

*The soil erosion paradox re-examined:
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British lowland river catchment in the Late
Holocene*

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

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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 ($\sim 2 \text{ mm year}^{-1}$) 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).

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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 fluvio-glacial 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 km² 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

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

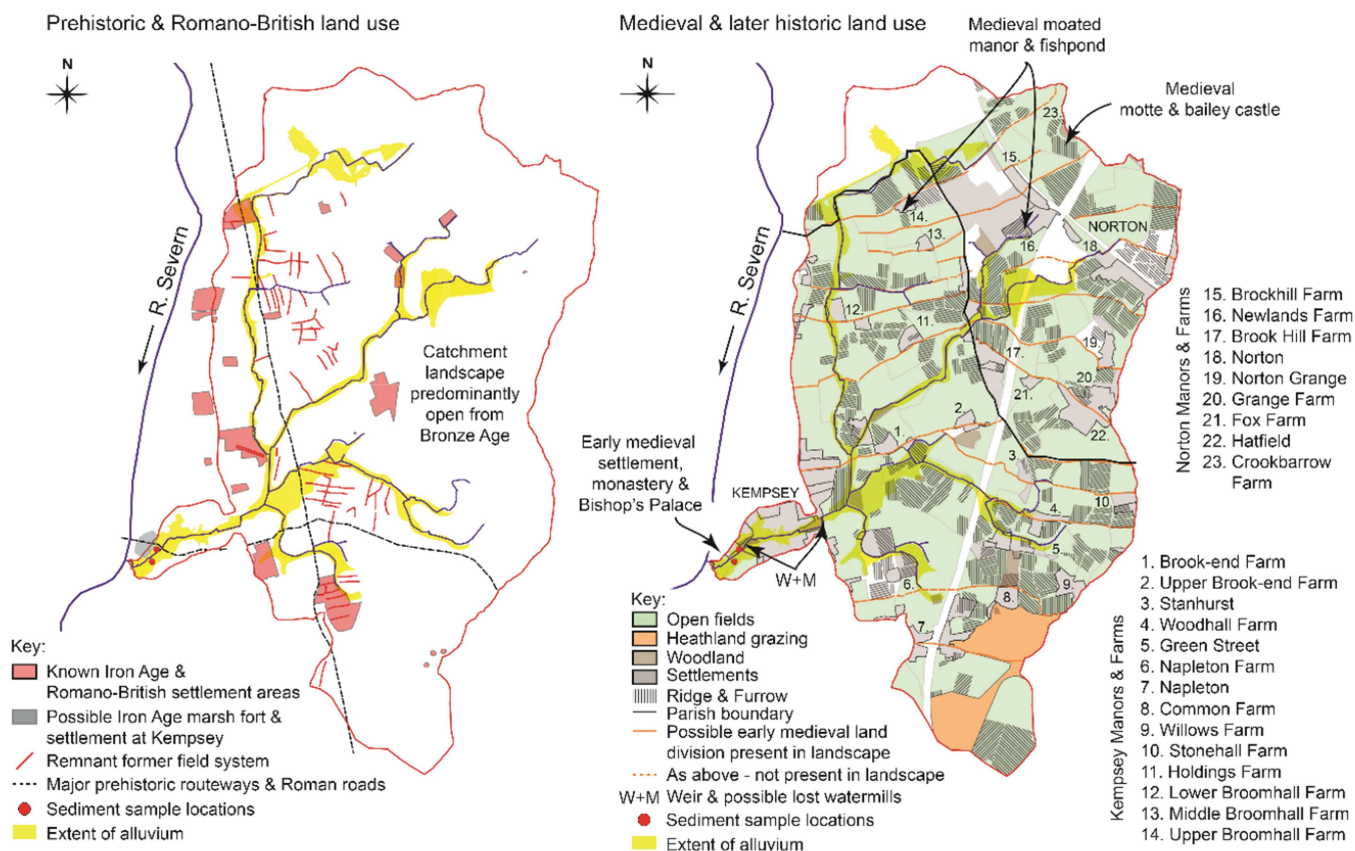


FIGURE 3 | Archaeology with prehistoric and historic land use across the Hatfield Brook catchment from the Prehistoric to Romano-British periods (c. 500 BC–AD 400) and medieval to later historic period (c. AD 400–1750). Both depicted with the area of alluviation, agricultural landscape and settlements/manor 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 km²) 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 (2σ 95.4%)	cal. BC/AD date (1σ 68.2%)
Hatfield Brook	8	136	Plant macrofossils	655 ± 36	UB-36952	cal.ADI266–1391	cal.ADI275–1318
		182	Wood, plant macrofossils, seeds	1100 ± 25	UB-36948	cal.AD898–1015	cal.AD915–993
10	228	228	Plant macrofossils, seeds	1298 ± 36	UB-36947	cal.AD660–770	cal.AD671–764
				701 ± 31	UB-36949	cal.ADI259–1387	cal.ADI270–1298
	210	286	Charcoal	2646 ± 35	UB-36950	895–787 cal.BC	831–796 cal.BC
				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

