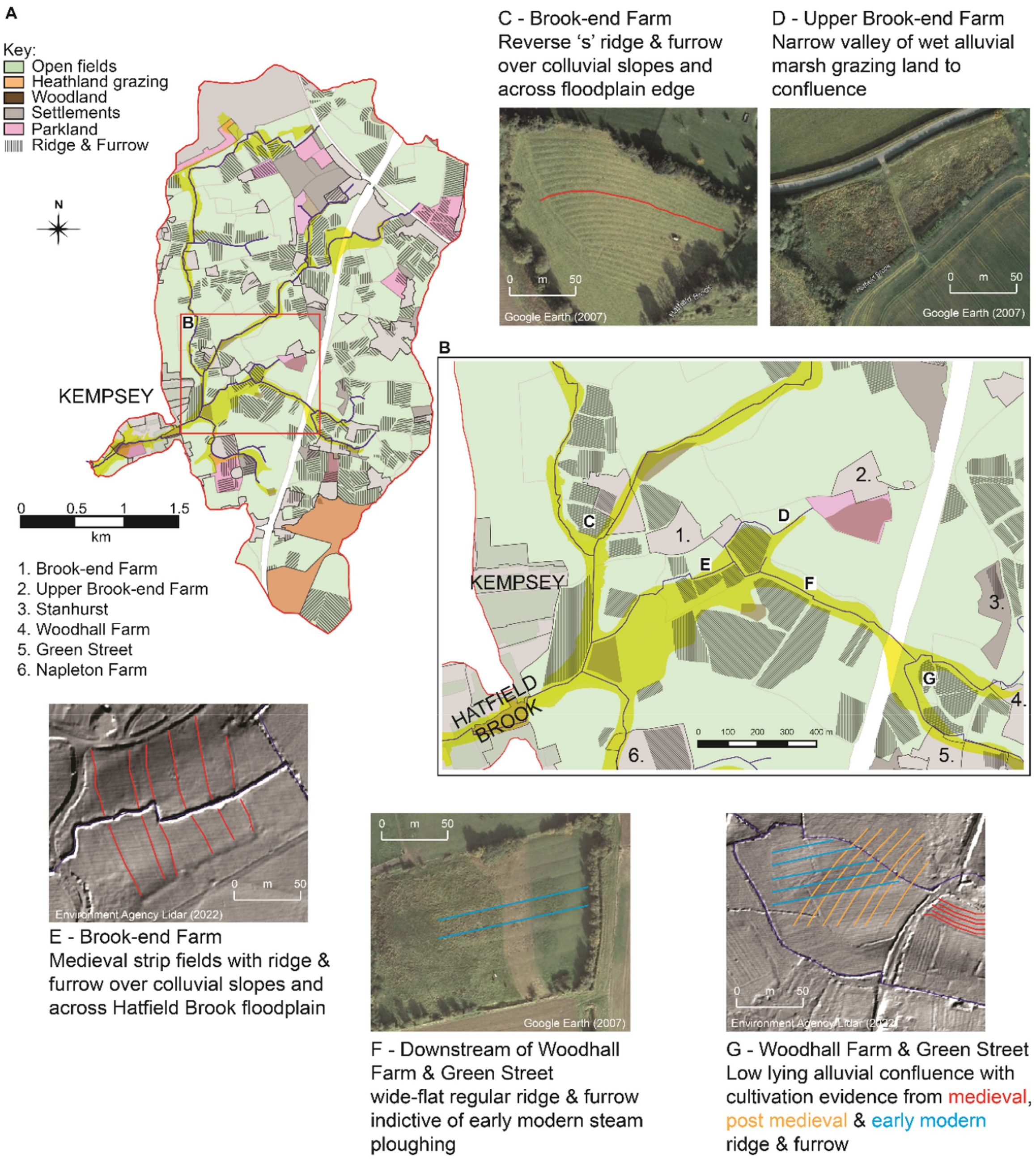


**FIGURE 10** | Examples of historic land use evidence present in the contemporary landscape (A), with particular focus on the Hatfield Brook area to the east of Kempsey (B). Including (C) medieval ridge and furrow (Google Earth 2007); (D) marshland grazing (Google Earth 2007); (E) medieval strip fields with ridge and furrow (1 m DTM Lidar Hillshade); (F) early modern steam ploughing (Google Earth 2007) and (G) multi-phase cultivation evidence from medieval to modern periods within and adjacent to alluvial areas (1 m DTM Lidar Hillshade).

through the later medieval period (Holt 1988, 30). However, geomorphological evidence in the contemporary landscape suggests that an unrecorded watermill possibly existed at the upstream entrance to the narrowing floodplain at Kempsey due to the presence of a remnant straightened secondary channel, possibly acting as a leat (Figure 1, arrowed). In general, mills in the United Kingdom probably had little effect on sedimentation because by law their dams could not obstruct the full width of the floodplain and so they were generally on secondary channels (Brown et al. 2018, Brown, Rhodes, et al. 2021), but in this case the upper mill could have ponded flows upstream. However, the effect of this would be to retain even more sediment in the catchment and further reduce the sediment flux downstream at the sampling area.

