Geoarchaeology Review Paper

Medieval Environmental Impacts and Feedbacks: The Lowland Floodplains of England and Wales

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Because of their varying channel styles (braided, meandering, and anastomosing) medieval lowland floodplains in England and Wales provided varying opportunities for defense, settlement, river crossing, and resource exploitation. In turn, these activities altered the character of channels and floodplains, with medieval and later development obscuring the former variety of floodplains themselves. The changing nature of river floodplains is reviewed using archaeological, documentary, and geomorphological evidence. Anastomosing channels and floodplain wetlands have now all but disappeared but were formerly of considerable significance; also discussed are interactions involving flooding, fording, bridging, modifications to channels and their dimensions, and those arising from accelerated soil erosion—most of which peaked in the medieval period when floodplains were significantly transformed. Deliberately or inadvertently, dynamic floodplain landforms were interactively involved with human development during a critical time period in a totality of ways not previously fully identified. © 2010 Wiley Periodicals, Inc.

INTRODUCTION

The lowland landscapes of England and Wales were a focus for change in the medieval period. At the time the population probably trebled and towns were growing apace; improving transport and a range of technological innovations supported a growing commercial and agrarian economy. Landscapes designed for impressive appearances, including parks and building surrounds (so-called "elite landscapes"), were also becoming more common. The physical environment of rivers and valleys in which these changes were set has often been viewed as a relatively passive backdrop to human enterprise, appearing then much as now, but without the intentional constructions and manipulations involved in such activities as extending crop cultivation, wetland reclamation, river bridging, channel engineering for milling and transport, and urban growth. But, then as now, geomorphological processes were both active and variable, and they operated in parallel with development. The passage of

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time and later rural and urban change may have obscured the evidence, but at the time fluvial transformations must have affected decision making, with quasi-natural processes also being affected by what was happening.

Today there is much more urgent concern with human–environment linkages and the impacts which current economic development may involve—whether in the form of industrial pollution, through responses to rising water demand and waste disposal needs, or following the impact of energy use on climatic change. Decision making and action take place in what is also known to be an environment under transformation, whether or not the causal linkages and consequences involved are fully understood. Although the nature and degree of environmental interaction may be dissimilar, and at the time knowledge about the matter was very much less assured, two-way interactions between human enterprise and environmental change are also likely to be true of long-past periods of development.

In this context, this paper focuses on the medieval floodplains of lowland England and Wales (Figure 1). Larger river floodplains are found below 200 m both marginal to the uplands of Wales, the Pennines, and in the southwest, and in the gentler topography of the southeast. Table I ranks the ten largest rivers; none of them actually is large by European standards, let alone in global terms, but their channels and floodplains and those of smaller rivers were highly significant for medieval activities. Major coastal wetlands like the Fenlands, Somerset Levels, or Humber Wetlands were also significant, but are not here reconsidered in detail (for recent surveys, see Van de Noort, 2004; Blair, 2007). The timespan discussed (ca. A.D. 800–1500) relates to available evidence for, or pertinent to, the period from Saxon times up until the Tudor period.

As crucial human resources, medieval rivers and floodplains became inadvertently self-modified as intentional developments proceeded. Catchment, river, and floodplain were parts of variable, dynamic, linked, and interactive systems which were simultaneously adjusting, in different ways and to different degrees, to the effects of human actions. The assumption that, shaved of their built environment elements, floodplains and river channels at the time had much their present form has to be questioned. The paper also examines whether their systematic variety at the time (now much concealed and overlain) played an important role in medieval development, and whether unintended environmental impacts had significant feedback effects on intentional development activities themselves. The approach is virtually the reverse of that usually central to medieval archaeology and history, that of needing to interpret the past as people at the time would have seen it. Instead, a rich body of archaeological, historical, and geomorphological research is synthesized to support a modern geoscience perspective on evolving floodplains in the medieval period, something that would at best have been differently and only tangentially appreciated at the time.

FLOODPLAIN AND RIVER CHANNEL STYLES

Rivers and their floodplains have been characterized in terms of a number of prototypes which relate to their discharge regimes, their available energy, and their bed material and finer sediment loads (Schumm, 1977; Brice, 1984; Ferguson, 1987;

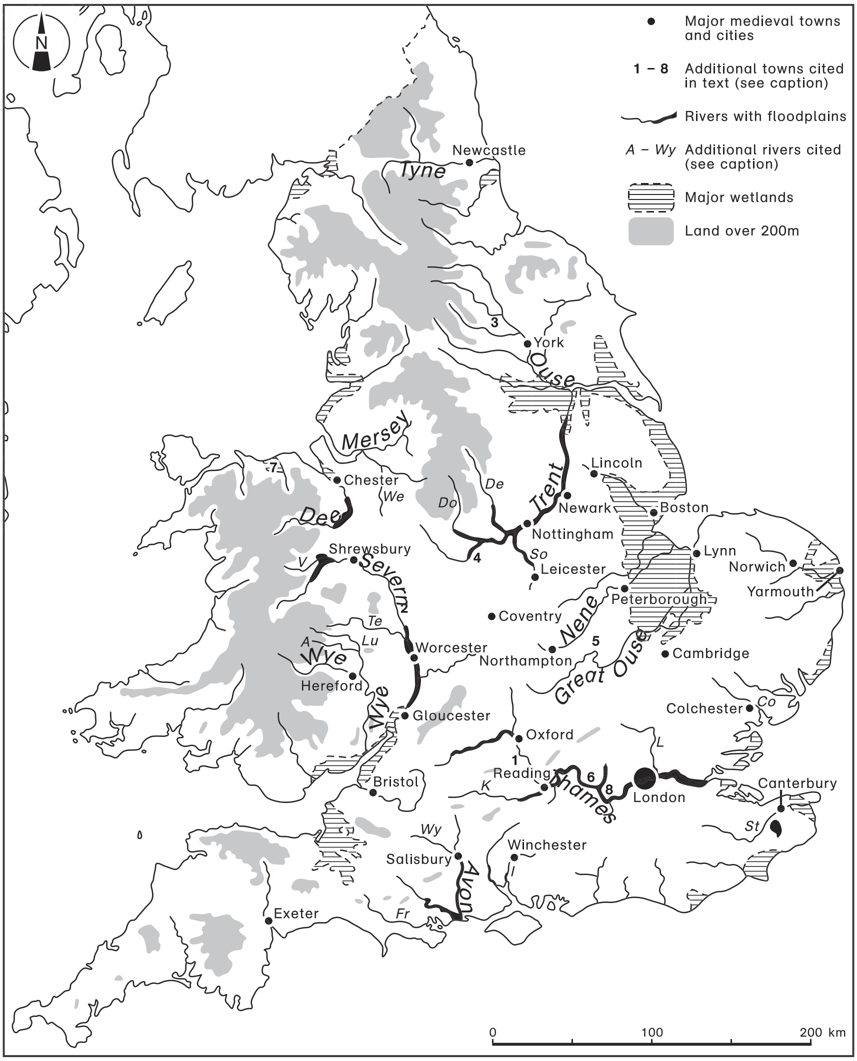

Figure 1. Major lowland rivers with floodplains in England and Wales. Additional places cited in the text: 1: Abingdon; 2: Bewdley; 3: Boroughbridge; 4: Burton-on-Trent; 5: Huntingdon; 6: Maidenhead; 7: Ruddlan; 8: Staines. Additional rivers: A: Arrow; Co: Colne; De: Derwent; Do: Dove; Fr: Frome; K: Kennet; L: Lea; Lu: Lugg; So: Soar; St: Stour; Te: Teme; V: Vyrnwy; We: Weaver; Wy: Wylye.

Knighton & Nanson, 1993; Miall, 1996; Nanson & Croke, 1992; Nanson & Knighton, 1996). Qualitatively, the now rather large number of recognized floodplain styles may be allocated to 16 fluvial models (Miall, 1996) or 15 orders and suborders (Nanson & Croke, 1992), with six styles of anabranching river alone (Nanson & Knighton, 1996). With increasing knowledge, the number of prototypes has proliferated, as have the

Table I. The largest rivers in England and Wales in terms of length, catchment area and mean annual discharge. The top ten rivers are listed in order according to the sum of their ranks by each criterion (data from Ward, 1981).

River	Length (km)	Area (km^2)	Mean Annual Discharge ($m^3 s^{-1}$)
1. Thames	239	9950	67.40
2. Trent	149	7490	82.21
3. Wye	225	4040	71.41
4. Severn	206	4330	62.70
5. Yorkshire Ouse	117	3320	40.45
6. Aire	114	1930	36.89
7. Tyne	89	2180	43.45
8. Dee	116	1370	35.70
9. Eden	102	1370	31.02
10. Ribble	94	1140	31.72

factors believed to make a difference in determining the styles observed. Now included are the presence of riparian trees and aquatic vegetation, river bank composition and stability, and the activity rates for the separable river processes which underlie the development of what are composite prototype assemblages. These involve the variable degrees and types of lateral channel mobility through bank erosion and deposition, vertical river incision or sediment accretion, channel bar formation, cutoffs and avulsions, levee development, overbank sedimentation, and organic wetland changes.

The provision of simple quantitative causative criteria for forecasting and discriminating between the domains of the main observed channel patterns has been frequently attempted, though not with the greatest of reliability (Ferguson, 1987; Lewin & Brewer, 2001; Latrubesse, 2008). Further complexity is provided by the fact that channels and their floodplains are historically contingent: Channel patterns can change within an inherited floodplain form, as in the case of parts of the Vistula River system in Poland, at first braided and then incised in the 18th to the 20th centuries, but all set within a dominantly meandering Holocene alluvial system (Starkel, 1982). In England and Wales, evidence suggests that soil erosion has flooded systems with fine sediment, creating tabular floodplains on top of a former, more varied topography of channel bars, levees, cutoffs, and wetlands (Brown, 1983; Robinson & Lambrick, 1984; Parker et al., 2008; Jones, Macklin, & Lewin, in press).

In this kind of context, medieval people would, of course, have been concerned with practicalities—possibilities for defense, the depth of river crossings and the ease of passage across floodplains, bridge building and the maintenance of structures once installed, mill siting, and the quality of floodplain agricultural land. Addressing these past practicalities directly, even with the benefits of science and hindsight, is not entirely straightforward, although there is some guidance to be had from consideration of the variable alluvial styles that were present at the time, together with the factors that were affecting them.

Table II presents a simplified four-category approach to channels and floodplain styles relevant to the medieval exploitation of lowland environments of England and

Table II. Lowland river channel and floodplain styles.

A. Braided
Unstable, high-energy (or steep-gradient), large width–depth (W/D) ratio branching systems with islands and mid-channel bars of coarser bed material which evolve by lateral growth/erosion; bars may also migrate downstream. High proportion of sediment load moving as (coarser) bed load. Courses change from flood to flood, including avulsion, bifurcation, and lateral migration. Generally one or two main active channels at any one time, but also extensive spreads of bed sediment with dormant channels which may be re-occupied in flood flows. Complex floodplain relief of old channels and bars. Relatively easy to cross at low flow, with a firm bed and without deep banks, but hazardous at high flows, with high water velocities and a changing bed. Absent from contemporary U.K. lowland environments. Some formerly active sites, otherwise most commonly present as Pleistocene gravels at base and margins of medieval floodplains.

B. Active meandering
Single channels in some ways similar to the above, but with lower stream power and W/D ratios. Mobile channels shift laterally with loop development, cutoffs, and other realignments. Channel morphology varied at the reach scale. Steep cut-bank profiles with pools at bends, and gentler, sedimenting point- and side-bar locations. Some slack-water margins. Shallows between bends (riffles) may be crossable and remain relatively fixed in position for a matter of years. Occasional islands, and floodplain relief reflecting former channel courses (cutoff channels and ridges and scrolls). Old channels may temporarily remain water-filled or as small-scale wetlands. Levees not prominent because of the shifting channel, which may sweep across and relocate anywhere on the floodplain on a timescale of decades to centuries. Common in higher relief upland-transition environments. Active zone may form part only of the total floodplain.

C. Inactive meandering
Sinuous courses with narrower and deeper channels (Brice, 1984, called them "canaliform"). Lower stream powers and a high proportion of suspended sediment load. Remain in approximately the same location. Floodplains commonly blanketed with fine overbank flood sediments, with levees along the channel where there is a sandy component to the sediment load. Where there is channel-zone aggradation, river and levee may be elevated above general floodplain levels, producing valley-margin wetlands. Very common in modified form, following accelerated soil erosion, in present-day U.K. lowlands.

D. Anastomosing
Low-gradient, low W/D ratio, aggrading and generally stable branching systems transporting fine sediment (sand to clay). May have aggrading channel margins with sandy levees, and new channels formed by avulsion, though this happens rarely. Interchannel wetlands. Individual channel branches may be meandering (with bend radii proportional to channel size) or of relatively low sinuosity. Especially vulnerable to blockage by trees and macrophyte plants which trap sediment leading to channel change. Rare in U.K. today, particularly because of human modification, but common in major wetlands and in valley floodplains historically, possibly in partly fossilized form in medieval times.

Wales. The objective here is to provide a minimal framework for considering environmental opportunities and impacts in the context of the societal transformations taking place. Fuller detail of alluvial styles is well presented in Brown (1997). Figure 2 gives graphic illustrations, while Figure 3 and Table III distill system elements and measures that were likely to have been of practical medieval significance. The important point to appreciate is the variety of lowland riverine environments, each presenting different challenges and opportunities. At least in part, these were themselves then liable to change as a result of human activities.