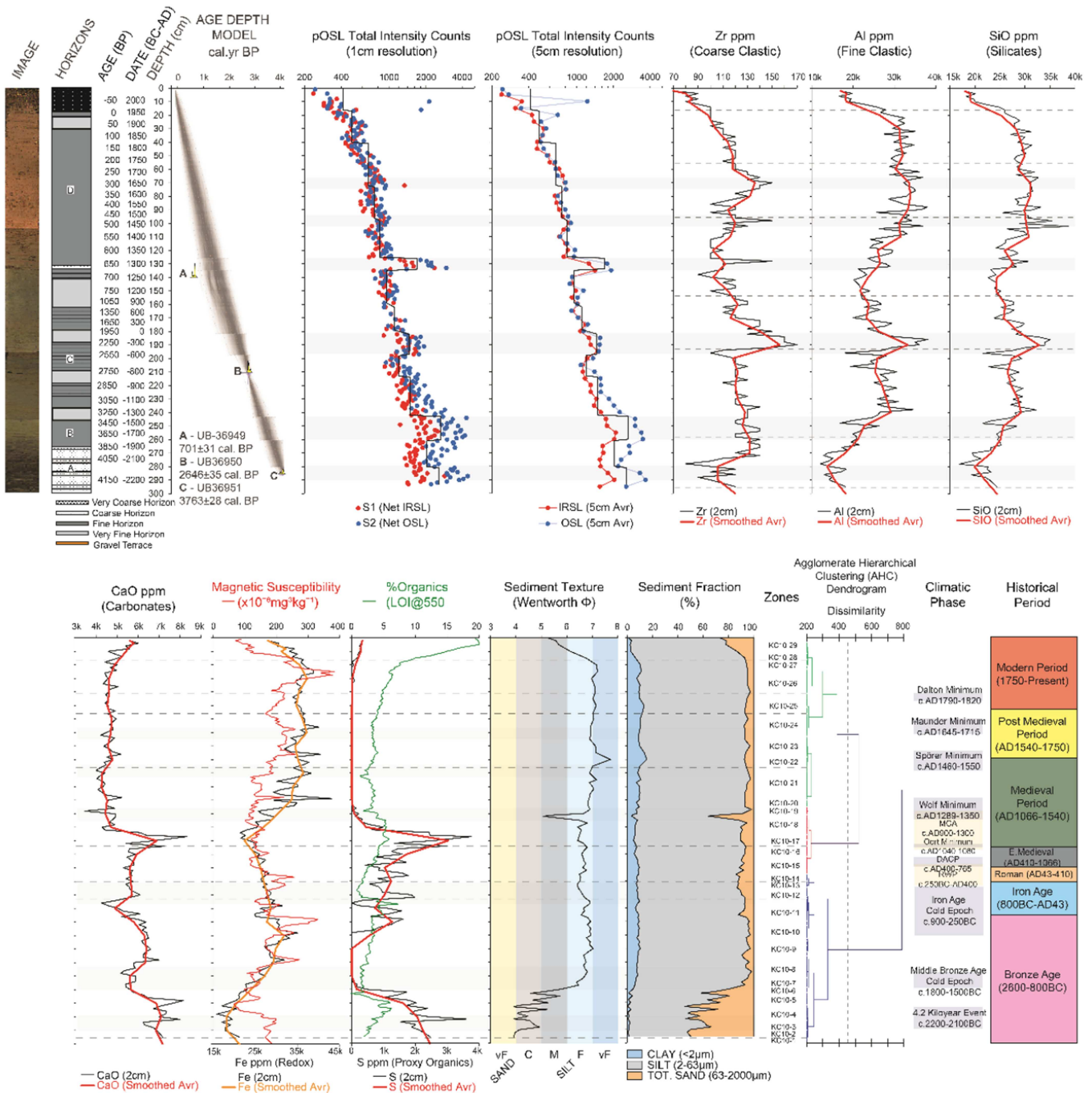


FIGURE 4 | Chronostratigraphical model of the lower Hatfield Brook floodplain core C10.

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.