## 8 | Conclusions

Increasing human occupation and agricultural activity in the West Midlands from the Late Bronze Age and Iron Age (1600–50 BC) meant that by the start of the Roman occupation c. AD 50, the Hatfield Brook catchment was an almost totally open, agricultural landscape with small areas of managed woodlands and open heath on the catchment margin, similar to other small fluvial catchments in Midland England. Open conditions continued through the Romano-British period, albeit with lower levels of arable activity recorded in the pollen. In contrast, by the early medieval period arable activity and rates of alluviation increased and especially after ca. AD 750 when the catchment came under the direct control of the Bishopric of Worcester. A further increase in arable activity and floodplain sedimentation occurred in the Hatfield Brook catchment during the medieval period to its zenith in the mid-13th century (ca. AD 1000–1250). The extent of cultivation and the utilisation of the open two-field agricultural system at this time generated alluvial sedimentation covering approximately 4% of the catchment which covered former wetland and mires creating new arable land (as identified by the distribution of ridge and furrow earthworks) and additional fertile grazing and meadowland. This grazing land was available for both draft animals and stock which increased resources for ploughing and maintaining fertility. This in turn allowed potentially continuous cultivation of the valley slopes despite high rates of soil loss but balanced with organic and inorganic manuring, during fallow, after harvest, and by hand (as revealed by pottery scatters). Overall, agricultural activity in the Hatfield catchment mirrors closely that of lowland Europe with growth in the late 11th to late 13th centuries AD, stagnation, decline and a rise in pastoralism in the 14th century AD, and further conversion to smaller independent tenancies, enclosure, sheep farming and orchards in the 15th and 16th centuries AD. This mechanism of catchment slope soil erosion creating new flat and well-watered land available for agriculture has been proposed for the semi-arid and Mediterranean zones (e.g., van Andel et al. 1990) but has not been identified in NW Europe as part of the open-field system and medieval investment in sustained and largely resilient agricultural productivity, at least prior to the Catholic Reformation in England (AD 1540).

This study has revealed that the inherent erosivity of the medieval open-field system was offset both by the keeping of stock and manuring, but also because much, if not the vast majority, of eroded soil was redeposited in the catchment effectively expanding the area of agriculture especially if drained and which must be seen as integral energy inputs to this integrated arable-pastoral human ecosystem. This suggests that our medieval predecessors were not profligate with their use of resources but adaptive, and that the open two-field system could be both resilient and sustainable. However, since its demise came from economic and political factors we can never know if soil exhaustion would have occurred in the sixteenth to nineteenth centuries AD although ironically the creation of arable super-fields in the last 50 years maybe a re-run of the experiment but without the livestock element.

## Author Contributions

R.J., A.G.B., J.C. and B.P. conceptualized the project, paper concept and provided funding acquisition. B.P. and A.G.B. developed combined methodology. B.P. and S.H. conducted fieldwork and all sedimentological laboratory, statistical and data analysis, and created graphics and figures. E.F. and S.H. conducted all palaeoenvironmental analysis and figures. B.P., A.G.B., E.F., S.H. and R.J. wrote the paper. B.P., A.G.B., E.F., S.H., J.C. and R.J. conducted review and editing.


## Acknowledgements

This work was undertaken as part of the Leverhulme Trust-funded 'Flood and Flow' project (RPG-2016-004). The authors would like to thank the landowners Peter Hughes of the Madresfield Estate, Reverend Phillipa Sargent of St Mary's Church, Kempsey, and Henry Morris, Chair of the Churchlands Trust. Thanks also to Tom Vaughan, Senior Project Officer at Worcestershire Archaeology for detailed archaeological and stratigraphical material. We also thank the Environment Agency for Lidar data. Pollen analysis was carried out as part of the ERC-funded 'FeedSax' (Feeding Anglo-Saxon England) project (No. 741751) based at the Universities of Oxford and Leicester.


## References


van Andel, T. H., E. Zangger, and A. Demitrack. 1990. "Land Use and Soil Erosion in Prehistoric and Historical Greece." *Journal of Field Archaeology* 17, no. 4: 379–396. https://doi.org/10.1179/009346990791548628.

Andersen, S. T. 1979. "Identification of Wild Grass and Cereal Pollen. Danmarks Geologiske Undersøgelse." *Årbog* 1978: 66–92.

Andersen, T. B., P. S. Jensen, and C. V. Skovsgaard. 2016. "The Heavy Plow and the Agricultural Revolution in Medieval Europe." *Journal of Development Economics* 118: 133–149. https://doi.org/10.1016/j.jdeveco.2015.08.006.

Arriaga, F. J., and B. Lowery. 2003. "Soil Physical Properties and Crop Productivity of an Eroded Soil Amended With Cattle Manure." *Soil Science* 168, no. 12: 888–899. https://doi.org/10.1097/01.ss.0000106403.84926.7e.

Bakker, M. M., G. Govers, R. A. Jones, and M. D. A. Rounsevell. 2007. "The Effect of Soil Erosion on Europe's Crop Yields." *Ecosystems* 10: 1209–1219. https://doi.org/10.1007/s10021-007-9090-3.

Barber, K. E., and S. N. Twigger. 1987. "Later Quaternary Palaeoecology of the Severn Basin." In *Palaeohydrology in Practice*, edited by K. J. Gregory, J. Lewin, and J. B. Thornes, 217–250. Wiley.

Barclay, W. J., K. Ambrose, R. A. Chadwick, and T. C. Pharoah. 1997. *Geology of the County Around Worcester: Memoir for 1:50,000 Geological Sheet 199*. British Geological Survey, HMSO.

Bartley, D. D., and A. V. Morgan. 1990. "The Palynological Record of the King's Pool, Stafford, England." *New Phytologist* 116: 177–194. https://doi.org/10.1111/j.1469-8137.1990.tb00522.x.

Bassett, S. 1989. "Churches in Worcester Before and After the Conversion of the Anglo-Saxons." *Antiquaries Journal* 69: 225–256. https://doi.org/10.1017/S0003581500085425.

Beales, P. W. 1980. "The Late Devensian and Flandrian Vegetational History of Crose Mere, Shropshire." *New Phytologist* 85: 133–161.

Bennett, K. D. 1994. "Annotated Catalogue of Pollen and Pteridophyte Spore Types of the British Isles." Unpublished Manuscript, Department of Plant Sciences, University of Cambridge.