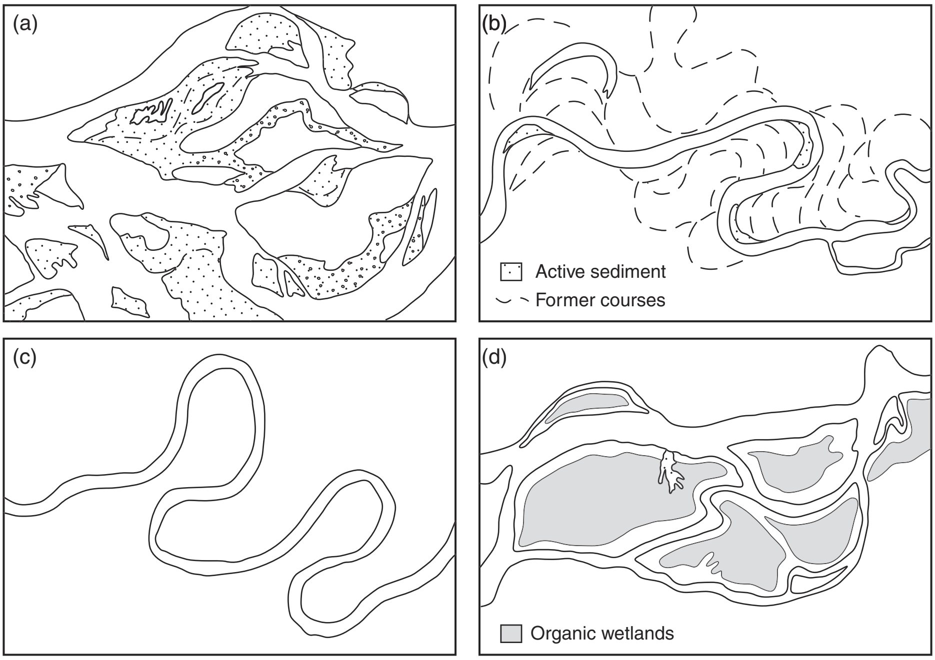

Figure 2. River channel styles: (a) braided, (b) active meandering, (c) inactive meandering, (d) anastomosing (see also Table I).

I.The channel(s)
(a) Fast-flowing or deep water
(b) Slackwater zones in main or separate channels
(c) Stable crossing points/emergent bedforms (riffles, mid-channel, side and point bars)
(d) Divided channels

II. Channel margins
(a) High and steep bank profiles
(b) Natural levees
(c) Actively eroding banks

III. The floodplain
(a) Overbank fine sediment cover and cultivable soil
(b) Relict bedform relief
(c) Abandonned channels and their fills
(d) Organic wetlands and ponds

Figure 3. Channel and floodplain elements affecting human use and passage.

Table III. Representative measures for present-day channel characteristics.

	W/D Ratio	Gradient/Specific Streampower	Bed Material	Dominant Features (see Figure 3)
A. Braided	>20	>5m km^{-1}, >100 W m^2	gravel	Ia, b, c, d, IIc, IIIb, c
B. Active meandering	5–20	>2m km^{-1}, 10–100 W m^2	sand/gravel	Ia, b, c, IIc , IIIa, c
C. Stable meandering	<15	<3m km^{-1}, <50 W m^2	sand/gravel	Ia, IIa, b, IIIa, d
D. Anastomosing	<15	<2.5m km^{-1}, <20 W m^2	sand/gravel	Ib, d, IIb, IIIc, d

THE MEDIEVAL GEOGRAPHY OF LOWLAND FLOODPLAINS

The four alluvial styles above may, at least theoretically, be found in sequence down valley as gradient and streampower decline and sediments become finer. *Braided channels* are not now to be found in lowland valleys in Britain; they were present in upland valleys in the 19th century and earlier (Passmore et al., 1993), while lowland valleys are underlain by partially buried Pleistocene gravels which are commonly believed to have been the product of cold-climate braided rivers. These remain at the surface in the form of terraces, paleochannels, and upstanding "islands" (former bar complexes) partly submerged by later sediments. These often formed the basis for early settlements and "stepping stones" for river and wetland crossing (Booth et al., 2007). The gravelly channel of the middle Trent may exceptionally have been braided in medieval times (Brown et al., 2001); to judge from historical maps, some active channel shifting continued on through the 19th century at river junctions (Trent/Dove, Trent/Derwent, and Trent/Soar; see Figure 1). An ongoing history of channel scour and fresh gravel deposition on the Trent before it was regulated is supported by biological and documentary evidence (Challis, 2004; Greenwood & Smith, 2005).

Active meandering is (and probably was in medieval times, if not converted to braiding) generally characteristic of upland valleys, though extending into lowland environments along rivers like the Dove; the Bollin, and the Dane coming from the Pennines to join the Mersey; the rivers draining the eastern Pennines to join the Yorkshire Ouse; or the Severn, Vyrnwy, Wye, Teme, Lugg, and Arrow in the Welsh Marches. Higher-energy streams draining Exmoor and Dartmoor were the equivalent in the southwest, while some chalkland streams like the Frome in Dorset continue to be laterally active today. These rivers may shift at the rate of a meter or more a year today, and the medieval channels did likewise, and so may have been considerably distant from their present positions.

But most truly lowland medieval rivers appear to have been either *inactively meandering* or *anastomosing*. There is much hitherto uncollated evidence to suggest that the last multichannel (anabranching) style was of far greater significance then than now, though different from much more active braided channels in steeper valleys. Tudor maps are about the earliest cartographical source at an appropriate scale that we have (Harvey, 1993; Delano-Smith & Kain, 1999), but there seems no great reason to doubt that what they depicted had survived from the late medieval period. The same applies to Speed's (1611–12) county maps and town plans, some repeating the detail of Saxton and other earlier cartographers (Ravenhill, 1992). These show many anabranching rivers and reaches that can be related to Leland's earlier descriptions, to later maps, and to relict channels still visible in contemporary remote sensing imagery (Table IV).

Along the Lower Thames, tributary rivers characteristically had multi-branching lower reaches, sometimes quite extensive, where their gradients dropped under the influence of the main river. Not to be unexpected geomorphologically, this led to anastomosis. Leland described the River Colne (after a journey probably undertaken in 1549):

Table IV. Historically anabranching rivers in England.

Rivers	Reach Length (km)	Floodplain Width (km)	Gradient (m/km)	Sources
Upper Thames (Radcot–Carswell)	4.81	0.78	0.62	4, 5
Thames (Wolvercote–Ifley)	7.25	0.5–0.96	0.55	2, 3, 4
Kennet (Reading)	ca. 4.0	c. 0.7	?	2, 3, 4
Lodden (Twyford)	2.53	0.34	0.79	3, 4
Wey (Woking)	2.76	0.52	0.72	3, 4
Colne (Denham–Staines)	15	0.72	1.9–1.45	1, 3, 4
Lea (Waltham Abbey–Blackwall)	27.5	1.26	1.14	1, 3, 4
Medway (Tonbridge)	5.3	0.41	0.94	4
Great Ouse (Huntingdon–St. Ives)	7.04	0.78	0.68	1, 4
Nene (Northampton–Oundle)	35	0.42–1.02	0.41–1.6	4, 5
Soar (Leicester)	3.4	0.5	1.4	2, 3, 4
Trent (Nottingham)	ca. 7.0	2.8	0.3	2, 3, 4
Trent (Newark)	4.49	2.47	0.45	1, 4
Itchen (Worthy–Eastleigh)	6.74	0.53	2.5	2, 3, 4
Test (Houghton–Dunbridge)	7.39	0.83	1.35	1, 4
Exe (Cowley Bridge–Exeter)	3.71	0.34	1.35	2, 3, 4
Severn (Gloucester)	2.95	1.4	0.68	1, 2, 3, 4, 5

Sources: 1. Speed county maps
2. Speed town plans
3. Leland
4. Remote sensing imagery
5. Others

> At the western end of Uxbridge town are two wooden bridges. The main-stream of the River Colne flows under the more westerly, and the lesser stream under the other. Each drives a large mill there. The division of the River Colne occurs barely a mile above Uxbridge, but the two arms do not rejoin. The larger flows for three miles through good meadows directly to Colnbrook, and so to the Thames. The other goes to two mills on the London road a mile and a half east of Colnbrook, and then likewise into the Thames. (Leland 2, 113/14; translation from Chandler, 1993:310–311)

This checks with both Speed and later 18th- and 19th-century maps. Archeaological evidence at Staines (Figure 1) on the Colne, with its Roman bridges, suggests earlier occupation of gravel islands between marshy multiple-channeled floodplains (Booth et al., 2007). Even in 1770, a map of the Thames and its tributaries downstream of the Kennet by Thomas Jefferys [British Library, Maps C10.c.24 (38)] showed the Colne with as many as six separate branches between Colnbrook and Staines. The valley has now been completely transformed by urban and reservoir development and gravel extraction, with little indication of the former anabranching river.

The lower Lea valley (Figure 1) was extensively anastomosing on Speed maps; it remained so in 1746 (Figure 4), with the final vestiges of multiple channels lasting to this day at the 2012 Olympic site in a form fossilized by railway and industrial development. Indirect confirmation of its medieval pattern is provided by an inquest following a hunting expedition by Edward I in 1277 which prompted royal displeasure. Some 107 bridges in the lower Lea valley should have been in good repair but

Figure 4. The anastomosing course of the River Lea (National Grid reference TQ 3883) in 1746, showing multiple channels and the causeway and bridges at Stratford. From John Rocque's "Survey of London, Westminster, and Southwark and the Country near Ten Miles Round." The lower part of the map shows the confluence of the Lea and the River Thames.

were not: Two were supposed to be 30 feet long, one 20 feet, but most under 10 feet (Cooper, 2006). Harrison called these streams "tributaries" (Harrison, 2004), but anastomosing distributaries within the hunting and hawking marshlands seems a likely technical description, considering both their dimensions and number.

Other larger lowland rivers like the Great Ouse, Soar, Upper Thames, and Trent had some divided reaches. Between Nottingham and Newark (Figure 1), the Trent was anastomosing in Tudor times (British Library, Cotton MS Augustus I.i.65), as it was still in 1646 at the time of the Civil War [British Library, Maps *4670 (1.); see also Salisbury, 1984]. This same reach had been the subject of dispute in 1346 when the passage of boats to Nottingham was impeded by alleged illicit diversion of flow down the Averham branch of the river (Calendar of Patent Rolls, Edward III iii Nov. 20, 1346). The long history of modification and adaptation of an already existing multichannel system has been described at Burton-on-Trent (Tringham, 2003), while later views of the Trent at Burton in 1732 and the Thames at Oxford in 1731 (Hyde, 1994) still show the anabranching channels known to have existed earlier (Dodd, 2003; Tringham, 2003). Maps of the Great Ouse (British Library, Cotton MS Augustus I i 78, and Maps K.Top.1641.1) show channel reaches that were divided in Tudor times through to 1768, as some still are.

The Nene appears to have had extensive anastomosis, to judge from both early survey and archaeological excavation (Jenkins, 1992; Brown, 2009). Leland described his approach to Oundle across a causeway and 16-arch bridge, and he left on another similar structure crossing the Nene further downstream. Despite the fact that channels here were engineered for milling (below Northampton and as far as Oundle, 25 Domesday mills were recorded for valley settlements at an average spacing down valley of 1.6 km), and the main channel was subsequently altered (with locks) for navigation (the engineered waterway opened in 1761), the low-gradient divided course still had a semi-natural anastomosing appearance in the early 19th century, with lengthy split reaches, each with meander loops proportional to their size. There is no reason why natural-looking bends and so many long bifurcated reaches should all have been deliberately engineered. Medieval people, like the Romans before them, could and did engineer new channels (Blair, 2007), but in many instances they did not have to: They adjusted and modified, as appears to have been the case on the Nene.

Another group of former anastomosing channels is to be found in southern England, where proximity to the sea was marked by low valley gradients (Table II), though with single "funnel" channels where dominated by two-way tidal flows (cf. also the lower meandering course of the tidal Lea). Some of these again have been much altered, for example, for water meadow irrigation from the 17th century onward (Cook & Williamson, 2007). Major wetlands and perimarine, tidally influenced environments are not discussed here, but it should be noted that transformation applies on a grand scale to the river systems of the Fenlands and the Humberhead, Somerset, and Severn Levels (Figure 1), following engineering for waterways, land reclamation, and drainage over a very long period (Darby, 1966; Cook & Williamson, 1999; Blair, 2007; Van de Noort, 2004). Here narrow sandy ridges between extensive organic wetlands mark the extensive fossil levees and networks of former anastomosing systems.

To summarize, most larger medieval lowland rivers in England seem to have been inactively meandering or anastomosing; the latter, with multiple courses and wetlands between, have now all but disappeared from the scene. The same also applies to much smaller streams, as at Bordesley Abbey, on the headwaters of the Arrow in Worcestershire, where building over a defunct anastomosing channel system provided a succession of foundation problems for the Cistercians (Astill, 1993). Marginal floodplain fenland along valleys was much more extensive, with marshy reedswamps and minor channels (Booth et al., 2007), making whole valley floors much more difficult to cross than is now apparent. These riverside wetlands were areas of high biological productivity; prehistoric sites appear to have favored them rather than the major extensive peatlands (Van de Noort & O'Sullivan, 2006:36–39). As a resource, they would have formed part of a mosaic of "taskscapes" in medieval times (for discussion of floodplain wetlands and ecology, see Brown, 1997:Chapter 4). In-channel and channel-edge vegetation is also likely to have steered channel development, although it can be difficult to know retrospectively what channel vegetation in medieval times was like at many sites. At some locations, relict Pleistocene braid bars formed drier islands between, or marginal to, narrower anastomosing belts or meandering valley-floor systems. So floodplains themselves represented a combination of systems, some inherited and overlain, and others laid out side-by-side in tributary or adjunct systems next to main rivers. In some places at least, active meandering or even braiding was more important than is now apparent where rivers have been regulated. Channel mobility would also have been more likely in the absence of so thick a unit of overbank fine sediment, a point that will be returned to later. What all this provided was significantly more varied site opportunities for use and for crossing than we now see, and the need for different tactical approaches from medieval people.

