Tools in Geomorphology
Archaeology and Geomorphology

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3.1 Introduction

Geomorphology and archaeology have strong historical and methodological links. Indeed the origins of both geomorphology and scientific archaeology lie in 18th and 19th century geology and the origins of the sub-discipline of geoarchaeology are largely fluvial as exemplified by the work of Zeuner (1945), Antevs (1935), Butzer and Hanson (1968), and Vita-Finzi (1969). The methodological links spring from the aims of modern, or at least processual, archaeology which include the conditions and processes of site formation and destruction (Schiffer, 1987). Both archaeology and geomorphology can be described as historical sciences and the rise of landscape archaeology has also given an additional, and integrating strand to understanding the evolution of the human environment.

In the early history of the relationship between geomorphology and archaeology the intellectual traffic was largely one way: geomorphologists (and geologists) working in the service of archaeology. This formed the basis for the sub-discipline of geoarchaeology, especially in the USA, and continues today (Herz and Garrison, 1998). Indeed there can be few fluvial geomorphologists who have not, at some stage in their career, worked for, or with, archaeologists. However, in the last few decades a counter information-flow has developed based on the use of archaeological information in geomorphology. This is an extension of the use of historical sources, which developed in the 1970s (Hooke and Kain, 1982) and is part of the attempt to reconcile process studies with longer-term landform studies. The value of archaeological data for the geomorphologist is two-fold; first it can date erosion or deposition at the 10^3-10^4 year timescale, and occasionally the temporal phasing of sites can be converted into a spatial phasing of erosional or depositional segments of the landscape providing rates of erosion or deposition. Classic examples include the use of tells or house mounds for estimating erosion rates (Kirkby and Kirkby, 1976), the use of site distribution for erosional surveys (Thornes and Gilman, 1983) or the use of artifacts and sites in the studies of river channel changes (Brown, 1997). A second value of archaeological data is its potential to provide information concerning processes. This is far more complex and is best seen through debates concerning the genesis of a particular feature such as argillic horizons or colluvial sediments (Bell and Boardman, 1992; Brown, 1992), and the processes and environmental significance of ancient mining (Thorndycraft, *et al.* 1999). Although less easily defined it is this second area which has spawned most methodological innovation of value to both disciplines.

Fluvial environments have the greatest influence on archaeology of all the geomorphic regimes due to the ubiquitous nature of fluvial processes and the close proximity of human settlements to fresh water sources for drinking and irrigation (Davidson, 1985). In essence, the goals of fluvial geomorphology in the archaeological context are a subset of the goals of geoarchaeology (Table 3.1). It is not the purpose of this chapter to review standard field methods of archaeology. These methods are covered elsewhere; e.g. Barham and Macphail (1995), Courtney *et al.* (1989), Gladfelter (1977), Holliday (1992), Rapp and Gifford (1985). Instead, this paper will elucidate tools and methods in fluvial geomorphology and archaeology that have been widespread and mutually rewarding in their applications.

Table 3.1. Goals of fluvial geomorphology. Adapted from components of geoarchaeology given by Hassan (1979), Goudie (1987), and Macklin (1995).

Locate sites	Interpret artifacts
Analyse geomorphology of sites	Model dynamics between culture and landscape
Develop the regional stratigraphy	Site preservation
Analyse the sedimentology	Dating
Reconstruct palaeo-environments	

Contributions to archaeology that can be made by fluvial geomorphologists include mapping present, past, and changes in landforms, soils, sedimentary deposits, and environments. Mapping should be aimed at the identification of both descriptive and analytical information (Davidson, 1985). Descriptions of the physical setting of a cultural site has the longest history in geoarchaeology due to the need to establish the time and physical context in which past human societies lived. Thus, stratigraphic and sedimentary evidence that constrains a culture in time and establishes the environment in which they existed is obviously germane. More recently, however, the analysis of how environmental change influenced cultures and *vice versa* has proven to be of great relevance to both archaeological and geomorphic studies (Hassan, 1985). Early examples of analytical studies include Bryan's (1926) study of the Chaco Canyon culture, Hack's (1942) analysis of the Hopi Indians in Arizona, and Jacobsen and Adams' (1958) documentation of environmental changes in Mesopotamia (cf. Davidson, 1985). Macklin (1995) identifies three areas of focus for such research in Great Britain:

