Geomorphology 39 (2001) 69–82

GEOMORPHOLOGY

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Late Holocene channel changes of the Middle Trent: channel response to a thousand-year flood record

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Received 16 December 1999; received in revised form 1 July 2000; accepted 11 November 2000

Abstract

This paper presents recent work on the floodplain sedimentology of the Middle Trent using data from gravel pits, archaeological sites and documentary sources. The Middle Trent has been unusually active during the Holocene in comparison with other large lowland rivers in the British Isles. The Holocene floodplain fill is dominated by sands and gravels with abundant structural evidence of changes in channel pattern and channel type. A thousand-year record of channel change has been reconstructed from palaeochannels and gravel units with radiocarbon dating of brushwood, palaeomagnetic dating of fine channel fills, dendrochronological dating of timber structures and dating via archaeological typologies. The Trent also has a reasonably well-recorded flood history at least since the 11th century AD. A comparison of the flood record and channel change indicates that the same degree of morphological and sedimentary response is not necessarily associated with floods of similar magnitudes, i.e. there is no constant relationship between event magnitude and landform change. Instead, the response seems dependent on the existing state of the channel and medium-term trajectory of channel change. There is evidence at both the Hemington and Colwick reaches of a cycle of channel change involving a change in channel typology, and dating evidence that this may have migrated downstream.

The results of this work provide a medium-term perspective on channel change, which may be more appropriate for large British rivers than short-term monitoring for both model validation and planning purposes. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Channel change; Floods; Late Holocene; Medieval bridges; Beetles; Trent

1. Introduction

In contrast to most other lowland rivers in Britain, the Trent has been particularly active over the last

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PII: S0169-555X(01)00052-6

1000 years. This paper presents evidence of this activity and attempts to relate it to the flood history of the Trent basin. Large lowland rivers in the British Isles are generally characterised by channel stability over the last 1000 years. The lower Severn has suffered from channel siltation in the perimarine zone (Brown, 1991), but otherwise there is little evidence of significant meander migration or avulsion over this period. Likewise, the middle and lower Thames remained largely stable since major changes in planform in Prehistory (ca. 3500–2000 years BP, e.g. Needham, 1992; Allan et al., 1997). This is not the case with upland rivers (Howard and Macklin, 1999; Merrett and Macklin, 1999), or many smaller piedmont and lowland rivers (Hooke, 1977; Hooke et al., 1990). Passmore et al. (1993) have shown how aggradation and transformation to a braided pattern occurred in reaches of the Upper Severn and the Tyne both in the late Roman period and the 13th and 14th centuries. The apparent Late Holocene stability