MEDIEVAL FLOODS AND FLOODPLAIN DYNAMICS

Floodplains evolve mainly under the influence of extreme river discharges; channels do most erosion and deposition as the channel gets at least near full, while overbank deposition requires even greater discharges. Systems as a whole also change when flood frequencies and magnitudes change, or sediment supply is altered. Archaeological evidence suggests that fluctuations occured in Roman times and subsequently. Plant, beetle, and molluscan evidence points to varying degrees of floodplain wetness, while overbank sedimentation from the influx of soil-derived sediment peaked in Roman and later medieval periods (Booth et al., 2007). In paleoclimatic terms, the present concern is mostly with what happened in what has been called the Medieval Warm Period (ca. A.D. 900–1400). Warmth is evidenced by vineyard production, upland cultivation limits, glacier extents, dendrochronology, and ice-core data (Lamb, 1995). The proxy climatic evidence is not always in agreement, but the period A.D. 1200–1350 may have had rapid fluctuations and both hot summers and cold or even severe winters (Ogilvie & Farmer, 1997; Glaser & Riemann, 2009).

Definitive and direct river evidence for runs of extremes—climatically induced large discharges and flooding, or distinctive floodplain and channel processes and change—is difficult to establish, and the Warm Period appears to have been less globally synchronous and continuous than once was thought (Hughes & Diaz, 1994; Ogilvie & Farmer, 1997; Glaser & Riemann, 2009). In England, for example, extreme events were recorded during the Warm Period in the Anglo-Saxon Chronicles in 1085, 1095, 1109, 1111, 1115, and 1117 (Swanton, 2000), together with crop failures and pestilences that may well have been weather-related. The Great Famine (1315–1317) was associated with a period of severe winters and wet summers (Jordan, 1996:Chapters 1, 2), while ice-floe bridge damage could be significant in winter floods

(Watson, Brigham, & Dyson, 2006). On a local scale, bridges at Burton-on-Trent were flood damaged in 1255, 1284, 1380, 1402, and 1574 (Tringham, 2003). Nationally, pontage grants for bridge repair increased between 1228 and 1400, but there were peaks in the early 1300s, 14 in the years 1334–1335 alone, and these on significant rivers and routes (listings in Cooper, 2006, Appendix 2). There was a lull for around three decades after ca. 1340. These data must be treated cautiously because the incidence and timing of bridge maintenance have social and economic as much as physical causes. Thus, Worcester's suit in 1328 arose because of destruction in war, while the Black Death (1348–1350) caused social havoc and economic disruption, with increased labour costs, difficulties in raising capital, and a decreased demand for transport services. Other extreme event records can be quite precise: Langdon (2004:27) noted four watermills destroyed by a flood at Warwick on October 17, 1315. At that time of year, the flood is not likely to have involved ice or frozen ground, nor an intense but localized summer convection storm, but more likely the passage of a slow-moving autumn depression.

In the round, these records are temporally and regionally fragmented, but at present it does rather look as if runs of wetter weather on a decadal timescale (as in the early 14th century) could be significant in geomorphological terms, although extreme events also produced extreme results on occasion throughout the medieval period. Contrasted weather types give rise to exceptional floods in different ways. There are floods caused both by winter snow and ice melt (or rain on frozen and snow-covered ground, as in the 1947 floods) and by slow-moving depressions involving large warm and moist air masses, facilitated by prior ground saturation. These floods are regional (>ca. 10,000 km^2) in scale, with high-intensity rainfall cells within them. Small catchments are at risk from more localized (<ca. 100 km^2) convective downpours in summer. It is quite likely that runs of individual floods of a particular type and spatial scale occurred more often at certain periods, but this is not directly revealed by the annual or decadal averages to which crop cultivation limits, glacier fluctuations, and seasonal surrogate indices bear witness. If available, flood level epigraphic records can be coupled with reconstructed floodplain topography and hydraulic roughness to give discharge estimates for extreme floods. Herget and Meurs (2010) have used such an approach for Cologne, where a disastrous flood on the Rhine in 1372 overtopped the city walls. Such evidence has yet to be found or exploited for the medieval period in England and Wales.

More persistent floodplain wetness (rather than individually large floods), as indicated from Roman times onward by biological evidence, later coupled with sedimentation (Booth et al., 2007), appears especially to have been brought about by purposeful human activities exploiting an agricultural landscape and modifying the variety of river and floodplain styles as seemed appropriate at the time. It is reasonable to argue that at this time these were more significant than externally determined climatic fluctuations in achieving medieval change to the physical environment itself—even though this was mainly achieved through the medium of high-flow events (Macklin, Jones, & Lewin, 2010). How rivers and floodplains suited, or got in the way of, medieval purposes will next be re-examined in this light.

RIVER ENVIRONMENTS FOR DEFENSE

Medieval towns and defended places had varied origins and strategic sitings involving, for example, contrasts between those inheriting and refurbishing dry sites on river terraces, like that of Roman Gloucester, and others with wetland locations, notably of some Saxon burhs (Schofield & Vince, 2003; Creighton & Higham, 2005). Canterbury and Winchester, initially Roman sites, both occupied anastomosing river sites, one river branch passing within the medieval walls and another without. Similar European sites (including ones which later became major cities, like Hamburg or Cork) are quite common as post-Roman settlements.

Wetland and bank and ditch combinations preceded walling as defensive means for most nascent towns and the later Norman castles that were implanted to dominate them. In practice, later town "defenses" turn out to have been highly varied, many being discontinuous barriers and without masonry walls, with staged extensions and suburbs beyond (Creighton & Higham, 2005). Many towns that later prospered were also on large navigable rivers, some (like York and Bristol) extending their walls to incorporate land on either side. In general it was a combination of factors that probably mattered: A major river could be important for both transport and defense, while a ford or bridging location controlled traffic on both road and river. Not that fording points were necessarily that rare; Eckwall (1960) listed 550 English place names involving "ford," and only a few grew to be large towns. It was larger rivers and the barrier of extensive wetlands that provided strategic opportunity.

Wetlands as well as walls were a considerable defense asset when required, making assault difficult and mining locally impossible in waterlogged ground. In a violent age, as in the 12th century in particular (Bisson, 2009), both defense and intimidation were involved. Contemporary accounts of actual sieges (Warner, 2004) were quick to report on the advantages of watery defense, as in the siege of Oxford in 1141 or of Cricklade in 1142 in the reign of King Stephen. Radcot Castle on the upper Thames was so surrounded by marsh as to be thought inaccessible, a very different situation from the state of the floodplain site today. The marches and armed encounters of this period of conflict and in the Wars of the Roses both suggest that floodplains of even quite small rivers were much more of a soggy barrier than their present topographies suggest.

For towns, a strong "promontary" site could include a river on one side joined by a wetland stream on another, the latter providing water for everyday purposes and milling as well, as at Northampton (Figure 5). The site well illustrates on a small scale the tributary/main river combination of channel pattern seen on the Lower Thames and its tributaries. At the comparable site of Worcester, initially a defendable burh beside its cathedral church to which extentions were made and a Norman castle insensitively added in the monks' graveyard (Baker & Holt, 2004), the Severn was joined by the insignificant but defensively useful and marshy Frog Brook (with its mill). The stream was of limited other use. The monks later had to bring clean water in an aqueduct from across the Severn itself. To avoid contamination, town ordinances from the reign of Edward IV specified the different parts of the main river banks which were to be used for what would otherwise be conflicting purposes (translation in Mortimer, 2008:229–232).

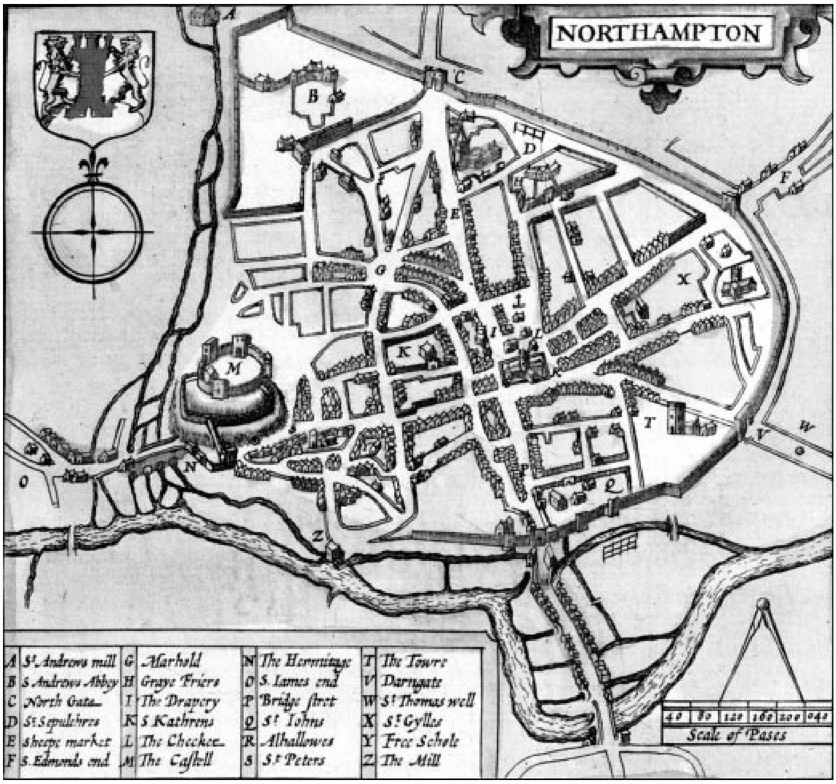

Figure 5. Speed's 1610 map of Northampton (SP 7560).

No town site proved to be perfect, but a dryland site with a combination of main-river and wetland boundaries, augmented by artificial ditches as necessary, and later by walls in some cases, was a usefully defendable and practical one. As in Italy (Squatriti, 1998:74), medieval wetlands were useful for reeds, rushes, wildfowl, and peat-cutting as well as defense. Topographically constrained sites, in all probability chosen to be so, were small in size (Barley, 1976). Judging by the lay returns of 1334 (not including London, and without data for Chester), the 20 most wealthy towns were based on walled or defensive enclosures averaging 76.5 ha. Without the exceptional size of Norwich (388.6 ha), this average drops to 59.2 ha (data from J. Kermode and A. Dyer in Palliser, 2000). This initial smallness had consequences, particularly when intramural space was used up for ecclesiastical or, in the largest enclosures, even for agricultural purposes (Hinton, 2000). Medieval town growth came to incorporate or leapfrog peripheral wetlands, rivers, and floodplains—to such an extent that these were to become environmental problems as much as the locational assets they had been in the first place.

FORDS AND BRIDGES

The earliest English topographic maps available (including Matthew Paris's maps of Britain and the Gough map of the 13th and 14th centuries) are dominated by towns and the rivers that were to be visited and crossed. A choice of route can be regarded as a choice of river crossings (Cooper, 2006:2). However, routes imply a destination, with travellers being driven by a variety of purposes including governance, pilgrimage, and commerce. It could be argued that "bridging points" represent a compromise between site suitability (in terms of available technology) and local or national connectivity frameworks (Hindle, 1982), with the growing commercialization of the Middle Ages driving a supralocal community hierarchical communications network of increasing density. However, the physical variability of ford and bridge sitings has hardly been considered at all.

A few difficult sites were critical for long-distance travel (for example, the Thames at London and Staines, the Trent at Nottingham, the Nene near Peterborough and Wansford, the Great Ouse at Huntingdon, and the Yorkshire Ouse and its large tributaries; see Figure 1). Elsewhere, and to judge by early English place names that have survived, there was probably no shortage of viable low-flow crossing places. Eckwall's many "ford" name elements (Eckwall, 1960) may be further qualified by reference to type, as in Bradford (broad-), Fulford (foul-), or Langford (long-) (Gelling, 1984). Many lowland rivers were gravel-bedded at known crossing sites, affording a good cobbled roadbed for fording traffic, although following the later narrowing and deepening of urban rivers (see below) this may not now be apparent. This was not true of the sand-bed channels of both the major wetlands and the lower reaches of anastomosing rivers. These would have been both relatively deep and narrow and especially treacherous for wheeled vehicles sinking into the river bed if the passageway was not stone-lined and well marked. Valley wetlands between channels were themselves also difficult to cross. Unsurprisingly, medieval road-based traffic generally kept a little upstream of the lowest reaches of the anastomosing Thames tributaries, and national itineraries as far as possible kept away from crossing major low-gradient sand-bed channels—as well as, of course, keeping clear of the major wetlands themselves. Nevertheless, sets of divided channels have the one obvious advantage that smaller channels are individually easier to bridge or even to walk across if small enough. Particularly helpful would have been gravel islands (the remnant Pleistocene river braiding features) sticking up through the shallow anastomosing systems of the Holocene.