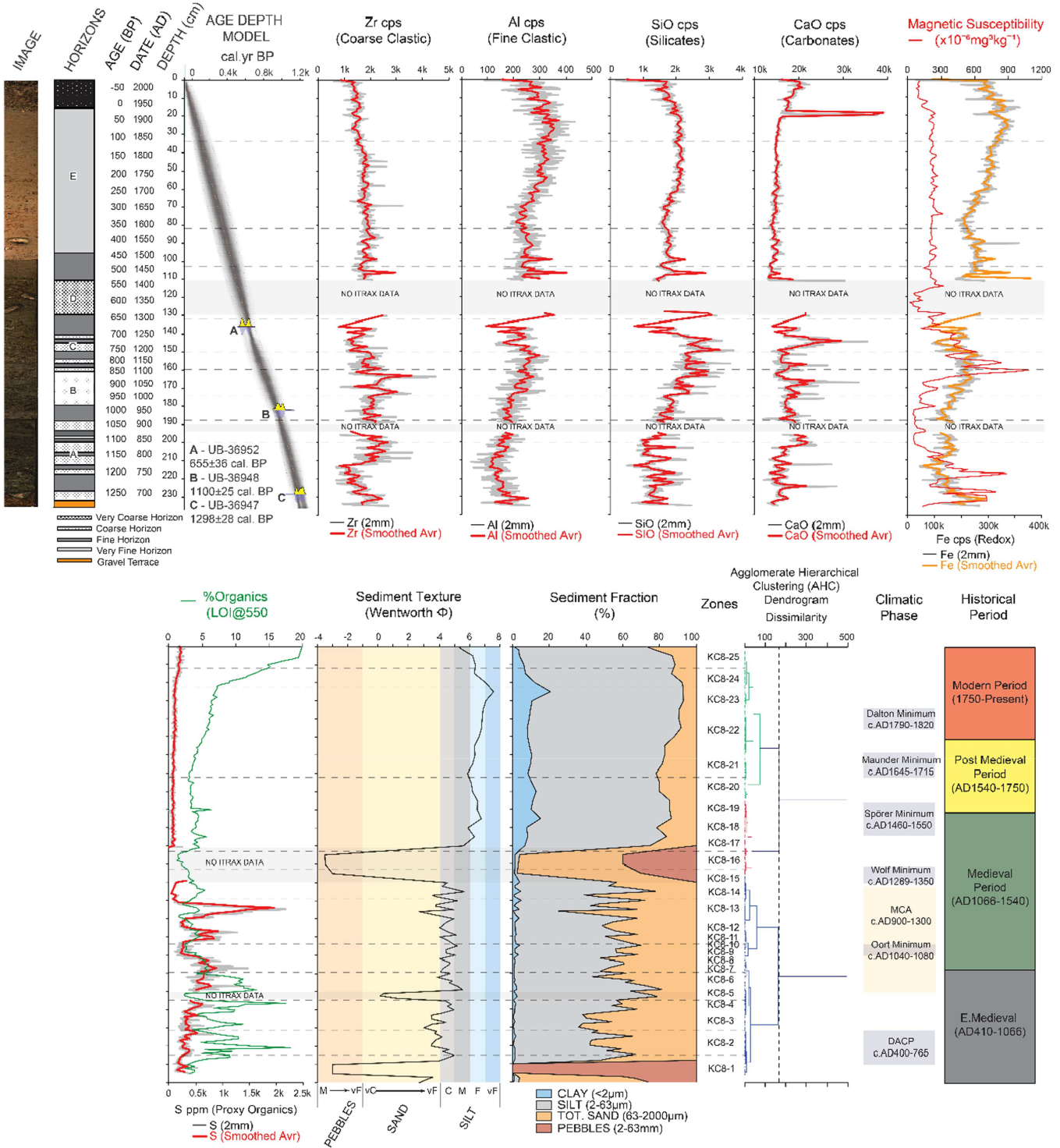


FIGURE 5 | Chronostratigraphical model of core C8 from the edge of the lower Hatfield Brook floodplain.