Blaauw, M., and J. A. Christen. 2011. "Flexible Paleoclimate Age-Depth Models Using an Autoregressive Gamma Process." *Bayesian Analysis* 6, no. 3: 457–474. https://doi.org/10.1214/11-BA618.

Blaauw, M., and J. A. Christen. 2013. "Bacon Manual e v2. 3.5."

Board of Agriculture. 1905. https://discovery.nationalarchives.gov.uk/details/c/F258985.

Boardman, J., and Poesen, J., eds. 2007. *Soil Erosion in Europe*. John Wiley & Sons.

Bond, C. J. 1988. "Church and Parish in Norman Worcestershire." In *Minsters and Parish Churches: The Local Church in Transition 950-1200*, edited by J. Blair, 119–158. Oxford University Committee for Archaeology, Monograph 17.

Bork, H. R., and A. Lang. 2003. "Quantification of Past Soil Erosion and Land Use/Land Cover Changes in Germany." In *Long Term Hillslope and Fluvial System Modelling. Lecture Notes in Earth Sciences*, edited by

A. Lang, R. Dikau, and K. Hennrich, 101. Springer. https://doi.org/10.1007/3-540-36606-7_12.

Bretherton, J., and L. Jones. 2000. *Salvage Recording Along the Route of the Kempsey to Littleworth Severn Trent Water Asset Renewal Scheme, Worcestershire*. Worcestershire County Council, Archaeological Service reports.

British Geological Survey. 2020. "GeoIndex Onshore Borehole Records." https://mapapps2.bgs.ac.uk/geoindex/home.html.

Bronk Ramsey, C. 2009. "Bayesian Analysis of Radiocarbon Dates." *Radiocarbon* 51, no. 1: 337–360. https://doi.org/10.1017/S0033822200033865.

Brooks, A., and N. Pevsner. 2007. *The Buildings of England: Worcestershire*. Yale University Press.

Broothaerts, N., G. Verstraeten, C. Kasse, S. Bohncke, B. Notebaert, and J. Vandenberghe. 2014. "From Natural to Human-Dominated Floodplain Geoecology–A Holocene Perspective for the Dijle Catchment, Belgium." *Anthropocene* 8: 46–58. https://doi.org/10.1016/j.ancene.2014.12.001.

Brown, A., P. Toms, C. Carey, and E. Rhodes. 2013. "Geomorphology of the Anthropocene: Time-Transgressive Discontinuities of Human-Induced Alluviation." *Anthropocene* 1: 3–13. https://doi.org/10.1016/j.ancene.2013.06.002.

Brown, A. G. 1983. "Late Quaternary, Palaeohydrology, Palaeoecology and Floodplain Development of the Lower River Severn." Unpublished PhD, University of Southampton.

Brown, A. G. 1988. "The Palaeoecology of Alnus (Alder) and the Postglacial History of Floodplain Vegetation. Pollen Percentage and Influx Data From the West Midlands, United Kingdom." *New Phytologist* 110, no. 3: 425–436. https://doi.org/10.1111/j.1469-8137.1988.tb00280.x.

Brown, A. G. 1990. "Holocene Floodplain Diachronism and Inherited Downstream Variations in Fluvial Processes: A Study of the River Perry, Shropshire, England." *Journal of Quaternary Science* 5: 39–51. https://doi.org/10.1002/jqs.3390050105.

Brown, A. G. 2009. "Colluvial and Alluvial Response to Land Use Change in Midland England: An Integrated Geoarchaeological Approach." *Geomorphology* 108: 92–106. https://doi.org/10.1016/j.geomorph.2007.12.021.

Brown, A. G., and K. E. Barber. 1985. "Late Holocene Paleoecology and Sedimentary History of a Small Lowland Catchment in Central England." *Quaternary Research* 24: 87–102. https://doi.org/10.1016/0033-5894(85)90085-7.

Brown, A. G., L. Lespez, D. A. Sear, et al. 2018. "Natural vs Anthropogenic Streams in Europe: History, Ecology and Implications for Restoration, River-Rewilding and Riverine Ecosystem Services." *Earth-Science Reviews* 180: 185–205. https://doi.org/10.1016/j.earscirev.2018.02.001.

Brown, A. G., E. J. Rhodes, S. Davis, et al. 2021. "Late Quaternary Evolution of a Lowland Anastomosing River System: Geological-Topographic Inheritance, Non-Uniformity and Implications for Biodiversity and Management." *Quaternary Science Reviews* 260: 106929. https://doi.org/10.1016/j.quascirev.2021.106929.

Brown, A. G., and K. Walsh. 2016. "Societal Stability and Environmental Change: Examining the Archaeology—Soil Erosion Paradox." *Geoarchaeology* 32: 23–35. https://doi.org/10.1002/gea.21611.

Brown, A. G., K. Walsh, D. Fallu, et al. 2021. "Ending the Cinderella Status of Terraces and Lynchets in Europe: The Geomorphology of Agricultural Terraces and Implications for Ecosystem Services and Climate Adaptation." *Geomorphology* 379: 107579. https://doi.org/10.1016/j.geomorph.2020.107579.

Carey, C., A. J. Howard, R. Jackson, and A. Brown. 2017. "Using Georchaeological Deposit Modelling as a Framework for Archaeological Evaluation and Mitigation in Alluvial Environments." *Journal of Archaeological Science* 11: 658–673. https://doi.org/10.1016/j.jasrep.2017.01.013.

Chambers, F. M. 1999. "The Quaternary History of Llangorse Lake: Implications for Conservation." *Aquatic Conservation: Marine and Freshwater Ecosystems* 9, no. 4: 343–359. https://doi.org/10.1002/(SICI)1099-0755(199907/08)9:4%3C343::AID-AQC354%3E3.0.CO;2-D.