At least at low flows in summer, shallower actively meandering or braided channels had banks and beds that allowed them to be forded much more easily. Summer spates could nevertheless create concealed scour holes in which it was possible to drown (Challis, 2004). Fording layouts differed in detail. Typically on actively meandering channels, the shallows associated with gravel bars or riffles (for this is what provides the fording opportunity) occur at crossover points between bends or even more frequently, with the outer bends themselves being associated with steep cut banks and deep pools and therefore best avoided. To ford the river, a track could make its way down a valley side onto a relatively dry point bar, but then reorient up- or

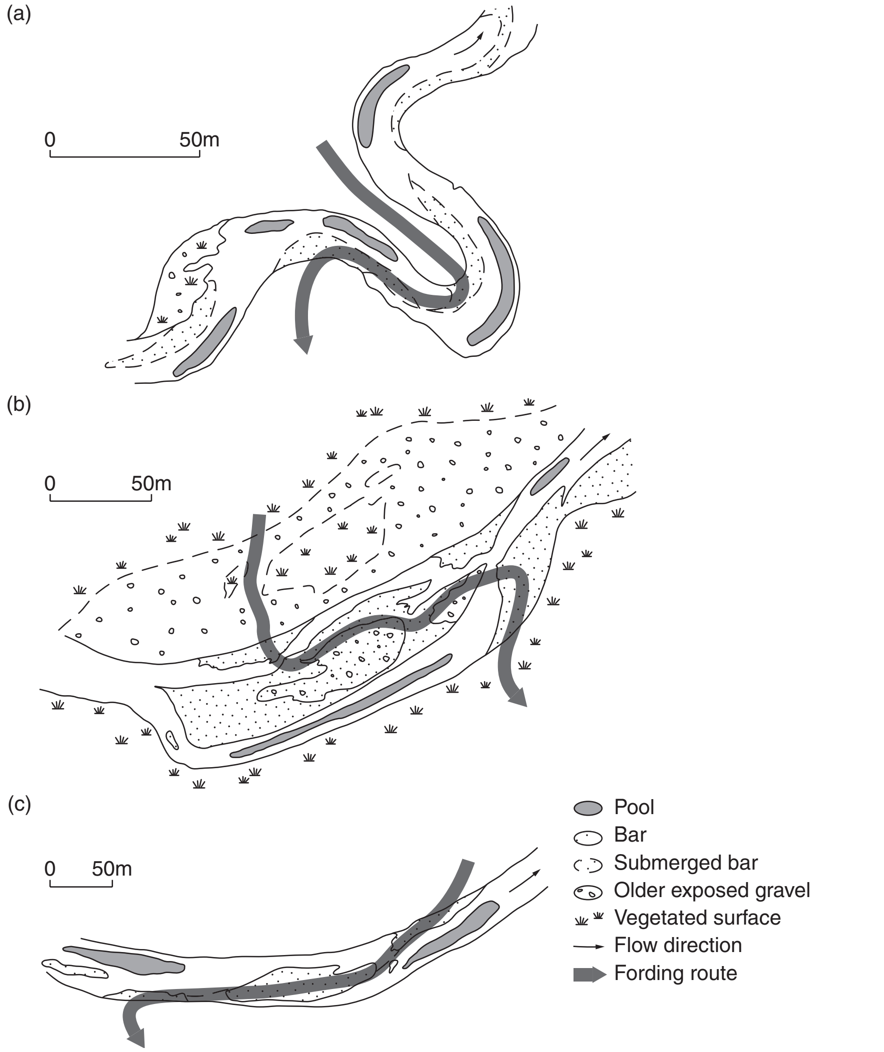

Figure 6. Illustrations of shallow-water river crossing potential: (a) a meandering reach (River Frome in Dorset, SY 8987); (b) a braided reach (Afon Ystwyth in Ceredigion, Wales, SN 7473); and (c) a straight reach with long diagonal bar (Afon Tywi in Carmarthen, Wales, SN 74303).

down-valley to cross the channel at the shallowest point, reorienting again when the river was crossed (Figure 6a). Because the meandering channel itself shifts over a matter of decades, the ford track shifts with it, becoming overtaken and buried under later (point bar) sediments.

This seems to be confirmed by historical evidence for larger rivers that were subsequently re-engineered for navigation. There are around ten bends between Bewdley and Upton on the Severn, some being less well developed and confined by river terraces. In 1858 it was reported that there had been 20 "fords" (as they were actually called) before the locks were built and the channel modified (Trinder, 2005:9). On the Trent between Twyford and Cavendish Bridge, a mid-18th-century survey [British Library, Maps C10.c.24 (7)] shows pairs of named "shoals" at the cross-overs between bends ("Oven Mouth" and "Norman's Friend," "Kingsmill" and "Old Barn," and "Mill" and "Folly" shoals). These were clearly as well known to navigators then as pools and riffles are to fishermen today. Use (or attempted use) of 14 fords further downstream in the Trent valley, in an area centered around Nottingham and Newark, is demonstrated by drownings recorded in coroners' inquests between 1485 and 1558 (Challis, 2004). There were many more active fords than place name evidence is able to confirm. In a regional sense, ford settlement names do concentrate along meandering rivers—such as the Upper Thames in Oxfordshire, the Wylye in Wiltshire, the Frome in Dorset, and the Great Ouse in Bedfordshire—where cobbly or stony channel-bed conditions for fording rivers look to have been good. The chalklands of southern England are particularly distinctive. Chalk itself provides little fine sediment, and larger particles are rapidly broken down by abrasion (Lewin & Brewer, 2002), but the flint nodules the rock contains are very resistant, and the result is clear-water cobble-bed streams.

With braided reaches, multiple shifting bars may appear less systematically arranged, but low-flow crossing of shallow channels may not be difficult, even though the fording line may need to zig-zag to cross several active and "dead" channels and bars, which get rearranged from one high flow period to the next (Figure 6b). But again the place name evidence does not reveal this, and it is unlikely that there were many braided reaches in lowland England and Wales in any case.

Where there are longer straight reaches without major bends, bed sediment accumulation may occur especially at the downstream end of longer "glides." Rivers may have a long but shallow diagonal crossing of the actual stream bed (Figure 6c). Were these the "long-fords" of early place names as Gelling tentatively suggested (Gelling, 1984:69)? Unfortunately, the answer is probably not: The bulk of place names that she listed as ford related, including the 26 that were "long" or "broad," are on quite small streams. Two of the eight Twyfords ("two fords") are plausibly on what were anabranching rivers, one on the Itchen in Hampshire and the other on the Loddon near Reading. The settlement of Langford on the Colne (a river now only visible in mutilated form between Heathrow Airport, the M4, and the M25) was also across an anastomosing system. Possibly the Twyford on the Trent, with no bridge still but a later ferry, recorded fords at the upstream and downstream ends of a meander bend.

Anastomosing channels were a mixed blessing: The larger ones could be difficult to ford but possible to bridge, branch by branch. The wetlands between channels might need to be bridged too. Wooden trestle bridges with "earth-fast" piling in soft sediment would not have been as difficult as attempting piling through gravel, and this is a supplementary explanation for the greater frequency of timber bridges which has been noted on the lower Thames and its tributaries through to Tudor times (Harrison, 2004). Even in 1729, the new Putney Bridge was a timber one and the "wooden zig-zag," as it was called, lasted until 1886 (Matthew, 2008). The relatively fixed location of the channel meant that bridge abutments did not have to survive any great tendency for lateral erosion, although bridge structures might be swept away in extreme floods or be damaged by traffic passing across or beneath. In the absence of fordable shallows, the larger canaliform channels (inactive meandering or anastomosing) would have needed ferries or bridges. Rackham (1986) noted that pre-Conquest (before 1066) English charters mentioned 666 bridge and ford crossings, one-sixth being bridges. The latter were uncommon on gravel-bed chalk streams and in Devon, but dominant in the Fenland. This fits neatly with the nature of the channels.

An early geographical differentiation between fording and bridging potential at both the site and the regional scale began to change as bridges replaced fords at a pace accelerating after ca. A.D. 800 (Cooper, 2006). The number of bridges peaked in the medieval period and remained roughly stable until the 18th century (Harrison, 2004). The precise location and orientation of "lost" fords could well have differed from later bridges (the fords themselves may have shifted anyway as the river bed changed), as has been suggested in the case of St. Ives (Beresford & St. Joseph, 1958). With stable channels, bridges could use old ford sites to lay good foundations in shallow water (Simco & McKeague, 1997:105). But bridges are greatly at risk from shifting channels, actively meandering or braided, with pier undermining and new channels likely to develop across and destroy bridge approaches on the floodplain. If the bridge cannot quasi-permanently constrain and fix the channel location, the river "fixes" the bridge in another sense, by destroying it. These problems are well illustrated by the Trent bridges at Hemington upstream of Nottingham, with many medieval rebuildings on shifting channel courses (Salisbury, 1992; Brown et al., 2001; Cooper, 2003; Brown, 2008). Also on the Trent, the bridge at Nottingham itself (known as Hethbeth Bridge) caused persistent problems (Cooper, 2006). In brief, fording works well enough with shifting shallows, but bridging benefits from stable narrows.

So when bridges replaced fords, this could involve a local shift in location, as at Northampton and Peterborough (Steane, 1974). Channel crossing lines were more direct than those exploiting the shallowest path (Figure 6). Alberti, writing in the 15th century (Alberti, 1755), cautioned against bridges on bends. But outer bends up against more stable valley floor margins (terraces or bedrock) might be different; they could provide a stable abutment at least on one bank, although abutments and pier foundations needed to be deep where adjacent to scour pools, and a set of land arches might be needed to bring the roadway down to floodplain level on the floodplain side. In the valleys of lowland England, rivers are commonly confined within valley meanders and by earlier gravel terraces, on some of which towns had been founded. Even though the rivers when unconfined would be well capable of lateral erosion, the confining valley side "steers" the channel into adopting a relatively stable location against the outer bends of valley-floor margins (Lewin & Brindle, 1977). This means that the active channel quasi-permanently hugs the outer valley bend. There might have been an over-deepened pool on the bend to cross (which could be useful for river passage and mooring close in, as on many outer-bend medieval town quays), but at least a lesser chance of lateral channel shift. If a high-level bridge was constructed it could lead into town on the level rather than requiring a gentle descent right down to ford level, the ford itself being away from the probable pool and undercut terrace slope. The terrace base became the town quay—but none of this was where the old ford would have been found.

To summarize, the domains of larger stable meandering and anastomosing channels were not so easy to ford, though the latter in particular might be easier to bridge incrementally in a series of bridges and causeways. For fording, the detailed passage across floodplain and river varied according to the style of river, but fords were liable to shift as channel beds changed, so that it is not surprising that fords have now become lost. Rivers have also been dredged and modified for navigation, as on the lower Severn in the 19th century. At Worcester a minimum depth of 10 feet (3.05 m) was created, thus putting paid to previous summer fording opportunities (Carver, 1980:19–20, 308). As the history of bridge repair following persistent destruction demonstrates (Harrison, 2004; Cooper, 2006), the greatest bridging difficulties occurred with the actively mobile middle reaches of large rivers like the Trent, Tyne, and Severn—upstream of inactive low-gradient sections where the more stable but deep and wide rivers would, of course, be difficult to cross other than by boat in any case. Broadly speaking, the size of a river is proportional to its catchment area, and the lower reaches of major English rivers were a problem for crossing because of their sheer size. Only the greatest strategic and commercial need, and expenditure, could here lead to bridge development, as in the case of old London Bridge (Watson, Brigham, & Dyson, 2006).

When bridges replaced fords, site requirements could shift toward a need for channel stability. In addition to avoiding ancient upkeep commitments (Cooper, 2006), there were physical reasons for some crossing sites to be moved—to find stable abutments and beds, with a different entry into towns. A deeper pool could now be less of a problem, and useful for river traders. Finally, it should be clear that there was no such thing as "the bridging point"; the crossing of rivers depended on technology, site opportunity, and intent, and these varied over time. Sometimes new settlements grew around new bridges, as at Boroughbridge, Fenny, and Stony Stratford, and the remarkable Stockbridge on the Itchen floodplain in Hampshire, with no less than seven bridges with burgage plot layouts following the streams (Beresford, 1967). But once settlements were established, it was they that determined, at a later date, the bridge location (possibly in challenging circumstances, as on the Trent at Nottingham) rather than the other way round. The transition from ford or ferry to bridge was frequently a matter of continuing expense.

MULTICHANNEL USE

Besides being helpful for bridging, the presence and stability of anastomosing channels also lent itself to easier use for milling or water-access purposes which would be more hazardous on single large channels with deep water or steep banks. For access, both flood-stage hazards and low-stage muddy margins on single large rivers were best avoided. If multiple low-energy channels were re-engineered or new ones added, they would also be likely to remain stable. This was a considerable advantage. From the milling point of view as well, the entire low-flow summer discharge could be diverted into the mill channel by temporarily damming others or the main channel (as is well illustrated in Hooker's ca. 1587 plan of Exeter; British Library, Maps C.5.a.3), while winter floods could mostly be taken by the main channel. Powerful undivided rivers like the Severn were less suitable for milling; Domesday mills are clustered along safer and more manageable tributaries rather than along the river itself (Darby & Terrett, 1971:259–261). Channel division was also helpful: At Chertsey, where the channel of the Thames was split, one arm was used for mills as a mid- to late-15th-century plan shows (PRO E164/25,f.222r), as was the Trent downstream from Nottingham to Newark in the early- to mid-16th century (British Library, Cotton MS, Augustus I.i 65). Channel engineering and division was involved in some cases, as at Abingdon (Bond, 2007).