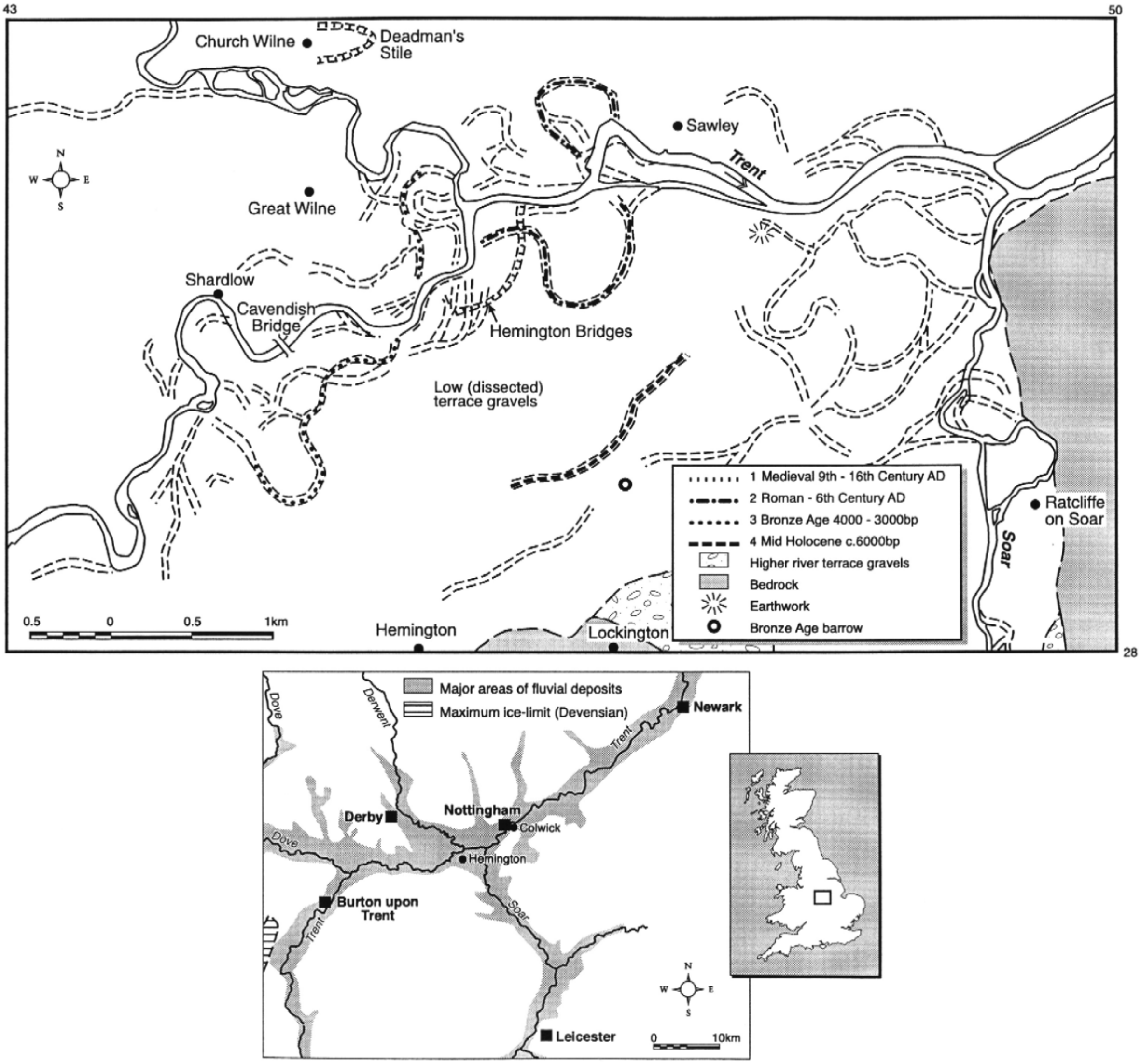

Fig. 1. Site location map (inset) and a map of palaeochannels in the Hemington area.

of lowland rivers is probably due to a combination of low stream power (Ferguson, 1981), the creation of highly cohesive banks by overbank siltation, and the management of watercourses through embanking, bank protection and similar measures. The Middle Trent, however, is anomalous as despite bisecting the English Midlands (Fig. 1) and having a moderate to low slope (average 0.5×10^{-3}), it has undergone major channel changes during the Late Holocene. The excavation of a series of medieval bridges, fish weirs and other structures at Hemington and earlier archaeological work at Colwick has provided a wealth of information on channel changes of the Trent, which extend back over 1000 years (Salisbury, 1992). This allows assessment of the response of the Trent to the combination of changing flood regime and intrinsic variables, which control the reaction and relaxation times of rivers (Brunsden and Thornes, 1979; Bull, 1991).

2. Methods

At all the sites referred to in this paper, the quarry faces (exposures produced by aggregate extraction) have been observed as part of archaeological investigations. Faces have been monitored since 1987 as part of planning consent (mostly by C. Salisbury) and archaeological remains and associated natural features are recorded and surveyed using an EDM Total Station and section drawing. As part of the excavation of the buried Medieval bridges at Hemington (Cooper and Ripper, 1994; Cooper et al., 1994; Cooper, 1998, 1999), the sediments were drawn and recorded using standard archaeological practise (i.e. recording by context) by the Leicester Archaeological Unit. The archaeological recording has also covered natural features including channels; around 40 sections and 80 EDM files over the last 2 years. This archaeological stratigraphy has been translated into an alluvial stratigraphy by applying standard sedimentological rules and procedures (Miall, 1978) largely involving the recognition of erosional bounding surfaces (EBS) and distinctions between clast- and matrix-supported gravels (Brown and Salisbury, in press). Multi-method dating has included dendrochronology, radiocarbon assay, palaeomagnetic dating (Ellis and Brown, 1998) and archaeological dating (artefact typology). An approximate estimate of the channel-forming discharge associated with the Medieval channels used both the slope–area method and HECII step backwater modelling. More detail of this is given elsewhere (Brown and Salisbury, in press). Coleoptera from organic layers within the gravels and associated with Bridge I were processed from bulk samples using the standard method of paraffin flotation as outlined in Kenward et al. (1980). The Coleoptera were identified using a range of entomological keys and by direct comparison to the Gorham Collection of British Coleoptera at the Department of Ancient History and Archaeology, University of Birmingham. The taxonomy follows Lucht (1987).

3. The record of channel change from sedimentary and archaeological data

The paper uses data from two sites within the Burton-on-Trent to Newark section of the valley (Hemington and Colwick, Fig. 1), a section in which the main channel is joined by two tributaries draining the northern upland half of the catchment (the Dove and the Derwent) and one draining the southern lowland catchment zone (the Soar). Both sites are the result of aggregate quarrying but stratigraphic investigations have been undertaken in support of archaeological investigations; at Colwick in the 1970s and at Hemington in the 1990s. The Hemington and Colwick reaches have a large number of still visible palaeochannels dating from most periods of the Holocene (Fig. 1). These are incised into the lower terrace, which is now known to be of Younger Dryas age on the basis of recent radiocarbon dating (Brown and Salisbury, in press). Extensive and systematic quarrying of aggregate in the Hemington reach has exposed a number of archaeological features over the last 10 years and from the Colwick–Holme Pierrepoint reach archaeological finds have included a dug-out canoes and fish weirs (Cummins and Rundle, 1969; Losco-Bradley and Salisbury, 1988).

The sedimentology of both Colwick and Hemington is both subtle and complicated as all the Holocene gravels are reworked Late Devensian gravels with only a minor reduction in mean grain size (Devensian d_{50} 13 mm, Medieval d_{50} 8 mm). The Deven-