1. The role of river processes in altering sites in channel and floodplain environments,
2. reconstructing past land use from alluvial sediments, and
3. integrating Quaternary alluvial histories with the archaeological record.

Alluvial deposits may provide a distinct stratigraphic marker allowing relative dating of surrounding materials, revealing the nature and magnitude of past environments, and, through provenance studies, providing spatial information about where environmental disturbances occurred in a watershed. The complexities of interpreting alluvial deposits are covered by Butzer (1980), who cautions against regional correlations based on local sequences.

The two-way relationship between archaeology and geomorphology is reflected in the composition of this chapter, which includes not only the use of archaeological techniques in studies of fluvial geomorphology but also the potential of geomorphology in environmental and landscape archaeology. This is not least because the two subjects are closely and conceptually connected despite the organisation of research funding.

3.2 Archaeo-historic Tracers

Archaeological data can often be used to correlate fluvial deposits, constrain them in time, and explain their genesis through the identification of cultural activities and fluvial processes. One common use of archaeological data is the mapping and analysis of anthropogenic tracers in fluvial sediments. Tracers are distinct elements that can be identified in downstream deposits. Many materials may act as tracers, including distinct lithologies, metals, magnetic materials, isotopes, mining sediment, and cultural artifacts. Chapter 10 provides a detailed discussion of the use of tracers in fluvial studies. This section is concerned with anthropogenic materials that can be used as tracers in fluvial sediment and how they may constrain the spatial and temporal nature of sediment genesis. A broad definition of archaeological tracers is adopted in this discussion that includes not only the use of cultural artifacts and materials of antiquity, but also the use of more recent human-induced markers such as metals, mining sediment, and radioactive isotopes.

The characteristics of archaeological tracers and the deposits in which they occur may indicate important aspects of their source, mode of transport, and age. Careful observations should be made to determine the geomorphic setting and the condition of artifacts, whether they occur in primary positions of human deposition or in secondary deposits, and the geomorphic setting. For example, the amount of abrasion on individual artifacts may reveal distance from their source. Abrasion increases downstream as has been shown with modern facsimiles of flint hand axes (Harding *et al*., 1987; Macklin, 1995). Concentrations of tracer materials generally decrease with distance downstream due to dilution by barren sediment from local storage sites and from tributaries. This principle has been used with white vein-quartz concentrations to demonstrate rates of sediment dilution (James, 1991). The identification of the source of artifacts has long been a concern of archaeologists and geomorphologists can learn much from recent archaeological studies of provenance. For example, X-ray fluorescence spectrometry has been used to identify the source of lithic artifacts (Jones, *et al*., 1997; Williams-Thorpe, *et al*., 1999), and a variety of techniques were used by Pollock, *et al*. (1999) to identify artifacts of various lithologies. Identification of the provenance of a stone tool can allow correlations of artifacts with particular groups and periods of activity. The use of artifacts as stratigraphic markers on floodplains is covered further in a later section (3.4c).

a) Mining Sediment and Metals
The link between cultural activities and sedimentation is particularly well expressed by mining. Mining sediment not only provides evidence of fluvial processes, but also

provides prime examples of fluvial responses to human alterations of the environment. All extractive mining and mineral processing produces some waste, which is either separated using rivers, deliberately added to rivers, or eventually enters rivers via natural geomorphic processes. This line of geomorphological research can be traced back to Gilbert's (1917) classic study of mining in the Sierra Nevada which produced about a billion m^3 of sediment (Gilbert, 1917; James, 1999, and as illustrated in Figure 3.1).