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

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

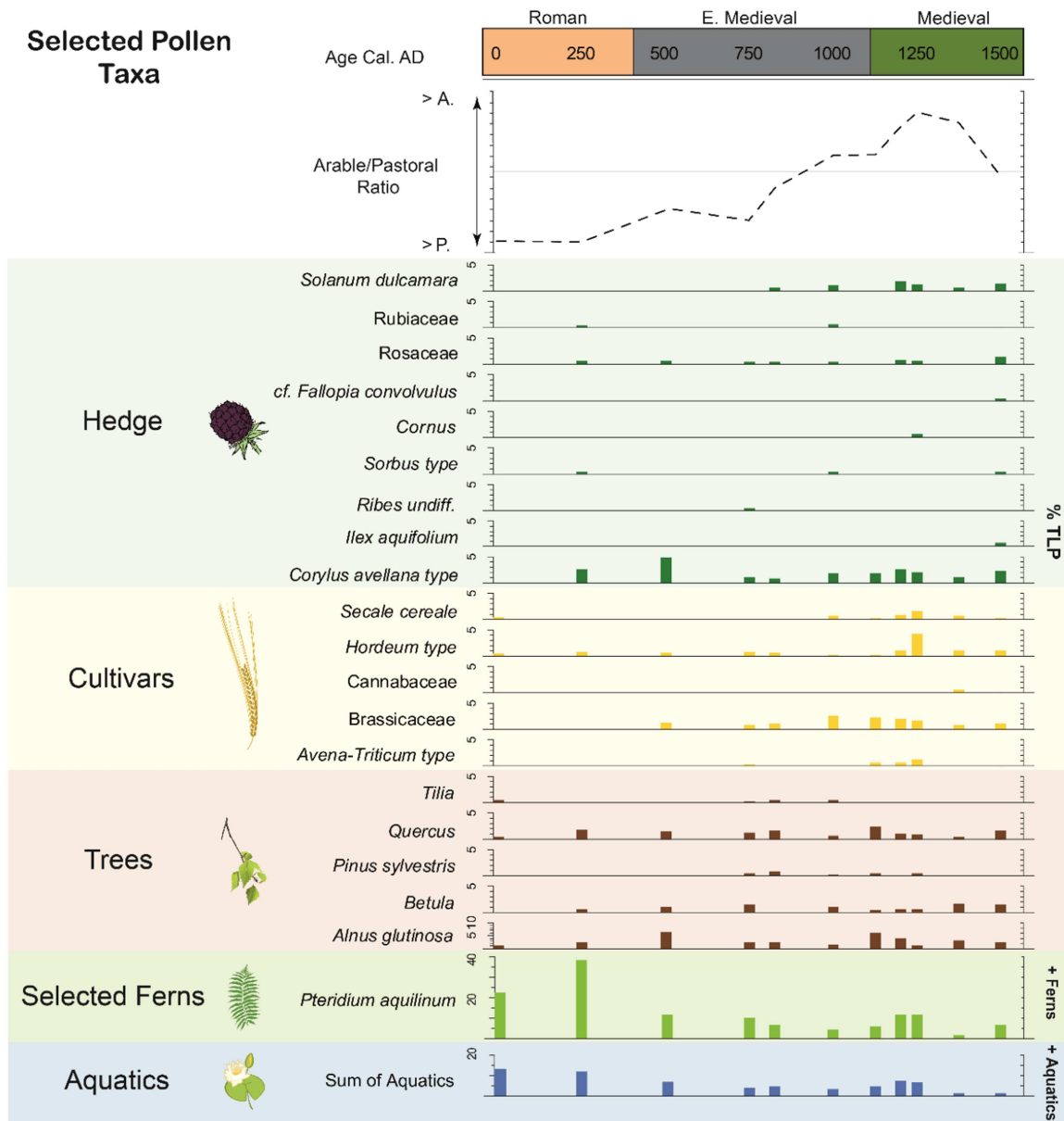


FIGURE 6 | Selected pollen types and land use ratios from sample core C10 from the lower Hatfield Brook floodplain. Full pollen diagram provided in Figure S4.