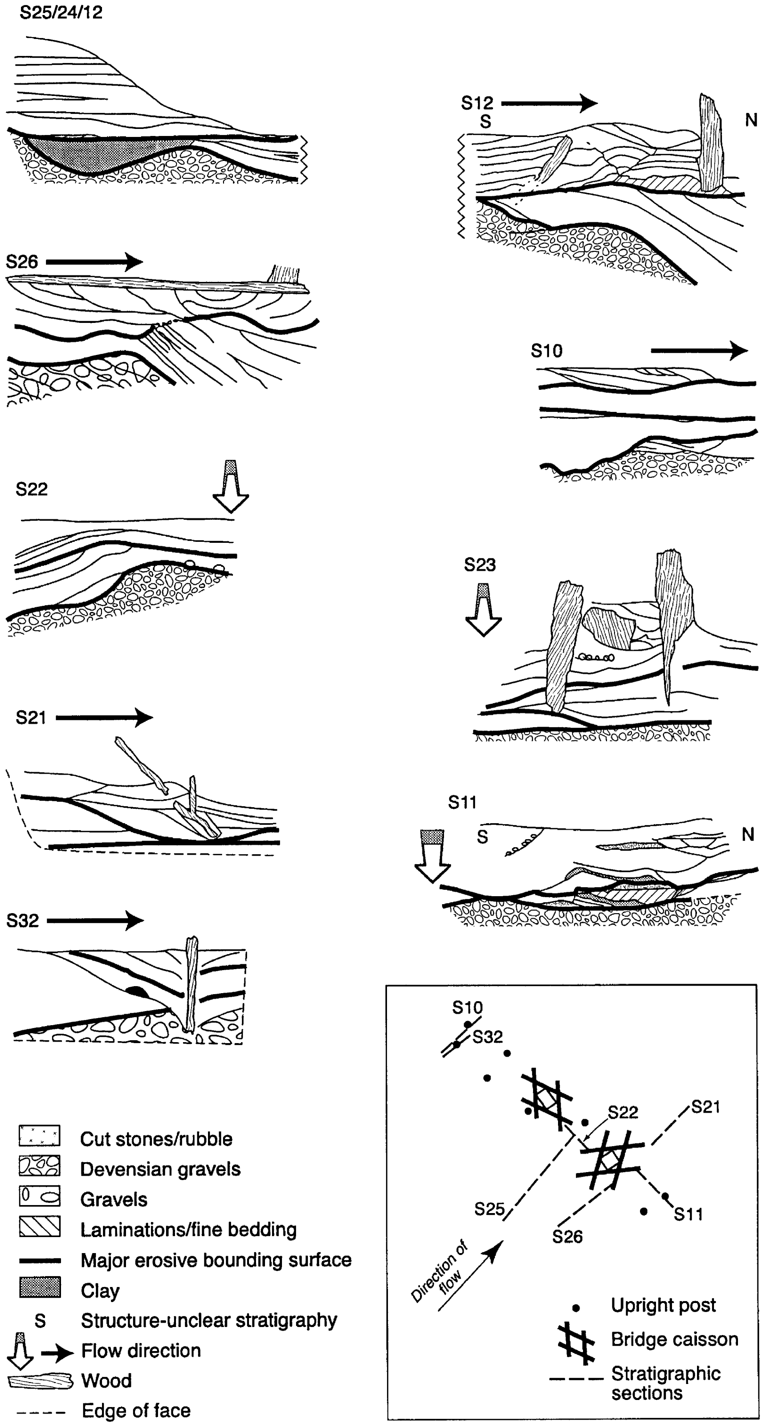

Fig. 2. Selected stratigraphic sections around Bridge I recorded by Cooper and Ripper and generalised into bounding surfaces (sediment discontinuities).

sian gravels contain many cryoturbation features, especially ice-wedge casts, while acknowledging the problems associated with the identification of such features (Worsley, 1996), the form and linearity hence polygonal planform of these features suggest they did originate from freezing of the gravels under mean annual temperatures below 0°C. Large intra formational masses of compact clay have also revealed, under SEM analysis, a lenticular microfabric typical of freezing (Van Vleit-Lanoë, 1986). The distinguishing criteria of the Holocene reworked gravels are lack of cryogenic features and colour, as the Devensian gravels have a red hue from the hematite-rich matrix. The presence of archaeological remains also distinguishes the Holocene from the Devensian gravels. At Hemington, over 50 sections surrounding the Medieval bridges have been recorded by Cooper and Ripper (in press). Fifteen of these have been redrawn and sedimentologically interpreted, a selection of which is presented in Fig. 2 in order to show the scour and fill nature of the stratigraphy. This suggests that there are at least three separate flood units recorded at the site of Bridge I. There is a general decrease in the complexity of the channel fill from the oldest (Bridge I) to the youngest bridge (Bridge III) as evidenced by the stratigraphy; however, this is probably also due to the changing cross-sectional shape of the channel that widens over time.

By combining the archaeological, sedimentological and dating evidence, a tentative sequence of channel changes over the last 1500 years can be postulated, based upon both the archaeological and geomorphological evidence (Fig. 3). The channel pattern is reconstructed from the bridge locations and dimensions, the sedimentology associated with the