Chew, S. C. 2001. *World Ecological Degradation: Accumulation, Urbanization, and Deforestation, 3000 BC-AD 2000*. Rowman Altamira.

Daffern, N., and J. Webster. 2013. *Archaeological Assessment of Plot 21, South Worcester, Norton Juxta Kempsey*. Worcestershire Archaeology. https://doi.org/10.5284/1049830.

Darlington, R. R. Ed. 1962–1963. "The Cartulary of Worcester Cathedral Priory (Register 1), (Pipe Roll Soc., 1xxvi)."

Denholm-Young, N. 1937. *Seignorial Administration in England*. Oxford University Press.

Dotterweich, M. 2008. "The History of Soil Erosion and Fluvial Deposits in Small Catchments of Central Europe: Deciphering the Long-Term Interaction Between Humans and the Environment - AReview." *Geomorphology* 101: 192–208. https://doi.org/10.1016/j.geomorph.2008.05.023.

Dyer, C. 1980. *Lords and Peasants in a Changing Society: The Estates of the Bishopric of Worcester 680–1540*. Cambridge University Press.

Dyer, C. 1990. "Dispersed Settlements in Medieval England. A Case Study of Pendock, Worcestershire." *Medieval Archaeology* 34, no. 1: 97–121.

Dyer, C. 2022. "Peasants and Their Crops." In *Peasants Making History: Living in an English Region 1200-1540*. edited by C. Dyer, 145–187. Oxford University Press. https://doi.org/10.1093/oso/9780198847212.003.0006.

Environment Agency. 2007. *Orthophotography, 20cm IRRGB for Tile SO84NE*. Department for Environment, Food and Rural Affairs, HMSO. https://environment.data.gov.uk/DefraDataDownload/?Mode=survey.

Environment Agency. 2015. "Kempsey Flood Risk Management Scheme." Policy Paper.

Environment Agency. 2022. *Raw Lidar Data, 1m Digital Terrain Model (DTM) Data for Kempsey and Hatfield Brook Catchment [tiles SO84NE, SO84NW, SO85SE SO85SW]*. Department for Environment, Food and Rural Affairs, HMSO. https://environment.data.gov.uk/DefraDataDownload/?Mode=survey.

European Pollen Database. 2024. http://www.europeanpollendatabase.net/.

Finberg, H. P. R. 1972. *The Early Charters of the West Midlands* (2nd ed.). Leicester University Press.

Forster, E., and M. Charles. 2022. "Agricultural Land Use in Central, East and South-East England: Arable or Pasture?" In *New Perspectives on the Medieval 'Agricultural Revolution' Crop, Stock and Furrow*, edited by M. McKerracher and H. Hamerow, 61–85. Liverpool University Press.

Fraser, E. D. G. 2011. "Can Economic, Land Use and Climatic Stresses Lead to Famine, Disease, Warfare and Death? Using Europe's Calamitous 14th Century as a Parable for the Modern Age." *Ecological Economics* 70: 1269–1279. https://doi.org/10.1016/j.ecolecon.2010.02.010.

Goad, J., L. Pearson, and E. Hindmarch. 2003. *An Archaeological Watching Brief at Old Road South*. Worcestershire Archaeology. https://doi.org/10.5284/1038548.

Goldberg, N., U. Nachshon, E. Argaman, and M. Ben-Hur. 2020. "Short Term Effects of Livestock Manures on Soil Structure Stability, Runoff and Soil Erosion in Semi-Arid Soils Under Simulated Rainfall." *Geosciences* 10, no. 6: 213. https://doi.org/10.3390/geosciences10060213.

Google Earth. 2007. *Orthophotography for Hatfield Brook Catchment, Worcestershire, UK*.

de Graaff, M.-A., N. Hornslein, H. L. Throop, P. Kardol, and L. T. A. van Diepen. 2019. "Chapter One - Effects of Agricultural Intensification on Soil Biodiversity and Implications for Ecosystem Functioning: A Meta-Analysis." In *Advances in Agronomy*, edited by D. L. Sparks, 1–44. Academic Press. https://doi.org/10.1016/bs.agron.2019.01.001.

Greig, J. 2007. "Assessment of Roman Archaeobotanical Material (Pollen and Plant Macrofossils) From Alcester AL80, Warwickshire." Report 07.01.

Greig, J., and S. Colledge. 1988. "The Prehistoric and Early Medieval Waterlogged Plant Remains From the Multiperiod Beckford Sites 5006 and 5007 (Worcestershire) and What They Show of the Surroundings Then." Unpublished Report No. 54/88.

Greig, J., and S. Colledge. 2005. "Prehistoric to Early Medieval Landscape Change in the Avon Valley; the Waterlogged Pollen and Seeds From Sites 5006 and 5007, Beckford, Worcestershire." Unpublished Report No. 05.10.

Greig, J. R. A. 1999. "Pollen." In *Archaeological Excavations in the Arrow Valley*, edited by S. Palmer, 176–179. Transactions of the Birmingham and Warwickshire Archaeological Society.

Hall, D. 2014. *The Open Fields of England*. Oxford University Press.

Hamerow, H. 2022. "The 'FeedSax' Project: Rural Settlements and Farming in Early Medieval England." In *New Perspectives on the Medieval 'Agricultural Revolution' Crop, Stock and Furrow*, edited by M. McKerracher and H. Hamerow, 3–24. Liverpool University Press.

Hamerow, H., A. Bogaard, M. Charles, et al. 2020. "An Integrated Bioarchaeological Approach to the Medieval 'Agricultural Revolution': A Case Study From Stafford, England, c.AD 800–1200." *European Journal of Archaeology* 23, no. 4: 585–609. https://doi.org/10.1017/eaa.2020.6.