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

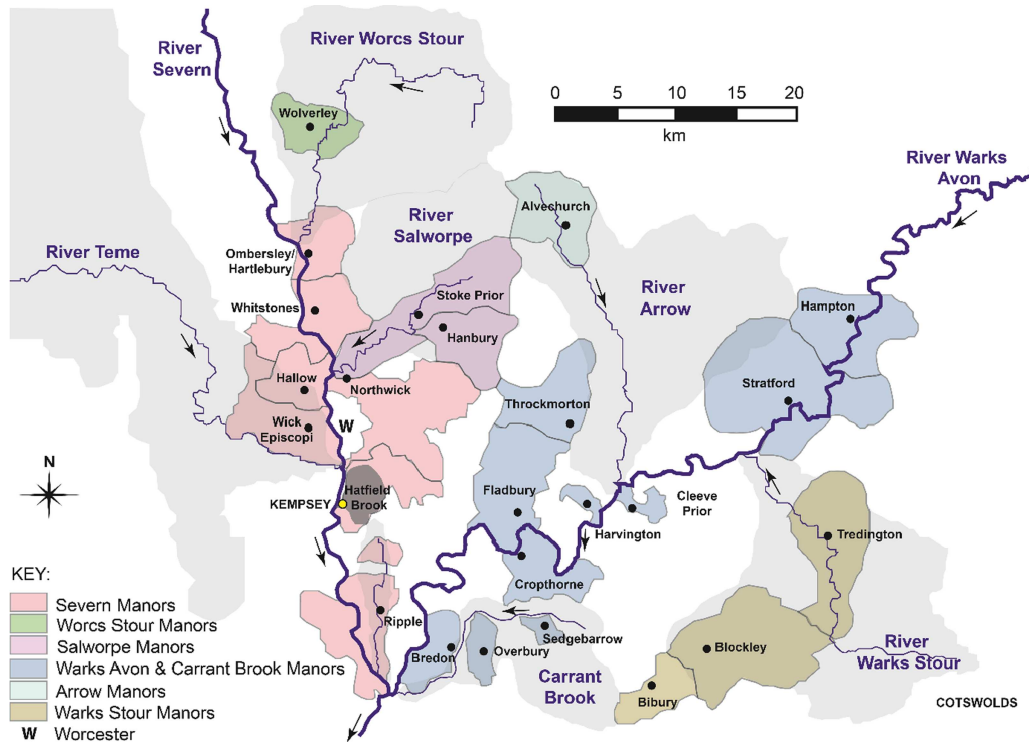


FIGURE 7 | Map of the lands of the Bishopric of Worcester in proximity to fluvial catchments of the Rivers Severn and Avon including small systems the Hatfield Brook and Ripple Brook.