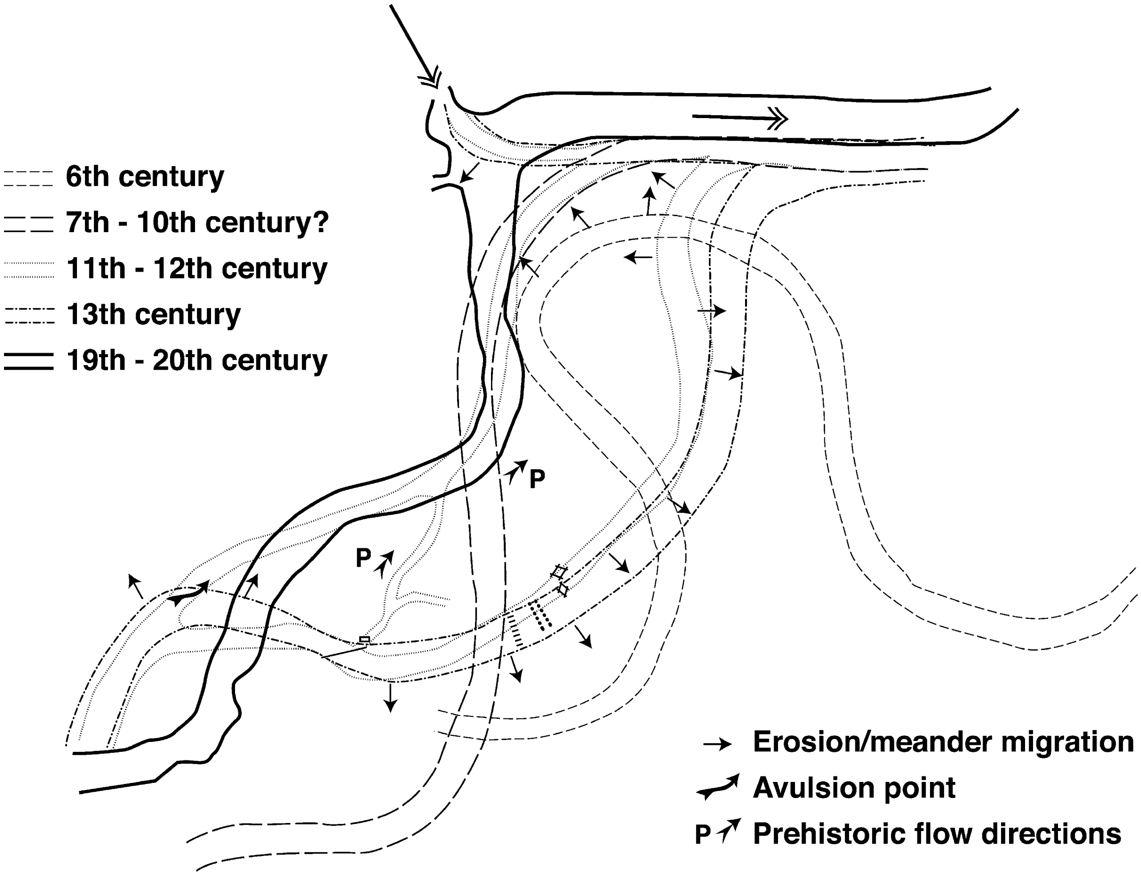

Fig. 3. Hypothetical model of channel changes at Hemington from archaeological, sedimentological and dating evidence.

bridges, the pattern of palaeochannels, derived from the monitoring and plotting of artefacts such as dated fishweirs and anchor stones. For an unknown period prior to the 6th century BC, the Trent had a single