Hamerow, H., T. Zerl, C. Kropp, and A. Bogaard. 2023. "Roman to Early Medieval Cereal Farming in the Rhineland: Weeds, Tillage, and the Spread of the Mouldboard Plough." *Landscape History* 44, no. 2: 5–13. https://doi.org/10.1080/01433768.2023.2284544.

Hamshere, J. D. 1980. "Colonization and the Evolution of Rural Settlement in Worcestershire, Prior to 1349." Unpublished Doctoral Thesis, University of Birmingham.

Harding, L. A. 2013. "Water as a Resource: The Significance of Milling in the Early Medieval Landscape of the South-West Midlands of England." Unpublished MSc thesis, University of Exeter.

Herbermann, C., ed. 1913. *Ancient Diocese of Worcester. Catholic Encyclopaedia*. Robert Appleton Company.

Hoffmann, R. 2014. *An Environmental History of Medieval Europe*. Cambridge University Press. https://doi.org/10.1017/CBO9781139050937.

Hoffmann, T., G. Erkens, R. Gerlach, J. Klostermann, and A. Lang. 2009. "Trends and Controls of Holocene Floodplain Sedimentation in the Rhine Catchment." *Catena* 77, no. 2: 96–106. https://doi.org/10.1016/j.catena.2008.09.002.

Hoffmann, T., A. Lang, and R. Dikau. 2008. "Holocene River Activity: Analysing 14C-Dated Fluvial and Colluvial Sediments From Germany." *Quaternary Science Reviews* 27: 2031–2040. https://doi.org/10.1016/j.quascirev.2008.06.014.

Hoffmann, T., V. R. Thorndycraft, A. G. Brown, et al. 2010. "Human Impact on Fluvial Regimes and Sediment Flux During the Holocene: Review and Future Research Agenda." *Global and Planetary Change* 72: 87–98. https://doi.org/10.1016/j.gloplacha.2010.04.008.

Holt, R. 1988. *The Mills of Medieval England*. Blackwell.

Honek, D., M. Š. Michalková, A. Smetanová, et al. 2020. "Estimating Sedimentation Rates in Small Reservoirs-Suitable Approaches for Local Municipalities in Central Europe." *Journal of Environmental Management* 261: 109958. https://doi.org/10.1016/j.jenvman.2019.109958.

Hooke, D. 1985. *The Anglo Saxon Landscape. The Kingdom of the Hwicce*. Manchester University Press.

Houben, P. 2007. "Geomorphological Facies Reconstruction of Late Quaternary Alluvia by the Application of Fluvial Architecture Concepts." *Geomorphology* 86, no. 1–2: 94–114. https://doi.org/10.1016/j.geomorph.2006.08.008.

Houben, P., M. Schmidt, B. Mauz, A. Stobbe, and A. Lang. 2013. "Asynchronous Holocene Colluvial and Alluvial Aggradation: A Matter of Hydrosedimentary Connectivity." *Holocene* 23, no. 4: 544–555. https://doi.org/10.1177/0959683612463105.

Jackson, R., D. Hurst, and E. Pearson. 1995. *Salvage Recording of a Romano-British Settlement at Norton-Juxta-Kempsey, Near Crookbarrow Hill: Archive Report*. Worcestershire Archaeology. https://doi.org/10.5284/1026872.

Jetten, V., A. De Roo, and D. Favis-Mortlock. 1999. "Evaluation of Field-Scale and Catchment-Scale Soil Erosion Models." *Catena* 37, no. 3–4: 521–541. https://doi.org/10.1016/S0341-8162(99)00037-5.

Jones, R. ed. 2016. "Understanding Medieval Manure." In *Manure Matters*, 145–158. Routledge.

Jones, R., and C. Lewis. 2012. "Chapter 12 the Midlands: Medieval Settlements and Landscapes." In *The Midlands: Medieval Settlements and Landscapes'. Medieval Rural Settlement: Britain and Ireland, AD800, 1600*, edited by N. Christie, and P. Stamper, 186–205. Windgather Press.

Jordan, W. C. 1996. *The Great Famine: Northern Europe in the Early Fourteenth Century*. Princeton University Press.

Kempsey Court Rolls. October 1394–October 1537. Ref. 705: 4 BA 54.

Klimek, K. 2002. "Human-Induced Overbank Sedimentation in the Foreland of the Eastern Sudety Mountains." *Earth Surface Processes and Landforms* 27, no. 4: 391–402. https://doi.org/10.1002/esp.342.

Knowles, D., and R. N. Hadcock. 1971. *Medieval Religious Houses in England and Wales*. Longman.

LandIS. 2024. *LandIS Soilscape Viewer for Kempsey, Worcestershire: The Land Information System*. Cranfield University. https://www.landis.org.uk/soilscapes/.

Larue, J. P., C. Leroyer, and J. P. Mahoué. 1996. "Les remblaiements defond de vallons: l'exemple du Royeau dans le bassin de la Sarthe, a′ l'ouest du Bassin Parisien (France)." *Geomorphologie* 4: 69–88. https://www.persee.fr/doc/morfo_1266-5304_1996_num_2_4_894.

Lespez, L., M. Clet-Pellerin, N. Limondin-Lozouet, J.-F. Pastre, M. Fontugne, and C. Marcigny. 2008. "Fluvial System Evolution and Environmental Changes During the Holocene in the Mue Valley (Western France)." *Geomorphology* 98: 55–70. https://doi.org/10.1016/j.geomorph.2007.02.029.

Lewin, J. 2010. "Medieval Environmental Impacts and Feedbacks: The Lowland Floodplains of England and Wales." *Geoarchaeology* 25, no. 3: 267–311. https://doi.org/10.1002/gea.20308.

Loney, H. L., and A. Hoaen. 2018. *Preliminary Report on the Excavations and Field Walking and Excavations at Oldbury Farm, Worcester*. Technical Report. University of Worcester, Worcester. https://eprints.worc.ac.uk/7028/.