No two sites are identical, but the now-obscured significance of multiple channel systems receives emphasisis in the case of Reading (Figure 1), which developed on the lower reaches of the Kennet rather than the adjacent Thames. Site advantages are clear from Leland's description from 1542:

> The River Kennet passes through the centre of Reading, but divides into two main streams, the larger of which flows under a great wooden bridge on the south side of the town. The other channel is generally known in the town as the Hallowed Brook. It leaves the main stream of the Kennet upstream from Reading to the WSW, near the Bere, where the Abbot of Reading had a fine brick manor house. Then it flows down through meadows towards Reading, running through part of the abbey and washing away its filth. A little below this it rejoins the main stream, and the reunited River Kennet flows into the Thames a little further down. The River Thames comes within half a mile of Reading on the ENE side. In the lower part of the town, where the two Kennet streams run close together, I noticed a number of little channels branching out of them and creating small islands, whch are approached over various wooden bridges. These channels are very suitable for dyeing and many dyers are settled there, since Reading's mainstay is its cloth industry. (Leland 1/108–11; Chandler, 1993:28–29)

THE BUILT ENVIRONMENT AND UNINTENDED IMPACTS

Desirably situated towns, formerly small-sized settlements, greatly developed their commercial activities and outgrew their originating site advantages during medieval times. Defense in post-Conquest towns seems to be far less important a factor than it was in continental Europe. Walled enclosure was in some cases very limited, in others symbolic, and in others embraced only privileged parts of the urban townscape (Creighton, 2007). In many instances, confinment by walls, ditches, marshes, and rivers led to extramural growth in "dryland" suburbs, but also a spread onto floodplains and wetlands (Table V). Some walled towns were large in area (for example, Norwich and Lynn) but others simply spread beyond the enclosures that also regulated commercial access. The strategically situated riverside sites were often the most confined, and many extended out onto their river floodplains right next to the town (E in Table V), as transpontine extensions on the other side of the river (T) and along causeways (C). Growth of a secondary settlement on the far side of the floodplain was another possibility (e.g., Gateshead on the River Tyne, Godmanchester on the Great Ouse). Bridges and their approaches had clear locational advantages for building: proximity to the town center, a captive clientele having to go past the door, and at least on causeways

Table V. English medieval floodplain suburbs.

	Town Rank	Suburb	Type
Bath		Southgate	E
Bedford	59	Bridge Street	H, T
Beverley		Beckside	
Bristol	4	Temple Fee & Redcliffe	T
Cambridge	17		
Canterbury*	9	St. Dunstan's	T
Chester			T
Exeter	51	St. Thomas's	E, T
Gloucester	12	St. Bartholomew's	C, E, M, T
Hereford	20	St. Martin's	T
Hull*	50		
Huntingdon			E
Leicester		Abbey Gate	E, M, T
Lincoln	3	Wigford	T
London	1	Southwark	T
Nottingham	40		
Newcastle	5	Gateshead	T
Norwich*	7		
Oxford	6	Grandpont, St. Thomas's	C, M, T
Reading	53	London Street	T
Salisbury*	14		
Shrewsbury	11	Abbey Foregate	M, T
Winchester*	19		
Worcester	54		C, T
York*	2		

Rank based on village taxation, population, and wealth, 1327–34, from Campbell and Bartley (2006).
Types: C: causeway; E: extramural; H: hospital; M: monastic; T: transpontine.
*Floodplain-sited cities.

and even the bridge itself, some security from floods. Medieval bridges with buildings on them lasted a long time (London ca. 1200–1758, Bristol 1247–1761, Newcastle 13 c.–1771, with a housed bridge still in existence at Lincoln). Security was not absolute or perpetual: Newcastle's bridge was eventually destroyed by a flood that also took out most other bridges in the area, while the houses on English Bridge at Shrewsbury suffered damage when timber floats dislodged the supports for overhanging houses (Morriss, 1994). London Bridge was often said to be "falling down"; more accurately, it was under frequent repair and maintenance.

Buildings also lined approach-road causeways, as at Northampton (Figure 5), Oxford (at Grandpont), and Gloucester (Figure 7a), where the long causeway and its bridges were described by Leland in 1542:

> Outside Gloucester's east north and south gates are suburbs, but at the west gate there is only a bridge and its causeway. The bridge over the principal channel of the Severn, which flows next to the town, has seven large stone arches. A little further west is another bridge, with one or two

> arches which at certain times serve to drain the meadows. Not far away another bridge, of five large arches, stands close to the west gate, and from it a great stone causeway, a quarter-mile long, has been thrown up across the low-lying meadows by the Severn. This causeway has a number of double-arched bridges which drain the meadows when flooded, and at the far end there is another eight-arched bridge which is not yet finished. (Leland 2/53–64; Chandler, 1993:177)

The inter-channel causeway near the town (Westgate Island, or in the medieval period "*inter pontes*") was lined with buildings, as shown on Speed's 1610 town plan. Many other raised medieval causeways existed (Table VI), not all of them urban. These varied in design, some with roads on embankments with bridging sections crossing both single or anastomosing channels, and others, like the impressive viaduct at Burton, with continuous runs of arching to make allowance both for the river and for flood drainage across the floodplain itself (Figure 7b). Anastomosing systems had advantages as well as disadvantages for floodplain siting, both for long-established (Winchester, Canterbury) and new (Stockbridge) medieval towns as well as suburbs. These included multiple mill sites and water access, as well as ease of construction and stability for modified channels and bridged-causeway construction in soft sediments. But flooding remained a problem.

Urban waterfront development on major rivers commonly led to marginal channel infilling and channel narrowing, as at Gloucester, Bristol, and Newcastle, and to a lesser extent at Worcester (Hinton, 2000; Baker & Holt, 2004), but particularly in London, where the archaeology of development on both sides of the tidal river has been well established (Milne, 2003; Watson, Brigham, & Dyson, 2006). The city pushed out into the river by some hundred meters. A riverside location was clearly desirable for water trade, and might be accompanied by boat building and rope or sail making. Other trades also benefited from river proximity, including dyers, fullers, tanners, potters, and tilers (Dyer, 2003). There was also the remarkable extramural trading suburb of Wigford at Lincoln, with its 12 churches and gated entrance, still liable to flood in Defoe's day (Defoe, 1724–6:410). Designed landscapes for the elite—kings, bishops, abbots, and manorial estate holders—also modified many smaller valley floors with embankments, ponds, and water gardens. More rarely these affected major floodplains, as in the large King's Pool on the Foss at York (dating from 1086), or the pleasure gardens at Peterborough Abbey on the Nene floodplain (Creighton, 2009).

Floodplain suburb development was often associated with (though not necessarily founded because of) hospitals and religious establishments (Table V, M and H). On the floodplain, these included: St. Bartholomew's Hospital at Gloucester; Leicester Abbey; Osney Abbey, Blackfriars, and St. Thomas's at Oxford; and Shrewsbury Abbey and the Abbey Foregate suburb (a separate borough). While friaries had an urban focus, enough space for monastic enclosures was often most readily available at extramural floodplain sites, and water provision (for domestic purposes and fishponds) was integral to monastic design. Abbeys like Peterborough (founded as Medeshamstede in 655–656) and Abingdon (of similar date) were in riverside locations where towns later grew up around them. Much later on, Cistercians were enjoined both to use water resources and to be in rural locations; their impact from

Table VI. Raised causeways in medieval England. Major wetland and tidal causeways are not included.

	Width	General Character and Date if Specified
Thames River System		
Banbury[5]	740 m	
Lower Heyford[8]	460 m	
Faringdon, Radcot[8]	520 m	
Newbridge[1,8]		6 arch bridge, stone causeway stone bridge, 1070–1100, 42 causeway arches
Oxford–Grandpont[4,8,9]		
Oxford–Magdalene[5]	460 m	20 arches, replaced 1772–82 causeway to ferry
Osney–Hinksey[1,11]		
Abingdon, Marcham[1,8]	1230 m	1416–22, 14 & 7 arch bridges
Dorchester, Oxon[1]		
Stratford, London[7,11,13]	1360 m	12 c., 5 bridges & causeway, Bow 7 arches?
Severn River System		
Worcester [3]	400 m	pontage 1272
Chesford, Warwks.Avon[8]		
Stratford on Avon[1,8]		late 15 c. by Sir Hugh Clopton
Gloucester[1,3,8,9]	1300 m	a bridge 1119, fortified 1264. Bucks[9] show river bridges and floodplain culverts
Trent River System		
Tamworth[1]		16 arch bridge & divided river
Burton on Trent[8,9,14]	500 m	36 arches, demolished in 19 c.
Swarkeston[7,8]	1000 m	13 c., bridge renewed after 1795 flood
Harrington Bridge[8]		
Nottingham[6,7,9]		19 arch bridge
Newark–Muskham[8]	2570 m	
Nene and Great Ouse		
Bromham[12]		13 c., long horse and foot bridge of 20 arches
Irthlingborough[8]	90 m	19 arch bridge
Stony Stratford[11]		removed 1834
Harrold-Chellington[11,12]		causeway & 9 flood arches; 20-arch foot causeway
Great Barford [8]	200 m	17 arches
St.Neots[10]	370 m	43 wooden arches & 29 “on a wall” in 1588
St Ives[9]		
Huntingdon-Godmanchester[3,11]		causeway added 1331–2
Oundle[1,8]		two causeways with multi-arched bridges
Others		
Chester[4]		late 14 c. in association with new bridge, earlier Roman causeway and bridge
Hull[1]	3250 m	
Holland Causeway[4,8]	5740 m	32 pontage grants 1349–99
Ferrybridge[1]	ca. 1500 m	14 c. bridge

Sources: [1] Leland (ca. 1540); [2] Fiennes (1697–1698); [3] Baker and Holt (2004); [4] Cooper (2006); [5] Dodd (2003); [6] Defoe; [7] Heath (1994); [8] Harrison (2004); [9] Hyde; [10] Jervoise (1930); [11] Jervoise (1932); [12] Simco and McKeague (1997); [13] VCH Essex; [14] VCH Stafford.

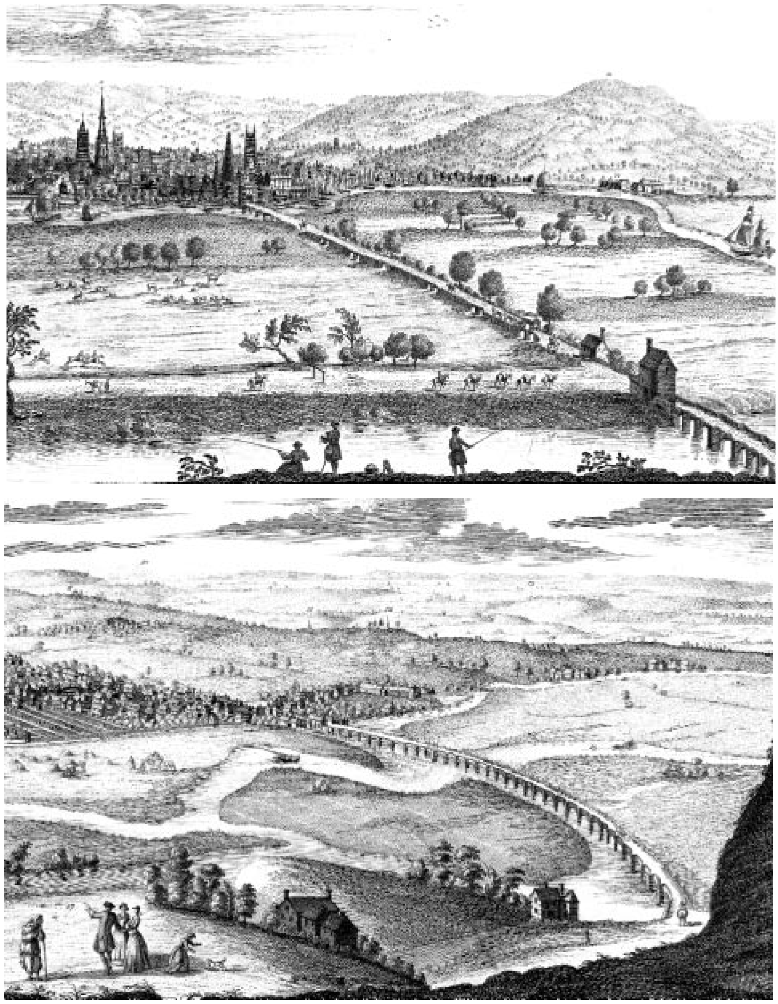

Figure 7. Medieval raised causeways as still existing in 1734: (upper image) at Gloucester (SO 8318), and (lower image) at Burton-on-Trent (SK 2523). The structure at Gloucester has been substantially built over, while that at Burton was dismantled after a new bridge was opened in 1864. From Town Panoramas by Samuel and Nathaniel Buck (see Hyde, 1994).

the 12th century onward was at isolated rural sites, where they transformed the floodplains of small valleys (Aston, 2000). The cathedral close in the new foundation of Salisbury (1223 onward) was also on the floodplain, and the whole city benefited from a river-fed system of open-water channels along its rectangular street layout, as is faithfully illustrated in Speed's later town plan. At an even later date (ca. 1720), Defoe was not impressed with the water flowing everywhere: "It keeps the streets always dirty, full of wet and filth, and weeds, even in the middle of summer" (Defoe, 1724–6:194).

The degree of overbank flood-flow constriction and back-ponding caused by all these building developments is difficult to gauge, but it was bound to have occurred at crossing restrictions and urban “pinch-points” like Grandpont at Oxford, where causeway and suburb blocked the floodway. The consequence would have been increased inundation and floodwater storage upstream, raised flood level in the narrowed floodflow channel, and a flattened and extended flood peak downstream as the floodwaters were delayed. Defoe acutely observed of Worcester:

> There is a good old stone bridge over the Severn which stands exceeding high from the surface of the water. But as the stream of the Severn is contracted here by the buildings on either side, there is evident occasion sometimes for the height of the bridge, the waters rising to an incredible height in the winter-time. (Defoe,1724–6:368)

Defoe was writing in the early 18th century, but the bridge at that time was still the medieval one. The environmental impact of more isolated monastic and manorial establishments, with mills, fishponds, and engineered channels, was local but considerable (Aston, 2000). On urban floodplains, religious establishments in particular joined with the buildings clustering around them to modify floodwater flow.