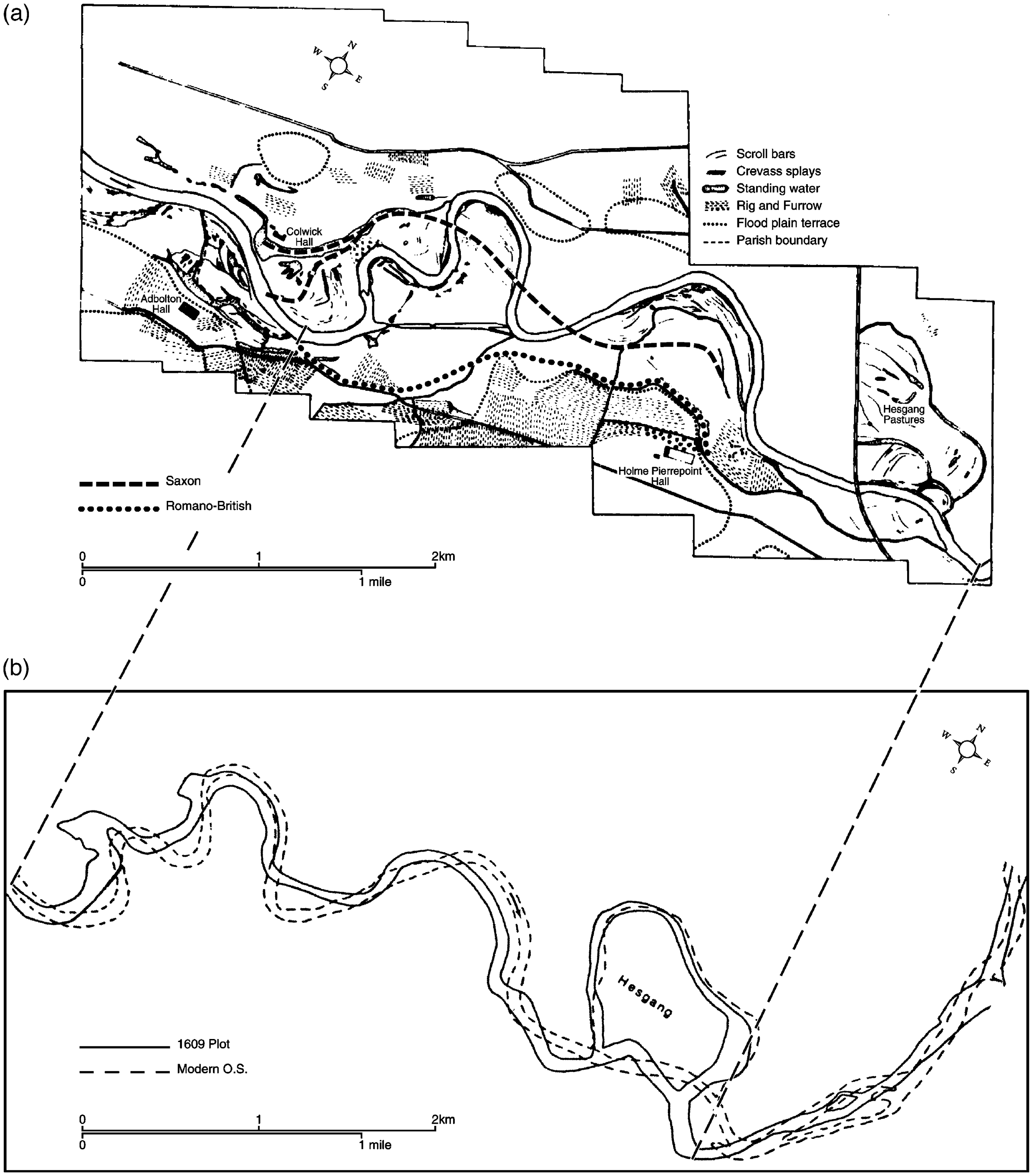

Fig. 4. Major Late Holocene channels of the river Trent at Colwick (a) and channel change 1609–1840 (b). Both adapted from Salisbury et al. (1984).

sinuous channel forming a large meander upstream of Sawley and across Hemington Fields. Evidence for a single meandering channel comes from several reaches including the dated meander at Hemington (which is of similar proportions to the Sawley palaeomeander, see Fig. 1), and downstream at Colwick (Salisbury et al., 1984) and Holme Pierrepoint (Cummins and Rundle, 1969). By the 10th century, sinuosity had decreased and there is some evidence of two channels. The primary evidence of this are fish weirs discovered in a western extension of the aggregate workings (FW I and FW II), at least one of which dates to the late 10th–mid 12th century (FW I), and a Norman Mill discovered in 1985 (Clay and Salisbury, 1990). Together, these indicate a WNW–ESE flow over the mill dam, which considering the evidence of a functioning channel at Bridge I (but one too small to accommodate the full Trent discharge) implies a bifurcation into eastern and western channels at or upstream of the Mill Dam. The Mill Dam was destroyed in a flood around 1140 AD (Clay and Salisbury, 1990). Between the 11th and 15th centuries flow in the easterly channel increases and is presumably balanced by a reduction in the discharge of the westerly channel. The evidence for this is primarily from the increased length and robustness of bridges built across the easterly channel and the results of slope–area and HECII step-backwater modelling, which suggest an increase from a bankful discharge of 50–140 $m^3\ s^{-1}$ for Bridge I to somewhere between 220 and 350 $m^3\ s^{-1}$ for Bridge III. The large ranges of the estimates reflect the many sources of error inherent in such calculations. One possible source of error arises because the input channel dimensions are based upon the structures rather than the channel edges (except in the case of the S bank of Bridge III) and therefore include an estimate for the maximum width of the outer casson or pier to the channel bank. However, the present bankful discharge of the Trent is around 200 $m^3\ s^{-1}$ suggesting that the majority or all the flow of the Trent had shifted into the channel by the estimated date of Bridge III construction in ca. AD 1239 (last felling date from bridge pile). Consistent paleomagnetic dates from a section adjacent to Bridge III show that fine sediments were filling the channel from 1375 ± 50 to 1400 ± 50 (Ellis and Brown, 1998, Section 10) onwards, implying that the main channel had avulsed back into the westerly channel by this date. However, it seems likely that the eastern channel remained open, taking flood flows between the 15th and 16th centuries, eventually leaving only an oxbow lake named the Old Trent along the line of the old county boundary. These dates provide a minimum date for the destruction of Bridge III by floods.

At Colwick studies by Salisbury et al. (1984) revealed a similar cycle of channel change during this period (Fig. 4) with a well-established southern Roman course, a northerly Saxon course with two meanders (9th century) and a divided section (at Colwick Hall) as recorded in 1270 (Salisbury, 1984; Salisbury et al., 1984). There is evidence that a phase of more rapid channel change occurred between 1300 and 1416 with limited braiding, avulsion and channel abandonment. In the late 14th century, considerable channel engineering was undertaken by Richard Byron (Lord of Colwick) and weirs were removed, which had obstructed the channels. By the 16th century (map of 1602; Salisbury, 1983), avulsion to the present meandering planform had occurred. Indeed, in the Colwick reach since 1609 channel change has been limited to abandonment of the Hesgang meander loop and limited meander expansion.

4. Coleoptera and channel conditions

Many issues concerning the response of the River Trent to the flood record and channel change are evident in the insect faunas recovered during archaeological investigations. This is particularly the case with those associated with the bridges at Hemington. The insect faunas are from organic sandy silts deposited below a hurdle (panel made of interwoven woody stems) and under dislodged timbers, associated with the second caisson (bridge pier of box-type construction) of the 11th Century bridge (Bridge I). The close association between the bridge structure and the insect faunas enables direct reconstruction of not only the landscape immediately surrounding the bridge, but also the nature of fluvial conditions, riversides and channel bottom at this time.

The continued existence of reworked gravel and sands in the bed of the channel is one of the key features that allowed the Trent at Hemington to maintain a multi-channel form through the accumulation of in-channel bars. The presence of these conditions in the past is clearly indicated by the insect fauna recovered. Many of the species of water beetle present are today more characteristic of upland gravel-bed rivers rather than those of the silt laden lowlands. *Stictotatsus duodecempustulatus*, *Potamonetectes depressus*, *Orectochilus villous* and the “riffle beetles” or elmids *Elmis aenea*, *Esolus parallelepipedus*, *Oulimmnius species*, *Limnius volckmari*, *Riolus cupreus* and *R. subviolaceus*, are normally distributed outside of the lowlands in Britain today (Holland, 1972; Friday, 1988). In addition to requiring oxygenated waters, elmids are limited in their distribution to those rivers with sands and gravels in their channel base (Nilsson and Holmen 1995; Holland 1972). This may be particularly true of two of the elmids present in the archaeological material at Hemington. *Stenelmis caniculata* and *Macronychus quadrituberculatus* are considered to be very restricted or rare in Britain today (the former has a Red Data Book (RDB) 3 status and the latter RDB 2 status in Shirt (1987). The literature suggests that these two species are often associated with scour holes and plunge pools in larger water channels, such as in rivers (Steffan, 1979). The subsequent decline of these species between the 12th century AD and today probably results from changes in the sediment input to the Trent or river modification and engineering, resulting in the formation of cohesive gravel channel bases and banks.