Lovett, P. 2015. *Archaeological Investigations of Land East of Main Road*. Worcestershire Archaeology. https://doi.org/10.5284/1042254.

Lovett, P., and R. Hedge. 2015. *An Archaeological Evaluation at the Firs, off Old Road North*. Worcestershire Archaeology. https://doi.org/10.5284/1042983.

Macaire, J.-J., J. Bernard, C. Di-Giovanni, F. Hinschberger, N. Limondin-Lozouet, and L. Visset. 2006. "Quantification and Regulation of Organic and Mineral Sedimentation in a Late-Holocene Floodplain as a Result of Climatic and Human Impacts (Taligny Marsh, Parisian Basin, France)." *Holocene* 16, no. 5: 647–660. https://doi.org/10.1191/0959683606hl961rp.

Macklin, M. G., E. Johnstone, P. A. Brewer, and C. H. Swain. 2007. "The Holocene Fluvial History of the Lugg Catchment." In *The Lugg Valley, Herefordshire: Archaeology, Landscape Change and Conservation*, edited by P. Dorling, 51–66. Herefordshire Studies in Archaeology.

Macklin, M. G., J. Lewin, and A. F. Jones. 2014. "Anthropogenic Alluvium: An Evidence-Based Meta-Analysis for the UK Holocene." *Anthropocene* 6: 26–38. https://doi.org/10.1016/j.ancene.2014.03.003.

Martínez-González, J. L. 2025. "Assessing Agricultural Adaptation to Changing Climatic Conditions During the English Agricultural Revolution (1645–1740)." *Cliometrica* 19: 163–193. https://doi.org/10.1007/s11698-024-00285-4.

McGurk, P. 1995. *The Chronicle of John of Worcester. Volume II: The Annals From 450-1066. Oxford Medieval Texts*. Clarendon Press.

McKerracher, M. and Hamerow, H., eds. 2022. *New Perspectives on the Medieval 'Agricultural Revolution' Crop, Stock and Furrow*. Liverpool University Press.

Mighall, T. M., N. J. Pittam, I. D. L. Foster, et al. 2023. "q56 The Midlands of England: Economic Backwater or an Agricultural Powerhouse? Environmental Evidence From Prehistory to Modern Times Recorded in Sediments From Aqualate Mere, Central England, UK." *Environmental Archaeology*: 1–26. https://doi.org/10.1080/14614103.2023.2187520.

Miller, D., E. Pearson, K. Head, and A. Crawford. 2004. "Archaeological Evaluation (Stage 3) at Ripple, Worcestershire (PNUM 3369). "Historic Environment and Archaeology Service Report No. 1231, Worcestershire County Council. https://archaeologydataservice.ac.uk/archives/view/ripple_eh_2007/downloads.cfm?report=evaluation&CFID=4242bc9f-7695-4c7e-aa76-41381fb7f014&CFTOKEN=0#anch.

Ministry of Agriculture Fisheries & Foods (MAFF). n.d. "Report of the MAFF Agricultural Land Classification Survey – The Nash, Kempsey." MAFF Report.

Montgomery, D. 2007. *Dirt: The Erosion of Civilizations*. University of California Press.

De Moor, J. J. W., C. Kasse, R. Van Balen, J. Vandenberghe, and J. Wallinga. 2008. "Human and Climate Impact on Catchment Development During the Holocene—Geul River, the Netherlands." *Geomorphology* 98, no. 3–4: 316–339. https://doi.org/10.1016/j.geomorph.2006.12.033.

De Moor, J. J. W., and G. Verstraeten. 2008. "Alluvial and Colluvial Sediment Storage in the Geul River Catchment (The Netherlands) - Combining Field and Modelling Data to Construct a Late Holocene Sediment Budget." *Geomorphology* 95, no. 3–4: 487–503. https://doi.org/10.1016/j.geomorph.2007.07.012.

Moore, P. D., J. A. Webb, and M. E. Collinson. 1991. *Pollen Analysis*. Blackwell Scientific Publications.

Morris, J. 1982. *Domesday Book: Worcestershire (Phillimore), Kempsey 2,2*. The History Press.

Mullan, J. D. 2007. *Mortality, Gender, and the Plague of 1361-2 on the Estate of the Bishop of Winchester*. Cardiff Historical Papers.

Nguyen, K. A., and W. Chen, 2018. "Estimating Sediment Delivery Ratio by Stream Slope and Relief Ratio." In *MATEC Web of Conferences* (Vol. 192, p. 02040). EDP Sciences. https://doi.org/10.1051/matecconf/201819202040.

Norton, S. 2021. *Assessing Iron Age Marsh-Forts With Reference to the Stratigraphy and Palaeoenvironment Surrounding the Berth, North Shropshire*. Archaeopress Publishing.

Notebaert, B., J. F. Berger, and J. L. Brochier. 2014. "Characterization and Quantification of Holocene Colluvial and Alluvial Sediments in the Valdaine Region (Southern France)." *Holocene* 24, no. 10: 1320–1335. https://doi.org/10.1177/0959683614540946.

Notebaert, B., and G. Verstraeten. 2010. "Sensitivity of West and Central European River Systems to Environmental Changes During the Holocene: A Review." *Earth-Science Reviews* 103, no. 3–4: 163–182. https://doi.org/10.1016/j.earscirev.2010.09.009.

Notebaert, B., G. Verstraeten, G. Houbrechts, and F. Petit. 2013. "Holocene Floodplain Deposition and Scale Effects in a Typical European Upland Catchment: A Case Study From the Amblève Catchment, Ardennes (Belgium)." *Holocene* 23, no. 8: 1184–1197. https://doi.org/10.1177/0959683613483626.