Figure 3.1. Hydraulic gold-mining sediment deposited in Greenhorn Creek, northern California, 1862-1880. Subsequent incision left high terrace (middle background) ~15 m above channel. View upstream, ca.1990.

Several workers have distinguished between two types of sediment transport: *active transformation* where the fluvial system is transformed by the introduced waste (e.g., Gilbert's study) and *passive dispersal* where sediment markers are passed downstream mixed with the natural sediment without causing a substantial change in channel morphology (Lewin and Macklin, 1986). While useful, this distinction does pose certain problems, as it is fundamentally a function of the degree of fluvial change and the sensitivity of our detection of that change. Secondly, mining is often accompanied by other land-use changes, often agricultural intensification in order to feed a growing population, and so sediment loads may increase indirectly and from other sources. Some of these questions are discussed in the case studies presented below (3.2b and 3.2c). Mining sediment has often been studied because it forms distinctive stratigraphic units that can be recognized throughout a river course, dated, and related to specific cultures or activities. Mining often amplifies background sediment loads by more than an order of magnitude as was shown in a basin-wide analysis by Gilbert (1917) and was demonstrated in a paired-watershed study of strip-mining in Kentucky (Collier and Musser, 1964; Meade *et al*., 1990). Several studies have documented severe alluvial sedimentation and channel morphologic changes below mines in Great Britain (Lewin, *et al*., 1977; Lewin and Macklin, 1987) and North America (Gilbert, 1917; Graf, 1979; James, 1989; Knighton, 1991 and Hilmes and Wohl, 1995).

Mining sediment is often rich in metals (Reece, *et al*., 1978; Leenaers, *et al*., 1988), The distinct signature of heavy metals associated with many mines often allows a local metal stratigraphy to be developed downstream of mines. For example, Knox (1987) was able to correlate floodplain strata with elevated concentrations of lead and zinc with periods of mining in southwest Wisconsin. Wolfenden and Lewin (1977) and Graf, *et al*. (1991) developed similar chronologies for rivers in Wales and Arizona, respectively. Sediment sampling for evaluation of metals requires an understanding of fluvial transport processes and depositional environments. Heavy metals are often concentrated in the fine fraction of sediment due to sorting processes of the denser metalliferous particles; i.e., the principle of *hydrodynamic equivalency* (Rubey, 1938). In mining sediment, however, this relationship may be complicated by the presence of multiple populations including coarse metal particles, fine metal particles, and coatings on or inclusions in particles of various sizes and densities. The importance of particle coatings varies with the metals being sampled and ephemeral environmental factors such as pH which encourage speciation into oxide, hydrous oxide, and other phases. Most studies perform chemical analysis on a sand fraction isolated by sieving. Sampling and sieving should be performed with a minimum use of metal tools to avoid contamination. In a comparison of laboratory methods Mantei, *et al*. (1993) found that metal concentrations were homogeneous in the very fine sand grade, that splitting samples into quarters was not necessary, and that crushing followed by sieving should not be done prior to chemical analysis.

Changes in metal concentrations below a source are often modeled as a simple downstream logarithmic decay function (Wertz, 1949; Lewin et al., 1977; Wolfenden and Lewin, 1978). Marcus (1987) showed that the downstream decay in copper was largely due to dilution by sediment from non-mining tributaries. Graf (1994) described the complexities involved in mapping downstream changes in plutonium and demonstrated a general decrease in concentrations downstream in tributary canyons to the Rio Grande (Figue 3.2). At the channel-reach scale, metal concentrations may vary greatly with geomorphic position. For example, Ladd, *et al*. (1998) sampled 12 metals in seven morphologic units of a cobble-bed stream in Montana, U.S.A. They found that concentrations varied between units; e.g., eddy drop zones and attached bars had high concentrations while low and high gradient riffles and glides had low concentrations. severely weathered source sediment enriched in resistant minerals,