A number of terrestrial species also suggests that the sands and gravels extended to the bank sides. In particular, the small ground beetle *Benbidion punctatum* is usually found on barren areas of stones and gravel beside fast flowing waters (Lindroth, 1974). It is clear from this insect fauna that though the bridge may have been undermined as the result of the 1141 flood events (Table 1) unstable gravel and sand bed conditions must have existed throughout the entire period of the use of the bridges. Such channel bed conditions can be expected to exacerbate the effects of high discharge events and floods. The implied bed instability is supported by calculations, which attempted to estimate the maximum scour depth from the structure of Bridge I. The relationship between actual scour depth and estimated scour depth only converges if the assumption is made that the bed was not armoured (Brown and Salisbury, in press).

One of the most important implications of the recent sedimentological work at the bridge site is the implication that the Trent, almost alone amongst Britain’s lowland rivers, experiences a period of large scale channel change and migration in the medieval period. This is also largely confirmed in

Table 1
Floods that occurred in the 11th–14th centuries on the Trent (largely from Potter, 1964) with the floods most likely for the destruction of the bridges at Hemington indicated. Potter also notes increase in river freezing and summer droughts in the 13th Century. Pontage is a tax raised for the repair of bridges

Date	Comments
1141$^{\text{Bridge I}}$ (2 Feb)	First recorded flood on the Trent, breached the Spalford Bank. A rain on snow flood similar to 1795, 1946 and 1947
1205	Severe winter, snow and river frozen
1216/17	Severe winter, snow and river frozen
1255 Jul$^{\text{Bridge 2?}}$	A summer flood exacerbated by flood debris
1279$^{\text{Bridge 2?}}$	Caused channel change in the lower Trent (Riley et al., 1995)
1305–1306 Dec–Jan	Severe winter freeze ended by 3 days of rain
1309/1310$^{\text{Bridge 3}}$	Severe winter floods destroyed several bridges and damaged Hethbeth Bridge, Nottingham (pontage issued for its repair) and may have caused channel change at Shardlow and Wilne Pasture (Lang Holme, Courtney forthcoming)
1315/16	Rainfall floods (pontage again issued for Hethbeth bridge)
1322	Severe winter floods
1310–1330	A period of severe winters with damage to bridges almost every winter
1403	A severe flood, which breached the Spalford Bank and caused channel change at Sawley and Lockington (Sand Holme, Courtney forthcoming)

the 11th century fauna of insects recovered at Hemington. The paleoentomological record of several of Britain's rivers, including the Trent, contains substantial numbers of elmid species in Neolithic and Bronze Age deposits (Dinnin 1997; Howard et al., 1999; Osborne, 1988; Robinson, 1991, 1993; Smith, in press) but, it is suggested, few after this time (Osborne, 1988). As suggested above, it is thought the decline of elmids in riverine insect faunas is linked to the onset of the deposition of fine grain "alluvial" sediment (Osborne 1988). The initiation of sedimentological change is normally thought to be either late Prehistoric or Iron age in date (Robinson and Lambrick, 1984), and so it is assumed that this is also the date of the disappearance of the elmids in most lowland rivers. At present, this is a persuasive, but to some extent a circular, argument due to a lack of research into the paleoentomology of post Iron Age channels outside of the Trent catchment (Smith, in press). In spite of this, it seems fair to assert that the Trent, both in terms of the sediments it produces and its insect fauna, is not following the normal pattern of development we observe in the other lowland rivers elsewhere in Britain.

5. The flood records of the Trent basin

The Trent basin has an unusually comprehensive, although incomplete, flood history for the last 900 years. This has been compiled by Potter (1964 and personal communication) for the period prior to the instrumented record. Although the record is essentially qualitative prior to the 18th century, there are two ways in which relative magnitude can be gauged. Firstly, only the largest floods breached the Spalford Bank, which was a flood defense protecting the Witham valley and the city of Lincoln. From the gauged record, it is known that it is breached at discharges over approximately 1000 m^3 s^{-1}. Secondly, damage to bridges and 'pontage' a right to borrow money for bridge repairs, can indicate the largest floods. However, the timing of the flood must be taken into consideration here as a major cause of bridge damage was late summer floods, which swept hay-ricks downstream causing bridge obstruction and damage greater than that which might be expected for the discharge. The flood record shows several large floods during the 12th–13th centuries (Table 1), which can be partly matched with the bridge record using the last felling date derived from dendrochronology and the date of the succeeding bridge. The dendrochronology shows that the first (casson) phase of Bridge I was destroyed in c. 111 AD, prior to the documented flood record, but that the 1141 flood was most likely responsible for the destruction of the second (pile) phase of Bridge I. The destruction of Bridge II is more problematic but the last timber date was 1224 so it could have been destroyed by recorded floods in 1255 or 1279, or unrecorded floods. The chronology of the third bridge is more difficult as it was partly of stone construction, with evidence of maintenance from an inter-pier timber with a felling date of 1270–1305 (Howard in Cooper and Ripper, in press), and so the 1309/10, 1316/16, 1322 and 1402 floods are all possible candidates. However, the last structural (bridge) timber recorded in the whole quarry is dated to 1270–1305, and historical (Courtney, in press) and topographic work has revealed that the inception of Wilne Ferry was in 1310/1311. Since the ferry would have charged and the bridge would not have charged, as it served the King's Road, this implies that the bridge had been lost. The date of 1305/6, or more likely 1309/1310, is also supported by an associated agreement between land owners, regarding access to cut-off land refereed to as Lang Holme and now believed to be Shardlow and Wilne pasture. The 1402 flood caused major avulsion between Hemington and Colwick at Sand Holme near the Sawley meander, leading to land exchange between two manors and agreements to try and stabilise channel location. It is noticeable that for at least 5 of the 11 floods or flood periods listed in Table 1 freezing conditions, rain-on-snow or snowmelt was a major factor, probably resulting from continental blocking of westerly depressions (e.g. a Scandinavian high pressure system). This is in contrast to only three similar events recorded out of the 10 largest recorded floods since the 15th century (Table 2).