Notebaert, B., G. Verstraeten, T. Rommens, B. Vanmontfort, G. Govers, and J. Poesen. 2009. "Establishing a Holocene Sediment Budget for the River Dijle." *Catena* 77, no. 2: 150–163. https://doi.org/10.1016/j.catena.2008.02.001.

Notebaert, B., G. Verstraeten, D. Vandenberghe, E. Marinova, J. Poesen, and G. Govers. 2011. "Changing Hillslope and Fluvial Holocene Sediment Dynamics in a Belgian Loess Catchment." *Journal of Quaternary Science* 26, no. 1: 44–58. https://doi.org/10.1002/jqs.1425.

O'Neill, H. E. 1956. "Court House Excavations: Kempsey, January 1956." *Transactions of the Worcestershire Archaeological Society* 101: 33–45.

Palmer, S. 1999. "Archaeological Excavations in the Arrow Valley, Warwickshire." *Transactions-Birmingham and Warwickshire Archaeological Society* 103: 1–231.

Panagos, P., P. Borrelli, K. Meusburger, C. Alewell, E. Lugato, and L. Montanarella. 2015. "Estimating the Soil Erosion Cover-Management Factor at the European Scale." *Land Use Policy* 48: 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021.

Parry, D. 2010. "Norton Lane, Worcester, Worcestershire: Archaeological Evaluation." Report No 10194. Cotswold Archaeological Trust.

Pastre, J. F., N. Limondin-Lozouet, C. Leroyer, P. Ponel, and M. Fontugne. 2003. "River System Evolution and Environmental Changes During the Lateglacial in the Paris Basin (France)." *Quaternary Science Reviews* 22, no. 20: 2177–2188. https://doi.org/10.1016/S0277-3791(03)00147-1.

Pears, B., A. G. Brown, J. Carroll, P. Toms, J. Wood, and R. Jones. 2020. "Early Medieval Place-Names and Riverine Flood Histories: A New Approach and New Chronostratigraphic Records for Three English Rivers." *European Journal of Archaeology* 23, no. 3: 381–405. https://doi.org/10.1017/eaa.2019.72.

Pears, B., A. G. Brown, P. Toms, J. Wood, D. Sanderson, and R. Jones. 2020. "A Sub-Centennial-Scale OSL Chronostratigraphy and Late-Holocene Flood History From a Temperate River Confluence." *Geology* 48: 819–825. https://doi.org/10.1130/G47079.1.

Pears, B., A. G. Brown, P. S. Toms, J. Wood, B. T. Pennington, and R. Jones. 2023. "Rapid Laminated Clastic Alluviation Associated With Increased Little Ice Age Flooding Co-Driven by Climate Variability and Historic Land-Use in the Middle Severn Catchment, UK." *Holocene* 33, no. 12: 1474–1488. https://doi.org/10.1177/09596836231197740.

Pears, B., A. Lang, D. Fallu, et al. 2024. "Lynchet-Type Terraces, Loess and Agricultural Resilience on Chalk Landscapes in the UK and Belgium." *European Journal of Archaeology* 27, no. 3: 329–352. https://doi.org/10.1017/eaa.2024.6.

Pickering, J. 1986a. *Oblique Aerial Photograph of Area East of Pear Tree Farm*. Worcestershire Archaeological Service.

Pickering, J. 1986b. *Oblique Aerial Photograph of Area Around Napleton Farm*. Worcestershire Archaeological Service.

Pittam, N. 2006. "Aspects of Vegetation and Land Use Changes During Historical Times From English Lowland Lake Records." Unpublished PhD thesis, Coventry University.

Pribyl, K. ed. 2017. "Climate and the Grain Price, 1264–1431." In *Farming, Famine and Plague*. Springer. https://doi.org/10.1007/978-3-319-55953-7_9.

Pribyl, K., R. C. Cornes, and C. Pfister. 2012. "Reconstructing Medieval April-July Mean Temperatures in East Anglia, 1256–1431." *Climatic Change* 113: 393–412. https://doi.org/10.1007/s10584-011-0327-y.

Rahtz, P. A., and D. Bullough. 1977. "The Parts of an Anglo-Saxon Mill." In *Anglo-Saxon England*, edited by P. Clemoes, 15–37. Cambridge University Press.

Ramsey, C. B. 2008. "Deposition Models for Chronological Records." *Quaternary Science Reviews* 27, no. 1–2: 42–60. https://doi.org/10.1016/j.quascirev.2007.01.019.

Ramsey, C. B. 2017. "Methods for Summarizing Radiocarbon Datasets." *Radiocarbon* 59, no. 2: 1809–1833. https://doi.org/10.1017/rdc.2017.108.

Rapuc, W., C. Giguet-Covex, J. Bouchez, et al. 2024. "Human-Triggered Magnification of Erosion Rates in European Alps Since the Bronze Age." *Nature Communications* 15: 1246. https://doi.org/10.1038/s41467-024-45123-3.

Rippon, S., C. Smart, and B. Pears. 2015. *The Fields of Britannia. Continuity and Change in the Late Roman and Early Medieval Landscape*. Oxford University Press.

Robertson, A. J. 1956. *Anglo-Saxon Charters* (2nd ed.). Cambridge University Press.

Rommens, T., G. Verstraeten, P. Bogman, et al. 2006. "Holocene Alluvial Sediment Storage in a Small River Catchment in the Loess Area of Central Belgium." *Geomorphology* 77, no. 1–2: 187–201. https://doi.org/10.1016/j.geomorph.2006.01.028.

Scholes, M. C., and R. J. Scholes. 2013. "Dust Unto Dust." *Science* 342, no. 6158: 565–566. https://doi.org/10.1126/science.1244579.

Shotton, F. W. 1978. "Archaeological Inferences From the Study of Alluvium in the Lower Severn-Avon Valleys." In *The Effect of Man on the Landscape: The Lowland Zone*, edited by S. Limbrey and J. G. Evans, 27–32. Council for British Archaeology.