Similar considerations apply to bridge design and in-channel flow. London’s great masonry bridge had around 20 small arches (initially built 1176–1209) and large “starlings” (timber piling with rubble fill) protecting the piers. The piers considerably constricted flow (Milne, 2003; Watson, Brigham, & Dyson, 2006), producing backwater ponding above, rapids and scour beneath, and scour downstream—and there were two-way tidal effects. The massive piers of Bristol Bridge over the River Avon took up nearly half the width of the river; the corresponding figure for Newcastle on the Tyne was about one-third, though the bridge here also had wide starlings and the flow between them amounted to only about half the river width (Ruddock, 1979). Simco and McKeague (1997:110) showed that for the multi-arched medieval river bridges at Harrold and Bromham in Bedfordshire, the ratio of pier to aperture was around 1:1. Before wider segmental arches came into use, the ratio of aperture to pier was generally quite small. This was an advantage in construction (wooden formers could be used repeatedly, and small arches constructed or repaired independently one by one), but a considerable obstruction for flood flows. Additionally, some bridges became greater barriers because of larger piers involving gatehouses, chapels, and chantries, while mills took advantage of flow constriction by being sited within the bridge arches themselves. Bridge repairs nationally, and who was responsible, proved highly vexatious in medieval England (Cooper, 2006). They were damaged by both river and road traffic, by war, and through their own structural or design weaknesses (Harrison, 2004; Cooper, 2006)—but especially by extreme floods, pier undermining, and the impact of floating ice blocks and debris jams (Watson, Brigham, & Dyson, 2006:138).

Channel constriction at major cities and flood-flow restriction out on floodplains was only beginning to produce effects in medieval times, locally hazardous to those who had put themselves in harm’s way, but not on the scale of the very much greater impact on flood hydraulics caused by the blanketing spread of floodplain housing, industry, and railway development in the 19th century. But multi-arched bridges with restricted apertures created greater floodwater ponding upstream than wider-aperture bridges designed at a later date. Urban waterfront development also altered channel forms and dimensions, making the present-day appearance of canal-like rivers very different from the shallower profile of many in earlier medieval times. Channel banks, ditches, and wetlands became waste dumping grounds, to the later benefit of urban archaeologists. A probable raising of flood levels by urban floodway constriction was in part counteracted in terms of flood avoidance by made-ground vertical accretion in built-up areas with successive phases of building development.

CHANNELWAY ENGINEERING

In-channel flows were modified by the redesign of floodplain channels to facilitate navigation, milling, and fisheries. Major canalization of river channels was yet to come, with weirs and gated locks on larger rivers like the Thames, Severn, Weaver, Lea, Stour, Nene, and Trent. But nevertheless medieval channel excavation and redirection did take place at many sites, as a great deal of recent research using a wide variety of evidence has shown (Blair, 2007). Many works were undertaken by monastic foundations to assist in the transport of building materials (see Bond, 2007, and the listing in his Table 9), though one of the largest was the ca. 4.5 km canalization of the Afon Clwyd at Rhuddlan in 1277 by Edward I. What amounted to major engineering works at Bristol in the later medieval period reorganized the courses of the Frome and Avon, while Bishop Godney of Winchester transformed the floodplain of the Itchen at New Alresford (Beresford, 1967:442). More generally, the widespread use of major rivers for transport involved at least local modifications (at landing places or loading wharves, or for passage maintenance), though it seems unlikely that this disrupted floodplain river systems unduly away from the major wetlands.

Mills were another matter; there were well over 6000 at Domesday and possibly 10,000 by 1300 (Langdon, 2004). Many of these were on small streams, but the potential of lowland floodplain rivers like the Nene was also distinctive and considerable. Of the 326 settlements recorded in Domesday for Northamptonshire, 155 had their own mills; of these, 48 were on low-gradient main rivers where the locations of most can still be identified. With gradients of 1.6 m km^{-1} or less, these mills were run-of-river in type, exploiting one channel and using another as a bypass at high flow and probably damming it when needed at low flow. Flow could also be regulated by sluices, as at Newark on the Trent (British Library, Cotton MS Augustus I.i.65). Valley-side leats were impracticable (and not in evidence) at such low gradients, and it was only later in the 18th century that channels were cut across one or two of the valley meanders, installing locks at the gradient drop accordingly. Mill power was derived from the depth and velocity of flowing water rather than having a large vertical drop, conditions favoring undershot rather than overshot wheels for which the power mechanics (and greater mechanical efficiency) are different. On the Thames between Oxford and Maidenhead (Figure 1), 25 places with mill weirs have been identified (Perberdy, 1996). Although stylized, illustrations of the Thames at Chertsey (PRO E164/25,f.222r) and the Trent near Newark (British Library, Cotton MS Augustus I.i.65) show undershot run-of-river millwheels on these large divided rivers.

Another advantage of larger rivers was that mills there could grind at times when smaller streams dried up. This was made clear in a later dispute reported in an Inquisition of 1576 by the inhabitants of Newark, who complained that their mills were in disrepair and water was being diverted into the alternative branch of the Trent at Averham (Brown, 1904). But their mills, they said, could grind at times of flood, low water, or freezing when others could not. Dual-purpose requirements for navigation and milling, and navigation and fisheries, led to other disputes, and some of these were resolvable by channel engineering, for example, the construction of "barge gutters" on the Severn to bypass fisheries and Orderic's Canal built in the 1050s for navigation at Abingdon on the Thames (Blair, 2007). Manorial and monastic fish ponds were common, generally in smaller valleys with associated diversions and flood channels (Aston, 1988). Fishweir construction on larger rivers has been studied in some detail on the Severn and following excavations on the Trent (Pannett, 1988; Cooper, 2003). This could involve oak piling, wattle sheeting, and stone infilling to create narrow apertures for fish traps. The extent of Domesday fisheries and the structures themselves suggests that these must have considerably impeded river flow. Removal of fishweirs on the Thames and Medway merited specific mention as a grievance to be righted in the Magna Carta. Conflict was inevitable because operating ambitions differed (Blair, 2007:263–264). Navigation required an open deep channel. Mill owners wanted waters to go their way, and for high levels to be maintained in their channels in summer; this produced waterlogged meadows, and stranded vessels in other channel branches. Millers were not popular for this as well as other reasons.

In places, industrial processes were also beginning to make their mark, even on floodplains. Higham (1989) has described flax-retting pools associated with fulling-mill sites on the floodplain of the Ribble. Sheffield metal forges were active at an early date in the Don valley (a tributary of the Ouse system), supplying thousands of arrowheads to the constable of Chester Castle faced with the threat of Owain Glyn Dwr from Wales at the beginning of the 15th century (Hey, 1998:23–24). Wastes from early upland metal mining were being disposed of down the floodplains of Wales, the Pennines, and the southwest (Lewin, Davies, & Wolfenden, 1977; Hudson-Edwards et al., 1999; Thorndycraft, Pirrie, & Brown, 2003). For the most part this all involved upland rather than lowland rivers, but problems with the quality of floodplain sediments had started to spread.

It may again be helpful to view all this through a fluvial-processes prism. For example, if a channel is dammed and its gradient decreased, or flow is restricted by in-channel structures, then a higher rate of sedimentation in lower energy conditions is to be expected. Augmentation of flow in one channel at the expense of another may lead to responsive enlargement of the one and shrinkage of the other, not just in terms of flows but also more permanently by enlargement or decrease in channel dimensions. Viewed in this light, the consequences for multipurpose and multichannel use (in the extreme case, one river branch for milling, another for a weir and fishery, and a third for transport) and the ensuing and persistent disputes may seem more understandable. Channel deterioration did not necessarily all arise from underhand behavior, though the documentary record might lead one to suppose that this was the case, and disputants at the time may have believed that it was. Preemptive use of the water itself on single or multiple channels (e.g., water retention in expanded mill channels rather than as in-channel flow for boat passage) was, of course, a matter of disputed or agreed rights. Thus on the upper Thames, it was reported that the meadows at Eaton and Radcot were flooded because the Abbot of Beaulieu's mill weir was raised so high (Flower, 1915:4). On the Severn, there were 13 fishweirs between Tewkesbury and Gloucester (Figure 1), an 18-foot gap supposedly being "always reserved for the passage of boats" (Flower, 1915:154–155). But in the long run, the effect of weirs, millponds, and the blocking of flows by the mills themselves (especially if they were not cleanly maintained) would be for selective channel sedimentation to take place, aided by plant growth. Head and stream energy loss for overshot wheels are concentrated in the fall of water at the millwheel, not along the channel, and the substitution of overshot for undershot wheels on efficiency grounds, with ponds or low-gradient leats, could carry an environmental penalty in the form of upstream sedimentation. Ultimately, this led to mill-channel shrinkage and the infilling especially of formerly managed binary channel systems which became neglected.

SOIL EROSION AND FLOODPLAIN SEDIMENTATION

An almost ubiquitous impact of medieval human activity on floodplains in Britain was the accelerated input of soil erosion materials. This formed part of a transfer system also involving hillslope erosion and gullying, and considerable colluvial accumulation in footslopes and headwaters (cf. Lang & Bork, 2006). The process would not exactly have been unknown to medieval people; Davies (1968:47) cites Bartholomaeus Anglicus, an English Franciscan writing ca. 1250, as an early proponent of denudation concepts. While a decrease in crop yields in medieval times has been reported, direct measures of soil loss on hillslopes are not easy to come by, though thin soils and linear rill patterns conforming to the patterns of ridge and furrow systems can be observed in places on imagery obtained under drought conditions. Brown (2009) has reported on truncated soil profiles on valley slopes together with thicknesses of colluvial materials and minor valley fills in a relatively low-relief area near Northampton at Raunds. Here there has been extensive archaeological field survey and excavation (Parry, 2006). On the "champion" plowlands of the English Midlands, such plowing is believed to have had a deliberate drainage role. But drainage also meant erosion, particularly on steeper slopes. What amounted to an artificial extension of rill and headwater networks could be very large scale. Ridges could rise a meter higher than furrows, with individual strips averaging 7 by 180 meters in the Midlands, with examples that were much longer. They could run up and down slope unless the slope was very steep, draining directly into watercourses or assisted by ditches and trenching (Hall, 1982, 1999).

Arable cultivation came to extend without much of a break across many rural landscapes. Extra ploughland was added through woodland assarting in previously marginal terrain, while the frequency of cultivation (and so the amount of soil exposure after plowing) also appears to have increased through the medieval period until the early 1300s. It is not easy to determine the exact extent and timing of clearance, and there is evidence both of woodland management and of areas of extensive wildwood remaining (Rackham, 1986). But what has been described as "the colonization of Northamptonshire" involving extensive assarting was incidentally recorded in post-Conquest documents from Peterborough Abbey (King, 1973:Chapter 4). Similar clearance and cultivation took place on the extensive estates of the Bishopric of Worcester (Dyer, 1980:Chapter 4). Here and elsewhere this was being achieved by ox-drawn mould-board plow teams that had considerably more impact than the earlier scratch (ard) plow. A review of what are often debatable matters concerning the nature and timing of settlement and cultivation practices in the medieval period is provided by Williamson (2003), with a pertinent consideration of marginal cultivation by Hatcher and Bailey (2001:33–43). "Marginality" is generally viewed in remoteness and fertility terms, but land colonization also came to involve more erodible terrains, with direct topsoil loss being a likely additional factor in fertility decline.

The amount of sediment reaching larger floodplains depended on the sediment-transfer coupling between eroding slopes, colluvial and minor valley deposition, and the major floodplains themselves (Brown, 1987b; Hoffmann et al., 2009). Mills and fishponds on small tributary streams appear to have trapped a proportion of eroded materials. On major floodplains, overbank sedimentation was under way in the earlier Holocene (Brown, 1983, 1987a; Brown & Keough, 1992; Lewin, Macklin, & Johnstone, 2005), but recent research suggests that in many places the bulk of it came much later. Following earlier work (Robinson & Lambrick, 1984), Robinson suggested for the Upper Thames an average of 0.5 mm yr^{-1} of floodplain deposition in the Roman period, slackening to 0.2 mm yr^{-1} between A.D. 400 and about A.D. 800, and then rising again to perhaps 0.5 mm yr^{-1} again until 1400 or so (Robinson, 1992; Booth et al., 2007). In the Nene valley medieval deposition was also extreme, with 2 m of alluvial clay over Late Saxon or early medieval ridge-and-furrow (Robinson, 1992). Alluvial clay content was probably exacerbated in the Midlands north of Anglian/Wolstonian glaciation limits. Glacial clay deposits from early glaciation extended south to the London Basin, but because of later valley incision (though long before the Holocene) they are now found capping upper slopes and interfluves. These steeper fringes, the ones later settled and plowed, were greatly affected by medieval woodland assarting. It was the accelerated transfer from these marginal terrains to floodplains that was probably most responsible for their volume and clay content as well as the input of finer components from upper soil horizons in general. It is ironic that the colonizing Cistercians, energetically extending their plowlands and assarting woodlands, probably had to live with some of the sedimentation consequences at their monastic precincts in valley-bottom locations. Elsewhere, the newly assarted claylands were in valley-floor lowlands, on Lias, Oxford, Wealden, Gault, or London Clays, and at lower slope angles may have been less of an erosion problem.