The record for the 17th–19th centuries shows a lower frequency of large (approaching or over 1000 m^3 s^{-1}) floods, with a return interval of 66 years for such floods between AD 1402 and 1792 as opposed to 24 years between AD 1100 and 1402. However,

Table 2
The 10 largest floods for which Q is known or has been reliably estimated on the Middle Trent

Rank	Date	Synoptic conditions
1	1795 Feb	Largely snowmelt with some rain, blocking conditions (1400 m^3 s^{-1})
2	1875 Oct	Depressional rain
3	1947 Mar	Snowmelt with heavy rain, blocking conditions—high over Scandinavia
4	1952 Nov	Depressional rain
5	1960 Dec	Depressional rain
6	1946 Feb	Snowmelt and rain, blocking conditions
7	1932 May	Depressional rain
8	1855 Mar	Depressional rain
9	1901 Jan	Depressional rain
10	1886 May	Depressional rain

this difference may partly reflect less information on particular floods and so a less complete series. The largest recorded flood in Britain occurred on the Trent in 1795 (Acreman, 1989). It had an estimated discharge 1416 m^3 s^{-1} (Archer, 1993) and was typically a rain on snowmelt flood associated with blocking of westerlies by high pressure over mainland Europe (Table 2). A period of increased flood magnitudes during the 12th–15th centuries AD is consistent with data indicating an increased frequency of wet and severe winters at the end of the Little Climatic Optimum ca. AD 900–1300 (e.g. Britton, 1937; Hughes and Diaz, 1994; Brown, 1996, 1998).

Given the evidence of the flood record, the cause of the phase of channel change recorded at Hemington would appear to be fundamentally climatically controlled reflecting the sensitivity of the reach to an increase in flood magnitude/frequency and bedload transport rates. High bedload transport rates are suggested by the abundant evidence of in-channel gravel deposition and little evidence of overbank siltation. In this respect, the delay of ca. 100–200 years in the response of the Colwick reach may reflect the time-lag associated with the movement of the bedload pulse or slug (sensu Nicholas et al., 1995) over a distance of 21 km (100–200 m $year^{-1}$). The passage of sediment through a reach typically induces aggradation, which may result in the conversion of a single-thread channel to a multi-channel system (Nicholas et al., 1995). An alternative hypothesis is that the intervening input of the Soar altered channel response. A combination of more accurate dating and clast provenancing would be required to test these hypotheses. Fluvial studies over the last decade have shown that climatic instability at the end of the Little Climatic Optimum was responsible for increased fluvial activity (Rumsby and Macklin, 1996) and alluvial fan sedimentation (Harvey and Renwick, 1987) in the uplands and pulses of topsoil erosion from lowland predominantly arable catchments (Borck, 1989; Foster et al., 2000).

6. Discussion

The question immediately raised is why did the floods of the 12th–15th centuries cause a complete cyclical metamorphosis of the channel at Hemington and similar changes at Colwick and yet later floods have had relatively little geomorphological effect. The first possibility is that the earlier floods were of far greater magnitude. It is extremely difficult to estimate the magnitude of single floods in alluvial reaches with a long flood history. The documentary record, while supporting the observation of a run of large floods over a relatively short period (300 years), does not support the hypothesis that they were of significantly greater magnitude than the 1795 or 1947 floods. A second possibility is that since the 15th century channel engineering has effectively constrained the channel. A common form of channel training on the Trent was the ‘kidweir’; a line of posts, brushwood and wattle. At Colwick, a kidweir has been radiocarbon dated to cal. AD 1458–1640 (Lord and Salisbury, 1997). There was also channel improvements for coal barges during the 16th century including lines of posts and piling designed to increase siltation of the banks and secondary channels, a process known as warping. Downstream of Nottingham, there was shoal removal the construction of rubble walls and the planting of willow trees (osiers); a progressive channelisation of the river. This may explain the lack of response to the 1795 flood at Colwick but not at Hemington where the river was far less channelised. An important indirect human impact has almost certainly been an increase in suspended load supplied from arable fields. The agricultural revolution in the 18th century facilitated the cultivation of the heavier and less fertile soils of the North Midlands and it is generally accepted that extensive land drainage has increased sediment conveyance and increased peak discharges from small tributaries (Green, 1979; Higgs, 1987). An increase in suspended sediment concentrations would have led to increased overbank sedimentation, helping to accumulate silt and fix channel banks and to increased silt and clay deposition on the channel bed on the falling limbs of floods. The cyclic form of channel change at Hemington also suggests there may be an autogenic component to channel response to floods whereby the channel is in transition, and so sensitive to moderate floods in between more stable states, the single-thread meandering pattern. On a Quaternary time scale, the Trent record would reveal a catastrophic change from a meandering to a multichannel state, through avulsion and an increase in stream power associated with a period of frequent large floods (Graff, 1988), but a more gradual change back from the multi-channel to the meandering state. Depending upon bank stability, and height, the meandering state may take many decades or centuries to become susceptible to avulsion as this increases in probability as sinuosity increases. This element, which is in essence Lane and Richards' (1997) 'configurational state', requires testing using numerical modelling and observations of systems over appropriate time scales, probably 1–2 ka years in medium-sized rivers.