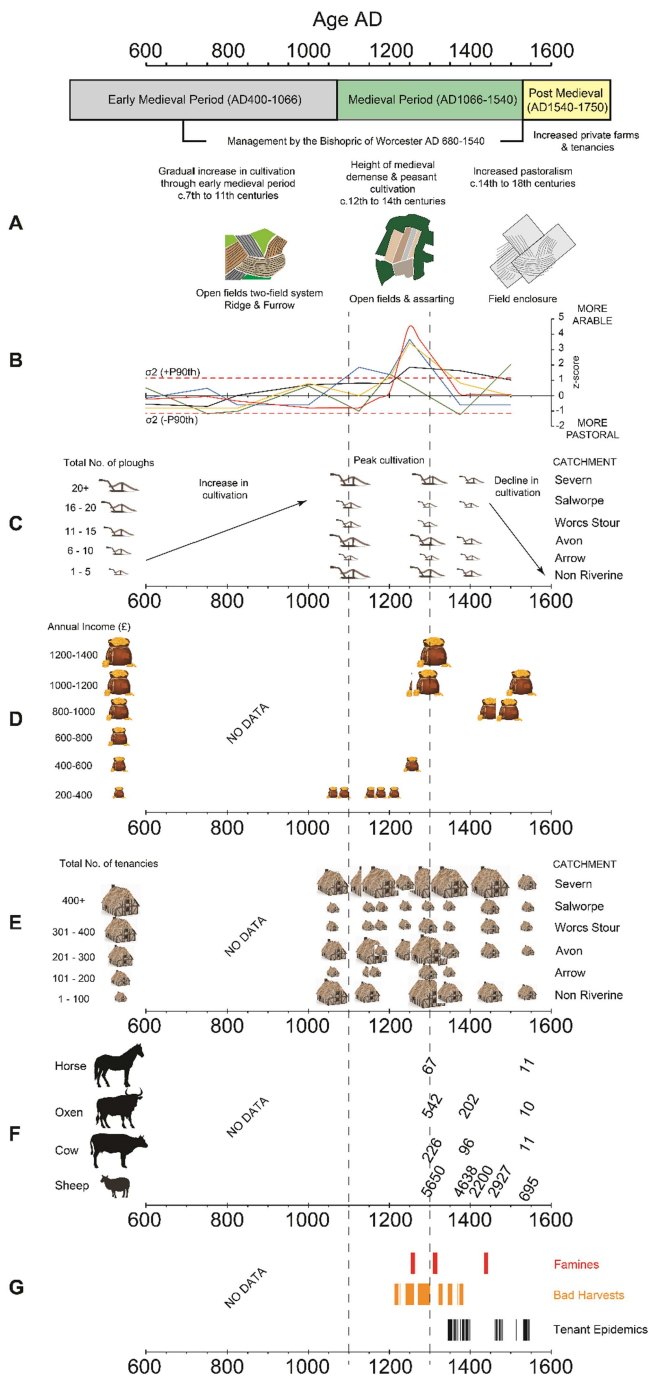


FIGURE 8 | Summary models of historic land use, palaeoenvironmental and economic history data from the Hatfield Brook and neighbouring manorial areas between AD 600–1600 including (A) Hatfield Brook catchment historic land use; (B) Hatfield Brook arable:pastoral ratio with Herbs; Hordeum, Secale; Avena/Triticum; (C) Total demesne ploughs at manors by major river valley from AD 1086–1389 (Dyer 1980; Hamshere 1980); (D) Annual income (£) 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 km² of sediment (using an average bulk density of 1.6 tons m³) the vast majority of which is post-Roman in age. This corresponds to an annual mean rate of 38.4 tons km² year⁻¹ or between 26.2 and 50.6 tons km² year⁻¹ using 1 σ 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 km² year⁻¹). In contrast, this value is significantly lower than the Rivers Perry, Teme, Arrow and Herefordshire Frome, (c. 90–129 tons km² 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.