Sims-Williams, P. 1990. *Religion and Literature in Western England 600-800*. Cambridge Studies in Anglo-Saxon England 3.

Souchère, V., C. King, N. Dubreuil, V. Lecomte-Morel, Y. Le Bissonnais, and M. Chalat. 2003. "Grassland and Crop Trends: Role of the European Union Common Agricultural Policy and Consequences for Runoff and Soil Erosion." *Environmental Science & Policy* 6, no. 1: 7–16. https://doi.org/10.1016/S1462-9011(02)00121-1.

Stace, C. A. 2010. New Flora of the British Isles. Cambridge University Press.

Staff, R. A., D. C. W. Sanderson, C. L. Rex, et al. 2024. "A Luminescence-Derived Cryptostratigraphy From the Lake Suigetsu Sedimentary Profile, Japan: 45,000–30,200 IntCal20 yr BP." *Quaternary Geochronology* 83: 101588. https://doi.org/10.1016/j.quageo.2024.101588.

Starkel, L., T. Kalicki, M. Krapiec, R. Soja, and E. Czyzowska. 1996. "Hydrological Changes of Valley Floors in the Upper Vistula Basin During Late Vistulian and Holocene." *Geographical Studies* 9: 7–128.

Starkel, L., R. Soja, and D. J. Michczyńska. 2006. "Past Hydrological Events Reflected in Holocene History of Polish Rivers." *Catena* 66: 24–33. https://doi.org/10.1016/j.catena.2005.07.008.

Szmanda, J. B., H. L. Oczkowski, and K. R. Przegietka. 2004. "Age of the Vistula River Overbank Deposits in Torun." *Geochronometria* 23: 35–38.

Thomas, G., G. McDonnell, J. Merkel, and P. Marshall. 2016. "Technology, Ritual and Anglo-Saxon Agriculture: The Biography of a Plough Coulter From Lyminge, Kent." *Antiquity* 90, no. 351: 742–758. https://doi.org/10.15184/aqy.2016.73.

Thompson, M. W. 1998. *Medieval Bishops' Houses in England and Wales*. Ashgate Publishing.

Thornton, D. E. 2018. "The Last Monks of Worcester Cathedral Priory." *Midland History* 43, no. 1: 3–21. https://doi.org/10.1080/0047729X.2018.1461774.

Twigger, S. N., and C. J. Haslam. 1991. "Environmental Change in Shropshire During the Last 13,000 Years." *Field Studies* 7: 743–758.

Upex, S. 2004. "A Classification of Ridge and Furrow by An Analysis of Cross-Profiles." *Landscape History* 26, no. 1: 59–75. https://doi.org/10.1080/01433768.2004.10594562.

Vaughan, T. M., and J. Webster. 2013. *Desk-Based Assessment of King's Hill*. Worcestershire Archaeology. https://doi.org/10.5284/1050460.

Vaughan, T. M., and J. Webster. 2016. "Archaeological Investigations on the Flood Alleviation Scheme, Kempsey, Worcestershire." *Transactions of the Worcestershire Archaeological Society* 25: 139–154.

Verstraeten, G., T. Rommens, I. Peeters, J. Poesen, G. Govers, and A. Lang. 2009. "A Temporarily Changing Holocene Sediment Budget for a Loess-Covered Catchment (Central Belgium)." *Geomorphology* 108, no. 1–2: 24–34. https://doi.org/10.1016/j.geomorph.2007.03.022.

Victoria County History. 1913. "Kempsey Parish." In *A History of the County of Worcester*. British History Online. https://www.british-history.ac.uk/vch/worcs/vol3/pp430-437.

Walker, M. J. C. 1993. "Holocene (Flandrian) Vegetation Change and Human Activity in the Carneddau Area of Upland Mid-Wales." In *Climate Change and Human Impact on the Landscape: Studies in Palaeoecology and Environmental Archaeology*, edited by F. M. Chambers, 169–183. Chapman and Hall.

Ward, Jr., J. H. 1963. "Hierarchical Grouping to Optimize an Objective Function." *Journal of the American Statistical Association* 58: 236–244.

Webster, G. 1955. "A Trial Excavation at Kempsey." *Transactions of the Worcestershire Archaeological Society* 32: 13–14.

Webster, J., E. Pearson, and D. Williams. 2012. "Archaeological Evaluation at the South Worcester Development, Kempsey, Worcestershire." Worcestershire County Council, Archaeological Service Reports. Report No 1960.

Wei, W., D. Chen, L. Wang, et al. 2016. "Global Synthesis of the Classifications, Distributions, Benefits and Issues of Terracing." *Earth-Science Reviews* 159: 388–403. https://doi.org/10.1016/j.earscirev.2016.06.010.

Wentworth, C. K. 1922. "A Scale of Grade and Class Terms for Clastic Sediments." *Journal of Geology* 30, no. 5: 377–392. https://doi.org/10.1086/622910.

Williams, J. R., and H. D. Berndt. 1972. "Sediment Yield Computed With Universal Equation." *Journal of the Hydraulics Division* 98, no. HY12: 2087–2098. https://doi.org/10.1061/JYCEAJ.0003498.

Williamson, T. 2000. "Understanding Enclosure." *Landscapes* 1, no. 1: 56–79. https://doi.org/10.1179/lan.2000.1.1.56.

Woodwards, L., and J. Greig. 1989. "Landscape Change Over the Last 2000 Years Deduced From Plant and Insect Remains From Alcester, Coulter's Garage." In *Roman Store Buildings at Alcester*, Vol. 94, edited by P. M. Booth, 63–106. Transactions of the Birmingham and Warwickshire Archaeological Society

## Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Pears et al Supplemental Material April 2025.