7. Conclusions

If it is accepted that the response time of geomorphic systems is scale-related (i.e. size-time related) then medium-sized to larger channels will only show explainable changes at the 10^2–10^3 time scale. If this is the case then historical and archaeological information is invaluable in allowing a reconstruction of fluvial trends, which may then be related to forcing factors such as climate and land use change. The broadening of alluvial palaeoecology has also allowed a new range of techniques to be used at indicators of fluvial conditions (Amoros and Van Urk, 1989). In particular, Coleoptera have the potential to add process detail to reconstructions of past fluvial regime including bed and bank conditions and floodplain land-use. In this case, they show how the channel had a mobile, un-armoured bed and relatively lower suspended sediment load than it carries today.

At both Hemington and Colwick, there is a cyclic phase of channel change from single channel meandering to active braided to fixed multi-channel state (anastomosing) and finally back to a single channel meandering state. This cycle rakes place over 300–400 years between the 9th and 14th centuries, or a little (100–200 years) later at Colwick, and is driven by a series of large floods (Fig. 5). During this period, the recurrence time of floods was probably far shorter than the relaxation time of the channel causing channel conditions to be predominantly transient (TF > 1 sensu Brunsden and Thornes 1979). The climatic context of these floods has been discussed elsewhere (Brown, 1998); however, they do coincide with the Late Medieval Climatic Deterioration, which is generally accepted to have been a time of climatic instability. This channel response is unique for a larger lowland river in England and is almost certainly the result of the unusual hydrometry of the basin. Within 50 km of the Middle Trent, four major tributaries join the main channel and, as

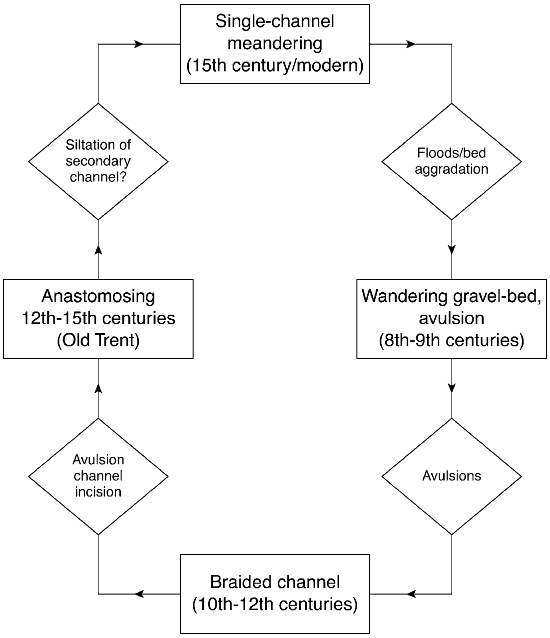

Fig. 5. Late Holocene cycle of channel change at Hemington, the driving mechanism is believed to be a flood-induced increase in bedload transport rates and low bank resistance.

Knighton (1987) has shown, the estimated mean annual flood increases from around under 200 m^3 s^{-1} to nearly 450 m^3 s^{-1}. Two of these tributaries drain adjacent uplands and they alone increase the estimated mean annual flood by 200 m^3 s^{-1} (Knighton, 1987). As Knighton (1998, p. 61) remarks such "discontinuity present in the fluvial system, ... has implications for downstream channel adjustment". The result is that the Trent is very sensitive to rain on snow events and these can cause a switch in the ratio of contributing discharge from a Trent-to a Derwent-dominance (Brown, 1998). The difference in hydrology is illustrated by the flood multiplier (ratio of mean Q to maximum recorded Q), which is 1.6 for the Trent at Shardlow and 3.2 for the Derwent at Longbridge (based on NERC 1975 figures). As Hemington is at the junction of the Trent and Derwent, this may have been particularly important in driving channel change in this reach. From the 14th century onwards, there is little relationship between the rates or relative magnitudes of channel change and flood history. Several possible reasons include a change in channel form causing an autogenic change in channel sensitivity, and increase in suspended sediment load and direct channel modifications encouraging a fixed single-channel form. The remarkable Late Holocene history of the Middle Trent illustrates how the response to floods may depend on the state of the channel and this is determined not only by the past flood history (sensu Erskine and Warner, 1999) but any other change in channel or floodplain conditions including both direct and indirect human impacts.

Acknowledgements

The authors must acknowledge all involved in the Hemington project especially S. Ripper, P. Clay, M. Beamish and other members of University of Leicester Archaeological Services (ULAS). The work was begun with support from J. Mellor and the Leicestershire Archaeological Unit, English Heritage with the agreement and help of Ennemix Construction materials. Work has continued supported by Lafarge Redland. Invaluable assistance was also given by the late H. Potter and his work on the flood records of the Trent.

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