A broad-scale recent survey (Figure 8) suggests widespread and rapid medieval (11th to 14th centuries) sedimentation at rates that could be ten times earlier Holocene rates (Macklin, Jones, & Lewin, 2010). Overall, a suggested medieval peak for Holocene soil: alluvium transfer in Britain is consistent with many European studies (Becker & Schirmer, 1977; Schirmer, 1995; Coltori, 1997; Bertram, 2004; Lang & Bork, 2006;

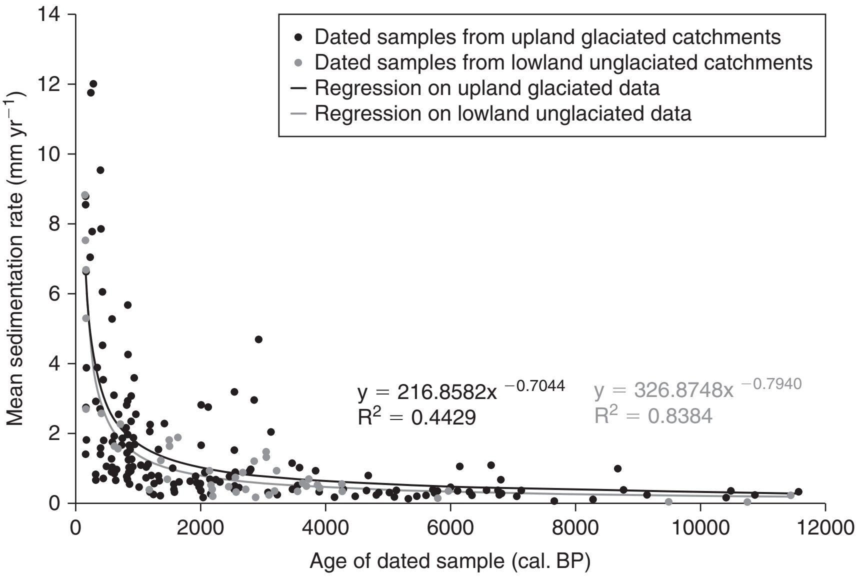

Figure 8. Mean sedimentation rates based on ^{14}C-dated overbank sediment depth (modified from Macklin, Jones, & Lewin, 2010).

Dotterweich, 2008; Enters, Dörfleer, & Zolitchka, 2008; Hoffmann et al., 2009), some demonstrating distinct sedimentation units, as in the Older Meadow Loam of Hagedorn and Rother (1992). An order-of-magnitude increase in sedimentation has similarly been suggested following the introduction of Euro-American cultivation in 19th-century America (Trimble, 1983, 1999; Knox, 2006). Walter and Merritts (2008) attributed the trapping of such sediment in the narrow valleys of the eastern United States to valley-wide mill dams, which accumulated a wedge of sediment behind them. This may apply in narrow valleys in Europe, but on floodplains dams were not valley-wide, and the system of water control in larger valleys was different. Walter and Merritts recognize but place lesser emphasis on accelerated soil erosion as the source of sediment in the first place. Elimination of wetlands by overbank sedimentation in Europe (at an earlier date) does, however, appear to have achieved much the same effect. This significant change had a considerable impact on the physical landscape and the purposes for which it could be used.

Modern studies for predicting soil erosion loss range from empirically based to physical models (Lane, Shirley, & Singh, 1988), but probably the most used still are versions of the empirical Universal Soil Loss Equation, which expresses loss (A) in terms of rainfall/runoff (R), soil erodibility (K), slope length (L) and steepness (S), the vegetation cover (C), and cropping practice (P):

$$A = RKLSCP$$

Conceived in such multifactorial terms, medieval soil loss is likely to have varied considerably given the range in soil materials, slopes, and agricultural practices involved. The thinner, calcareous, and stonier soil sources of chalk and limestone terraines contrast with the glacial clay "champion" plowlands of the Midlands, and the gentler slopes on sandy tills and other glacial deposits in Norfolk. In this respect it is interesting to note that Williamson (2003), in his terrain-based consideration of settlements and agriculture in eastern England, remarked on the distinctly peaty valley floors of East Anglia. Earlier wetlands here do not appear to have been so thickly blanketed by deposits from medieval soil erosion, despite the dense settlement and cultivation of clay and loam soils around them (for the larger-scale Norfolk Broad peatlands, see also Lambert et al., 1960). This contrasts with the situation in the Thames valley (Dodd, 2003; Booth et al., 2007; Parker et al., 2008). Chalk downlands elsewhere, although showing evidence of earlier anthropogenic soil erosion and colluvial deposition, unsurprisingly do not appear later on to have delivered the marked acceleration in alluvial deposition arising elsewhere from medieval arable cultivation (Favis-Mortlock, Boardman, & Bell, 1997; French & Lewis, 2005; Collins et al., 2006). Catchments with a capping of loess, a wind-blown sediment that carpeted southern England during the last glaciation (Catt, 1977), produced more permeable soils and thicker silty floodplain materials (Burrin & Scaife, 1984), some the so-called brickearths. Redeposited loess in alluvial silts, much from an earlier period, may also have eroded soil and till components as well (Gibbard, Wintle, & Catt, 1987; Rose et al., 1999). But the most liable to medieval erosion must surely have been the Midlands plateau and valley-crest pelosols (slowly permeable clayey soils)—on steeper slopes, not lacking in nutrients but liable to waterlogging, and surface-drained by the ridge and furrow systems created across slopes by cumbersome eight-ox plow teams extending tillage to the limits. The plowing could require careful timing: not when the ground was waterlogged, nor set hard when dry. The history of settlement in this region is presented by Lewis, Mitchell-Fox, and Dyer (2001), while clay soil variability and cultivation is fully discussed by Williamson (2003), though neither discusses erosion and sediment transfer. In the context of meadow land availability, Williamson (2003:169–173) has emphasized the regional variability of English floodplains and their soils. These range from broad Midland valleys with seasonally waterlogged conditions, to narrower and sometimes drier valley floors, to the peaty and channel-divided floodplains of East Anglia and the London Basin, where little alluvial meadowland was available at all. Environmental contrasts were present long before the medieval period, but the suggestion made here is that modified characteristics emerged following agricultural activities within the medieval period itself.

Modern studies of floodplain deposition show spatially variable rates, which are especially high on levee backslopes (near the channel) and in pond depressions (Simm, 1995), while channel-edge fine-grained vertical accretion can be higher still (Rumsby, 2000). Given the easy overbank dispersal of fine soil-derived materials, the general tendency was to even out floodplain relief, as in the case of infilled dead channels and wetlands, depositing any slightly coarser materials alongside the channels, as in the inactive meandering model of Table II. The detail of medieval floodplain relief at specific times is difficult to assess. The bounds given in Anglo-Saxon charters commonly rely on landscape elements, and among these are rare mentions of floodplain marsh, river cliff, pools, and islands as well as weirs and fords (Hooke, 1990). But these tend to be more specific away from main rivers, along which boundaries were clear enough. For the large Yorkshire Ouse, the only way to get from Airmyn to Ousefleet during floods in 1362 was along the river bank (Beresford, 1967:521), which implies a levee of some kind. Sedimentological evidence is more general. Overall on the lower Severn, alluvial soil types show a gradation from silty levee sediments to clay gleys, waterlogging in ponded areas, and a topographic gradient away from the river (Lewin, 1982). On the upper Severn near Welshpool a considerable thickness of fine sediment accumulated quite widely (Jones, Macklin, & Lewin, in press). This contrasts with domination by narrower mineral-sediment raised levees in the major wetlands where river sedimentation was relatively restricted laterally.

Contemporary process studies combine direct observations from sediment traps and post-flood survey with the use of recent marker horizons involving metal pollutants and radioactive fallout (Walling, He, & Nicholas, 1996; see Rumsby, 2000:Table I, for comparative figures). Data for Figure 8 covering a longer period derive from single-site ^{14}C-dated buried organic materials. This means that the figures have to be treated with some caution because dated organic materials are best preserved in pondage locations where sedimentation rates are high. Nevertheless, the quite even spread and thickness of post-Saxon overbank sediments is considerable, and this transformed floodplain morphology. Some indication of this is provided by the half-buried appearance of the earliest arches (many were later raised) of some surviving medieval bridges (Table VII). Other early bridges have, of course, been lost or modified, while some (especially in northern England) had high arches, but in the East Midlands a combination of longevity, design, and post-construction soil erosion and deposition seems likely to have contributed to present-day sunken appearances. Deposited material was also transferred beyond river valleys out across fenland margins (French & Heathcote, 2003) and into the major saline estuarine environments of southern England (the Thames, Severn, Humber, and Wash), where early reclaimed land may be found buried under alluvium (Cook & Williamson, 1999).

Figure 9 summarizes the floodplain transformations that occurred. Where it happened, sedimentation smoothed floodplain relief, up to a point improving floodplain soils and meadow (with a greater depth of fine material, and nutrient input), but particularly with clay sediments also retaining flood inundation and ponding right across floodplain surfaces rather than having a paleochannel network available for drainage. While organic wetlands got buried, the soil itself showed increased waterlogging and gleying where clay sediments were involved. The amount of floodplain deposition varied regionally (because of catchment slope and soil conditions, catchment size, and the nature of cultivation), but further data allowing standardized quantitative comparison is required. It is perhaps also worth noting that meadowland was often in short supply, but that what may be called floodplain meadows were actually on floodplain (terrace) gravels, as at Yarnton near Oxford, rather than strictly on the wetlands and fine alluvial fills of the bottomlands (see, for example, Booth et al., 2007). In this context, soil redeposition was a significant means of

Table VII. Surviving medieval bridges in the East Midlands.

	Grid Ref.	Date	General Character
Nene			
Ditchford*	SP9368	early 14 c.	6 arches, 3 more in both approaches
Irthlingborough	SP9570	14c.	19 arches, later widened, insc. "1668"
Thrapston*	SP9978	?	9 arches (Leland 8), damaged in 1795 flood. Pontage 1369, 1373, 1377, 1382, 1385, 1388, 1392.
Wansford*	TL 0999	14 c.	12 arches, semicircular, insc. "PM1577." 3 rebuilt 1672–4. Hollinshead reported 3 arches destroyed in 1571 tempest. Pontage 1333, 1334, 1337, 1340, 1357, 1363, 1369.
Welland			
Wakerley*	SP9599		5 arches, widened, 18 c. insc. "TS 1793"
Duddington*	SK9900		4 pointed arches
Great Ouse			
Huntingdon	TL2471	c.14 c.	6 arches, 1 earlier* (bridge present in 1194). Pontage 1279, 1344, 1356.
St.Ives	TL3271	c.14 c.	6 arches, 1 pointed
Great Barford*	TL1452	ca. 1440	15 arches, later widened

* Buried arch springers.
Sources: Jervoise (1932); Harrison (2004); Pevsner (1973); Cooper (2006).

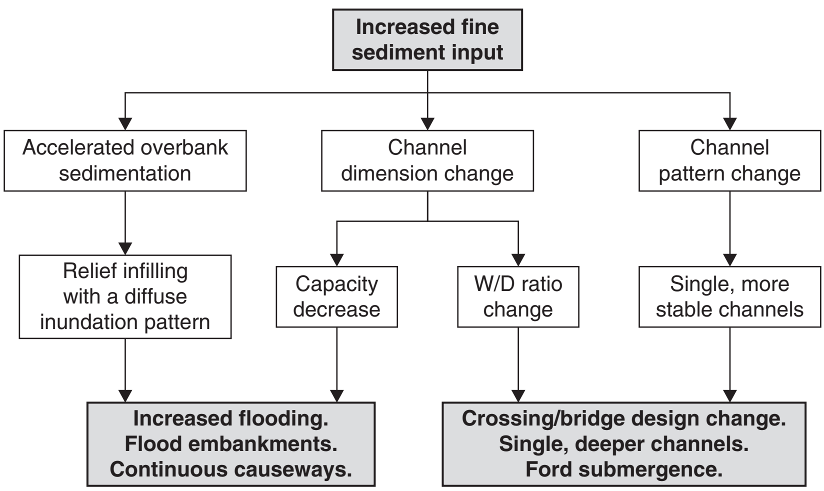

Figure 9. The impacts of accelerated soil erosion on floodplain environments.

meadowland extension into valley-floor wetlands that were not so suited in earliest medieval times.

Soil redeposition had other effects. Channel dimensions were also likely to have changed, with deeper narrower channels (Brown & Keough, 1992), as would be expected with this change in bank materials. It is also possible that channel dimensions

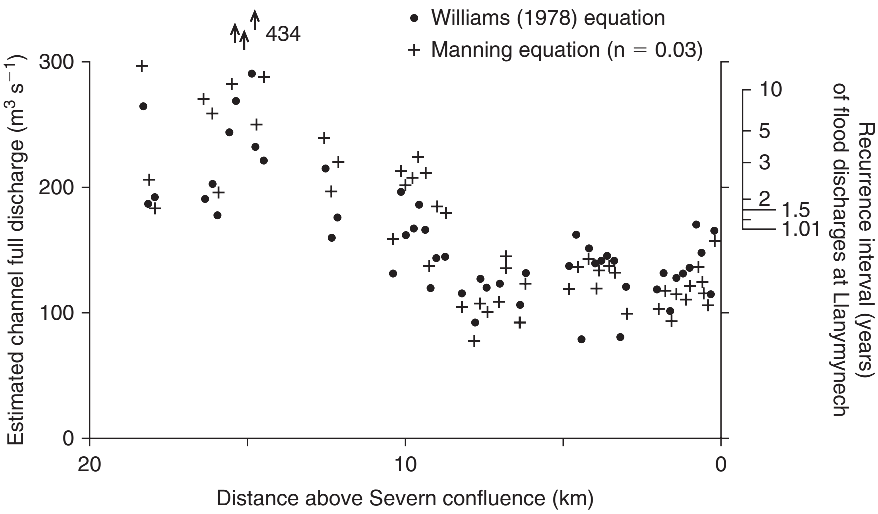

Figure 10. Down-channel decrease in channel discharge capacity on the River Vyrnwy (SJ 31) (from Lewin, 1987).

adjusted to take a smaller proportion of extreme flood discharges (Hey, 1975; Lewin, 1987). Both on the Severn and on the lower Vyrnwy (Figure 10), channel capacity falls downstream without effective change in discharge as bank materials get finer and valley gradient declines, an effect that is also seen elsewhere (Lewin, 1989). All this could actually have led to increased overbank flooding as channels and floodplains were transformed, even without any change in climatically determined flood regime.