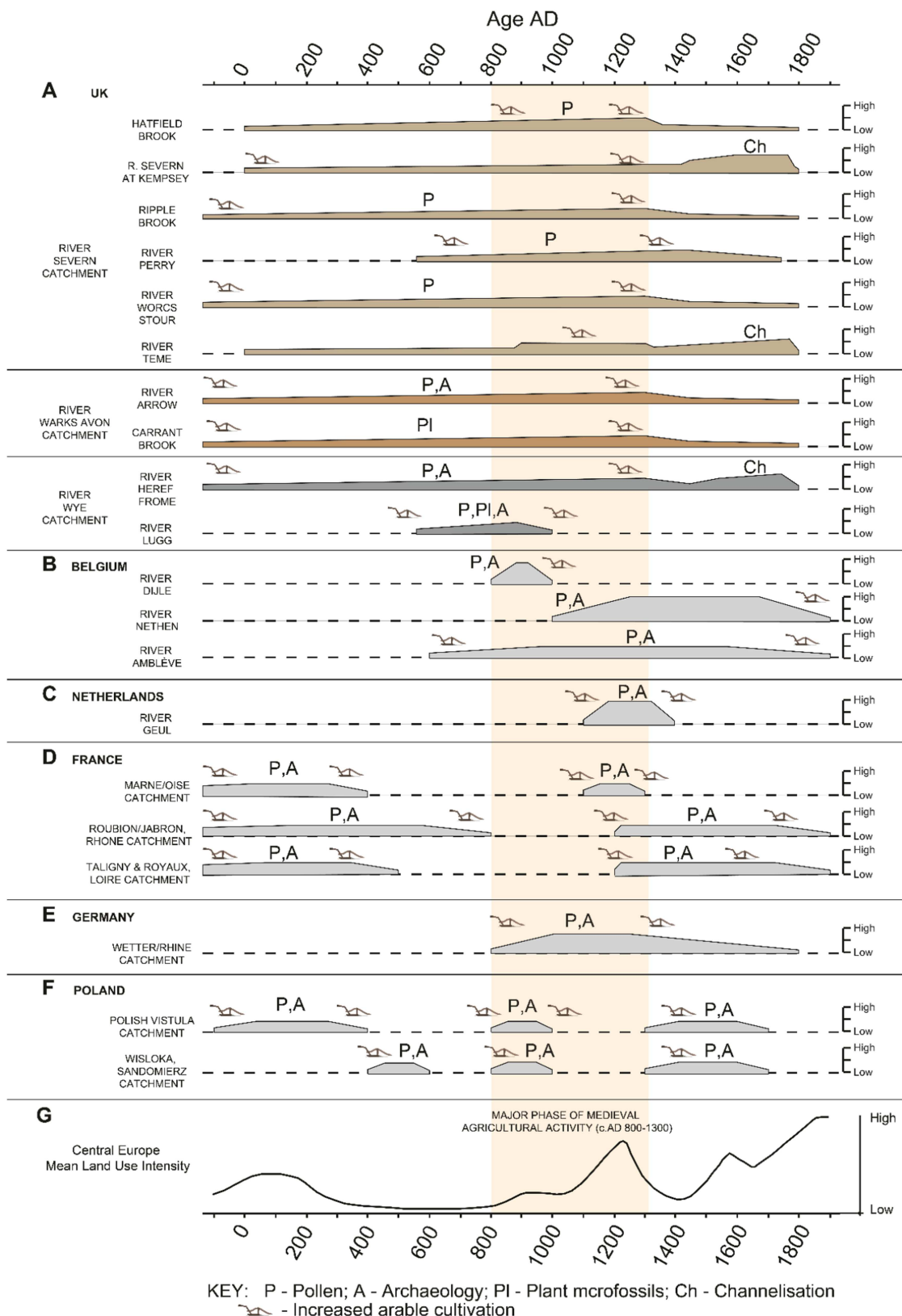


FIGURE 9 | Modelled historic alluviation, environment and land use in the Hatfield Brook and comparative catchments from mainland Europe between AD 0–1800. (A) (this paper; Pears et al. 2023; Brown and Barber 1985; Brown 1990; Brown 1988; Pears et al. 2020a; Shotton 1978; Palmer 1999; Greig and Colledge 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 km² year⁻¹. In contrast, the Dijle catchment has a considerably higher figure of 90–210 tons km² 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 Hoan 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