b) Tin Mining and Fluvial Response

Alluvial tin mining produces large amounts of sediment which is directly input to rivers along with an increase in competent flows. Tin mining also has a long history, since it is one of the constituents of bronze and has been mined in Europe since the beginning of the so-called Bronze Age (third millennium BC). Both archaeologists and geomorphologists have a shared interest in the period before written records; the archaeologist in using sediments to search for pre-Medieval tin mining and geomorphologists in both dating alluvial deposits and understanding river behaviour at the 10^3 -years timescale. A geochemical survey of rivers draining Dartmoor, SW England was undertaken by Thorndycraft *et al.* (1999) in order to address both these questions. In this case archaeological evidence of pre-Medieval tin mining is unlikely due to the almost complete reworking of any earlier deposits by late and post-Medieval tin streaming. Floodplain sedimentary successions, that had not themselves been mined, but are downstream of known areas of tin streaming, were found to retain a geochemical record of the mining activities because the early tin streaming released large quantities of mine waste tailings. Radiocarbon dating of these sequences has shown an excellent match with the documentary record confirming a first phase of streaming commencing in the 12-13th centuries AD, reaching a maximum in the 16th century, and a later phase in the

19th and early 20th centuries AD (Figure 3.3). A combination of XRF on particle-size fractionated sediment and SEM/EDS studies of density separated samples allowed the geochemical characterisation of, and distinction between, streaming waste and naturally tin-enhanced sediments. In the Avon, Teign and Erme valleys there is considerable overbank sediment aggradation coupled with the tin enhancement and this was probably associated with changes in channel pattern and morphology.

A clear example of active transformation associated with Sn mining is Knighton's (1989, 1991b, 1999) work on the Ringarooma basin in Tasmania. In this case mining lasted for over a hundred years from 1875-1982 during which time 40 million m^3 of sediment was added to the river. The result was channel metamorphosis with bed aggradation, an increase in width where the channel was not confined, and the development of a multiple channel pattern. Only now is degradation in the upstream reaches returning the river to something like its pre-mining condition. Similar results have come from studies of the fluvial response to lead mining in upland Britain and in particular the combined effects of increased sediment supply and climate change in the form of perturbations in flood magnitude-frequency relationships (Macklin, *et. al,*, 1992).

c) Slags, Bedload and Hydraulic Sorting

Bedload transport has been evaluated in rivers using slags coming from old ironworks settled in the south Ardennes valleys in the early 17th century (Sluse and Petit, 1998). During these periods, the slags have been introduced to the rivers and they continue to be transported even though these factories have been closed for a long time. The slags are easily recognizable due to their low density of 2.1 g cm^{-3}. The slags have been sampled in nineteen riffles situated along the River Rulles, in its tributaries where ironworks have been installed, and downstream, in the River Semois into which the River Rulles flows**.** Figure 3.4A shows the trend of the size of the ten biggest particles measured by the b-axis (corresponding to D_{90}), along the River Rulles course, using a cumulative distance from the most downstream of the iron factories (explaining the decrease of the size in sites 1 to 3). The slags brought down by tributaries explain the increase of the slag size in the Rulles (e.g. site 4, and sites 7 to 10). Slags have also been found in the Semois (site 15) but none 4 km downstream of this last site.

A relationship is drawn between the slag size and the distance from the ironworks where these slags have been delivered to the river (Figure 3.4B). This curve shows a rough decrease of particles size which range from 80 mm to 20-30 mm in diameter in less than 5 km; afterwards the slag size decreases slowly. Slags fining in the first few kilometers downstream the ironworks does not result from variations in hydraulic characteristics of the river or from a diminution of its competence. Indeed, the unit stream powers remain identical along its course. This slag size reduction does not result from abrasion, neither from granular disintegration nor gelifraction effects (Sluse and Petit, 1998). It results from an hydraulic sorting occurring in the few kilometers following the deposition sites.