Discussions of a probable later medieval decline in the navigability of English rivers have explored the contrasting pictures gained from different documentary sources. Explanations for decline have reasonably focused on obstruction by mills, weirs, and fisheries (Edwards & Hindle, 1991; Langdon, 1993; Jones, 2000; Booth et al., 2007). It does seem unlikely that the major navigable rivers were seriously troubled by an extra clay and silt load. Yet it is interesting that medieval sedimentation or the need for "cleansing" was reported from the Lea, Foss Dyke, and Nene at Stamford, while early development and use of the upper Thames for navigation (including the excavation of canals) seems to have declined (Jones, 2000; Blair, 2007). In Nottinghamshire in the early 14th century, tributaries of the Trent also needed "to be cleaned out, as the lands of the king, and of others in those parts, are frequently flooded" (Calendar of Patent Rolls, Edward II ii, Feb. 20, 1316). The evidence does not suggest that sedimentation was overall a major cause for a decline in navigability on larger rivers, but an increased fine sediment load cannot have helped on smaller low-energy ones, especially when trapped behind weirs and the like. Low-energy river channels are especially liable to blockage by trees, logjams, and macrophyte plants which trap sediment (Gurnell et al., 2009; Sear et al., 2009). Sedimentation was also a major problem in low-energy tidally dominated rivers with a consequent relocation of harbors and the development of outports, as in coastal Kent and Sussex, or at Chester.

A final effect, in addition to changes in flooding and floodplain relief and of channel dimensions, concerns channel patterns. A gradual Holocene decline in the number of anabranches has been reported by Brown and Keough (1992), and a more abrupt pattern transformation from anastomosing to single-channel meandering by Jones, Macklin, and Lewin (in press). We have seen that anastomosing patterns persisted in lowland locations right through the medieval period, but clearly minor slack-water channels and wetlands were impacted by deposition from high suspended sediment inputs, and liable to infilling (Brown, 2009). As has been discussed above, where such channels were being used, and flows impeded, there would be additional channel maintenance problems caused by higher fine sediment loads. Ultimately, and possibly inadvertently, this use contributed to the increasing dominance of single- rather than multichannel (anastomosing) systems. Similar post-settlement channel change patterns in more recent times have been reported post-1820 in Australia (Johnston & Brierley, 2006) and since the 1600s in the United States (Walter & Merritts, 2008). Geomorphological contexts do vary: Accelerated soil erosion in medieval Italy led to a change from meandering to braided channel style on actively incising rivers (Coltori, 1997), and also to braiding on Polish rivers in the last two centuries prior to channel control (Starkel, 1982).

COPING WITH CONSEQUENCES

For practical travel, there are three levels of challenge in crossing rivers and floodplains. Can the channel be forded at lower flows, can it be bridged at all but overbank flood times, and is it possible to traverse the wider floodplain without getting bogged down? Fording would have been affected not just by more frequent high-flow conditions, but also by changes to channel dimensions (narrowing and deepening), and by increasingly muddy waters. Fine sediment gets deposited in-channel as floodwaters recede, and this can leave a slippery and treacherous surface at channel margins until washed away by rain into the riverbed or until it dries out. Given also a medieval shift from oxen to the use of more vulnerable carts and horses (Langdon, 1986), fording must have become increasingly impractical—because of the mud, and not just because of floods. The mud may also have been a factor in delaying the use of horses for plowing and haulage in vulnerable terrains (see Langdon, 1986:255–257), as well as affecting aquatic ecosystems and fish stocks through increased stream turbidity (Hoffman, 1996).

For river crossing, and despite the cost of building and maintenance, bridging certainly became the preferred alternative from late Saxon times onward (Harrison, 2004). Increasing prosperity and trade, and resources for arch-bridge technology in stone as well as timber construction, made this desirable and possible for year-long passage. Surviving structures show that medieval bridges were widened and raised, largely to cope with both road and river traffic, but possibly in some cases also because of partial submergence in sediment.

But why was *raised* floodplain causeway bridging (Figure 7, Table VI) seen as desirable? Though variable, overbank flows are usually taken to occur about once every year or two (Lewin, 1989), and this should not have been disabling if the roadbed was firm or paved or there was a Roman-style *agger*. There are records of maintenance being done, for example, to the causeway on the River Lea between Bow and Stratford "to take sand and gravel at certain places in the said highway and to carry the same to other places less deep and therein to make a dry way for those passing" (Calendar of Patent Rolls, Edward II ii, Jan. 3, 1317). "Caused ways" of this kind were commonplace, and not all of them were raised or major feats of medieval engineering. But we should perhaps think of earlier floodplains as more like permanent wetlands in which it was not only a single channel that needed to be crossed. At the beginning of the medieval period, many lowland floodplains were not "plains" but patchworks of drier gravel islands (bar complexes from prior Pleistocene braided rivers) between multiple-channel anastomosing river belts with reed beds in old channels and swampy interchannel and valley-margin depressions. Timber crossing structures in early river wetlands are being discovered in increasing numbers (e.g., Siddell, 2003). Things became different but not necessarily an unalloyed improvement if the floodplain became more impermeable and blanketed with clay-rich sediment so that waters did not drain, and if overbank inundation became much more frequent. If medieval floodplains were being submerged more persistently by ponded and flowing water than previously (or under present-day conditions), then the need for high-rise causeways becomes clearer. The clay content of Midland floodplains derived from eroded glacial deposits has already been noted. It may be suggested, therefore, that an extra impetus was added to commercial expansion for both bridge building and raised causeway construction. This came partly from a floodplain topography no longer visible to us, and partly from the transformations previously brought about—a narrowing of channels and the floodplain deposition of eroded soil material. The positive advantage of this for later generations was the increased potential of flatter floodplains with deep soils for summer hay pasture and watermeadows, particularly if erosion intensity and inundation frequency eased.

Buildings on floodplains for the most part simply had to put up with flooding or adapt in relatively minor ways, as in the case of raising the floor of Bordesley Abbey (Aston, 2000). By contrast, Abbot Martin at Peterborough shifted his dependent settlement from a flood-prone site to a location on the west of the abbey in the 12th century, while Abbot Godfrey had a bridge built over the Nene in 1308 at the hythe, which was a distance from the former crossing (Steane, 1974). In modern terms these could come under the heading of alternative strategies for flood mitigation. Some monasteries relocated because of flood problems (Williams, 1998:146, 182). Complaints about medieval flooding have been commonly recorded; this was seen as a manifestation of divine judgment, and sometimes personal misfortune or culpability, as much as anything else. Medieval flood embankments do not appear to have been systematically studied for their own sake, but many monastic precincts had banks that were extra to their fishpond, moat, and ditch systems, and it would be interesting to know how much of this was in response to a developing need for flood defense. Mills, monastic or otherwise, were particularly vulnerable, as would be expected.

Some of the problems associated with medieval floodplains were inadvertently solved in the years after the Black Death (1348–1350, with subsequent fresh outbreaks). Rural depopulation, a lessening in cultivation intensity, the conversion of arable land to pasture, and field enclosure—these all amounted to soil conservation practices. Soil accumulation behind post-enclosure hedges and banks bears witness to the fact that, while some soil erosion continued, sediment delivery to floodplain rivers was being impeded. Given a decline in sediment yield, it is likely that river incision rather than sedimentation took place, as has happened in the more fully documented aftermath of Euro-American agricultural impact in the United States (Trimble, 1999; Knox, 2006). There is evidence of post-medieval incision on upland rivers in Britain (Macklin & Lewin, 1986; Hooke et al., 1989; Taylor & Lewin, 1996; Howard et al., 1999; Rumsby, 2000). Here a thicker unit of medieval deposition caps the sediments of terraces now at a higher level than actively migrating rivers. Possible post-medieval channel enlargement in lowland England or Wales has yet to be fully investigated. When rivers do incise, this may decrease the frequency of overbank inundation, with feedback effects involving increased in-channel velocities and scour of a deepening channel (Wyžga, 2001). In the United States, later incision through thick fine-sediment units retained by cross-valley mill dams has been suggested as a means of enhancing stream power in the deepening channels, thus eroding right through to earlier Pleistocene gravels beneath (Walter & Merritts, 2008). In such circumstances in Europe, new but now less frequently inundated tabular floodplain fills could be used and crossed with greater impunity in post-medieval times. The next widespread perturbation to affect lowland floodplains was perhaps less the responsibility of human activity and more the effect of floods and icing related to the climates of the so-called Little Ice Age (Rumsby & Macklin, 1996, Macklin & Rumsby, 2007).

CONCLUSIONS

This paper has examined the workings of the “natural” floodplain environments in which medieval people lived, built, and worked. Even in lowland England, these provided quite variable opportunities for human use—whether for defendable urban sites, as terrains to get across, as single or multiple channels to use, or as land to cultivate. It is suggested that urban and agrarian entrepreneurial activities impacted and transformed the floodplain environments that were being made use of—not just intentionally, but also inadvertently and in several different respects. Economic and social development had interactive effects on river systems, and these in turn impacted on development requirements (Figure 11). Medieval conditions have been physically obscured and overlain by later developments, and perhaps conceptually because of a limited awareness of the variability and dynamics of the physical environment. The challenges and opportunities that were presented in medieval times need to be teased out for what they once were. And even then, rivers and floodplains

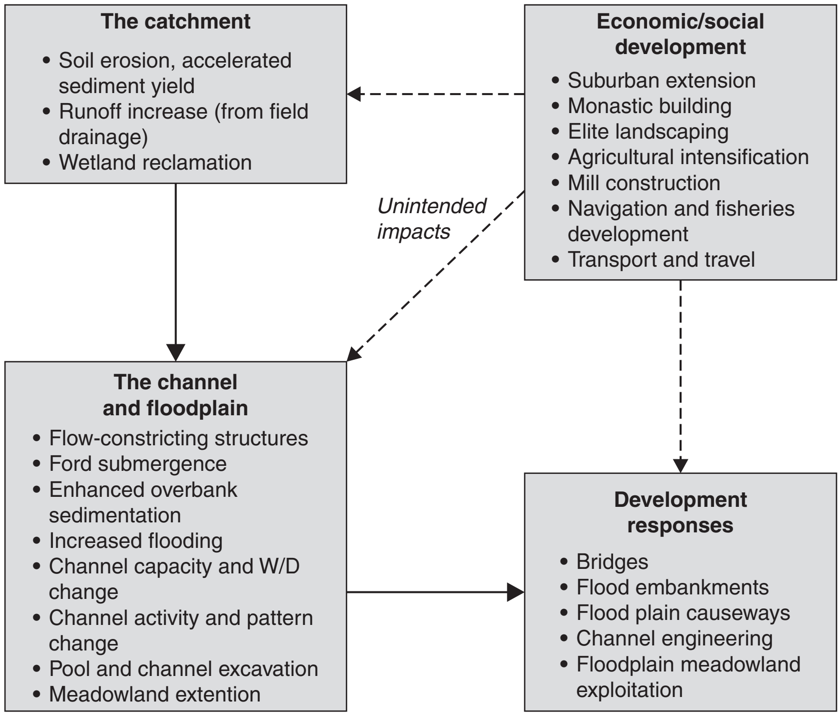

Figure 11. Interrelationships between medieval economic and social development and fluvial systems.

were far from "natural"; they were on the change, responding to the pursuits of urban and agrarian societies.

Emphasis has also been placed on rivers and floodplains as being sediment-conveying as well as water-discharging systems. It is the combination which determines floodplain and channel styles, including the dimensions and number of channels, the quality of fords, and the ease with which floodplains can be crossed or cultivated. Sediments are crucial, and it is too simple to think of floodplains as places passively liable to floods which just might be more or less frequent on average over centuries-long climatic "periods." It was into quite complex spatial and temporal fluvial systems that medieval activities entered, in turn producing transformations through urban and roadway building, channel engineering, and agricultural activity. What we now see by way of rivers and wetlands is not what medieval people saw, any more than contemporary riverside perceptions involving summer recreation and winter hazard get near appreciating the multifaceted resource and challenge rivers and floodplains represented in medieval times.

Clearly, human endeavors have many causes which may be viewed historically from a variety of social, economic, political, and technical perspectives. Using historical and archaeological evidence, past human activities have been extensively explored in such ways, and archaeologists have understandably recoiled from the cruder horrors of environmental determinism in interpreting designed landscapes and their contents. This paper has sought to supplement (not to replace) these interpretations with a parallel geomorphological perspective, figuratively speaking exploring what happened following the spread of mud and mortar into a dynamic geomorphological environment. Environmental processes were altered by the developments that took place, varying opportunities were provided, and with transformations further innovations and changes were instigated.

In a pious age, this would all have been viewed very differently. People commonly believed that in a decayed world they were (to use an interesting word) "*re*claiming" wilderness back into its previous and properly cultivated state, as it had been before the Fall. It was wild savagery that was thought to have pushed back the boundary of the cultivated world, not the other way round. But at the same time, and although floodplains as a resource were appraised differently, what happened to them also involved harbingers of modernity, which has its own level of environmental insouciance, with embankment-protected urban landscapes linked by communication lines cobwebbing indifferently across the intervening workspace of an industrialized agriculture. For contrasting reasons in both the medieval and the modern, regard for the consequences and hazards involved in development across variably dynamic environments has been patchy. This is a (post)modern perspective, but the themes of site adaptation, and environmental impact and feedback, do sit comfortably with what is now known actually to have happened to the medieval floodplains of lowland England and Wales.

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