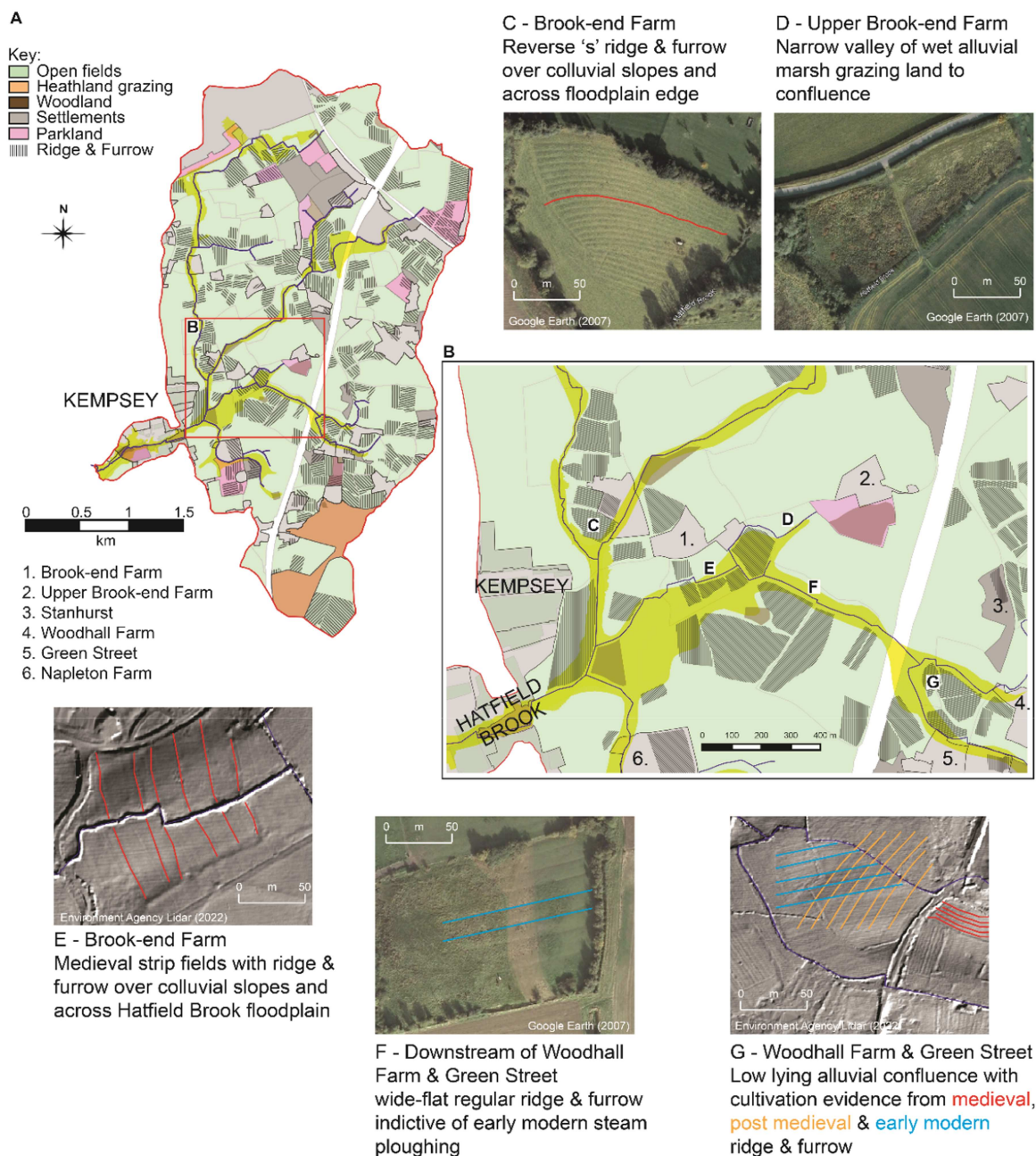


FIGURE 10 | Examples of historic land use evidence present in the contemporary landscape (A), with particular focus on the Hatfield Brook area to the east of Kempsey (B). Including (C) medieval ridge and furrow (Google Earth 2007); (D) marshland grazing (Google Earth 2007); (E) medieval strip fields 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.

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Supporting Information

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