The slag size which, after 5 km, remains almost constant regardless of the distance, represents the actual competence of the river (the particle size transported along substantial distances and evacuated out the catchment). The particle size is relatively small (12 mm maximum with regards to equivalent diameters using a density of 2.65 g cm^{-3}), which is explained by low values of the unit stream powers (25-30 W.m-2 at the bankfull discharge). More competent flows allow better hydraulic sorting, but is exerted only locally and during intense events.

Several slags (10-14 mm in diameter or 9-12 mm using equivalent diameters) have been found 12,5 km downstream from the closer iron factory, which produces a bedload wave progression of 3.3 km/century (Figure 3.4A). The most upstream site in the river Semois where no slag has been found shows that the bedload wave progression is less than 17 km since the middle of the 17th century (<3.9 km/century). Such progression is low in comparison with others studies (between 10 and 20 km/century) but has been observed in mountain rivers with high energy (Tricart and Vogt, 1966; Salvador, 1991).

3.3 Archaeology as a Tool in Geomorphology

Archaeology can provide far more valuable information than just dating, indeed dating has now become the prerogative of the geomorphologist with artifact typological chronologies being re-evaluated using sediment-based dating techniques. Archaeology can provide rapid evidence of landsurfaces, sediment reworking and palaeoenvironmental conditions. It can also under favourable conditions set parameters which can be used in the modelling of past processes.

a) Lateglacial and Early Holocene Rivers and Floodplains

The distribution and character of Palaeolithic and Mesolithic sites in Europe owes much to geomorphological processes. Indeed as Wymer (1976) pointed out "artifacts in river gravels constitute 95% of the evidence for Lower Palaeolithic human activity in Britain and over most of the Northern hemisphere": the figure would only marginally be less for the Upper Palaeolithic. The role of artifacts for dating purposes (typological chronology) has been largely replaced by a combination of geochemical methods such as electron spin resonance (ESR), thermal and optically stimulated luminescence (TL and OSL) and amino-acid racemisation (AAR) and good biostratigraphic markers such as small mammals (Brown, 1997). The distinction between *in-situ* and transported artifacts is, however, highly significant in geomorphic terms since *in-situ* flint scatters mark ancient floodplain surfaces and breaks in vertical deposition. The occurrence of *in-situ* archaeology becomes more common in the early Holocene where we can clearly see a geomorphic element in site distribution. Artifact scatters are frequently found on what were large exposed gravel bars particularly at tributary junctions and downstream of gorges. This distribution suggests that downstream of both tributaries and gorges, or valley constrictions, channel change has proceeded by nodal avulsion either side of large bars which were the result of downstream changes in hydraulic conditions during the Lateglacial. These relict gravel bars constituted the floodplain surface in the early Holocene before significant overbank deposition buried them and transformed lowland floodplains (Brown, *et al*,, 1994; Brown and Keough, 1994). The archaeological sites are invariably near palaeochannels and presumably were associated with the use of water, relatively open areas and possibly fishing as revealed at Noyen-sur-Seine (Mordant and Mordant, 1992). Studies of these sites have produced the most detailed 3-dimensional reconstructions the geomorphology of early to middle Holocene floodplains such as the

Thames (Allen, 1997) and the chalk valleys (Evans *et al*. 1988), revealing how different these floodplains were from those that evolved during the late Holocene and exist today.

b) Holocene Channel Changes and Palaeohydraulic Conditions

Archaeological finds can provide both the opportunity and raison d'etre for the reconstruction of past geomorphic and hydraulic conditions. The exploitation of aggregate from large areas of the Middle Trent floodplain in central England has allowed the excavation and recording of hundreds of archaeological finds including, human and animal skeletal remains, log-boats, fish weirs, anchor weights, revetments, bridges and a mill. Together with `natural' finds such as tree-trunks, organic palaeochannel sediments and flood debris this has allowed a geomorphological reconstruction of the Holocene evolution of the Middle Trent floodplain based on both an archaeological and radiocarbon chronology. From Hemington and surrounding investigations the following a partial fluvial history can be postulated (Table 3.2).

Period	Channel type	Sites	Notes
Windermere Interstadial	**meandering**	*Hemington*, basal channel peat (Brown *et al*. in prep.)	down-cutting into terraces and bedrock
Loch Lomond Readvance	**braided**	*Hemington* basal gravels (Brown et al. in prep.), *Church Wilne* (Coope and Jones, 1977; Jones *et al*. 1977), *Attenborough* (BGS, Brown unpub.)	deposition of basal `Devensian' gravels and intense frost action creating polygons
Mesolithic	**low sinuosity, possibly multiple-channel (anastomosing)**	*Shardlow*-stocking palaeochannels (Challis 1992, Knight and Howard, 1994), *Repton* (Greenwood and Large, 1992), *A6 Derby By-pass* (Brown in prep), *Attenborough* (BGS, Brown unpub.)	some avulsion leaving linear palaeochannels, which are often over a kilometer from the present channel
Neolithic	**multiple channel-braided, low sinuosity**	*Hemington* (Clay and Salisbury, 1990), *Colwick* (Salisbury et al. 1984), *Langford* and *Besthorpe* (Knight and Howard, 1994)	fishweirs and black oaks in small-shallow channels
Bronze Age	**meandering?**	*Colwick* (Salisbury *et al*. 1984), *Collingham* (Greenwood, pers. com.)	little evidence except at Colwick and downstream
Iron Age and Roman	**meandering, sinuous, point-bar sediments**	*Holme Pirrepoint* (Cummins and Rundell, 1969)	palaeochannel associated with settlement at Sawley and evidence of settlemnt on the terraces, excavated site RB site at Breaston (Todd, 1973)
6th-9th centuries AD	**meandering, highly sinuous**	*Hemington* (Ellis and Brown, in press)	large palaeochannel dated by radiocarbon and palaeo-magnetics
11th-13th centuries AD	**braided, unstable**	*Hemington* (this publication), *Colwick* (Salisbury, et al. 1984), *Sawley* palaeochannel (this publication)	channels associated with the bridges
17th-19th centuries AD	**anastomosing to single-channel, moderate to low sinuosity**	*Hemington* (this publication)	avulsion sometime between 15th-17th centuries from the Old Trent to the modern Trent
19th-21st centuries AD	**meandering, stabilised**	map and documentary evidence	embanked, partially regulated and engineered, construction of the Trent and Mersey canal,

			Sawley cut and Beeston canal

Table 3.2. A tentative chronology of the channel change Hemington-Sawley reach of the Middle Trent derived largely from geoarchaeological studies.

The middle Trent has been characterised by channel change throughout the Holocene. In the absence of a high slope (Hemington-Sawley average only 0.0006 m m^{-1}), this is most likely due to a rapid downstream increase in discharge from the four major tributaries which enter the main channel in under 40 kms, the flood characteristics of two of these tributaries and an abundant supply of unconsolidated or cemented sandy gravels provided by the low and wide Devensian terraces. The unusual width of the Late Devensian (oxygen isotope stages 3-2) gravel terraces here is proximity to the Devensian ice margin which was just under 30 km upstream. The early to mid-Holocene data are largely derived from palaeochannels whilst the late Holocene period is known in most detail due to the occurrence of buried bridges, a mill and weir and abundant other evidence of channel change. Several geomorphologists have attempted to use archaeological structures to quantify geomorphological parameters. This is based on the rationalist assumption that structures such as bridges, weirs etc. were built to contain a certain flow, functioned by containing a run of flows. In some cases destruction of the structure by a flood can also be used to estimate the magnitude of the event. Geomorphological studies of three Medieval bridges buried under gravels in the floodplain of the Middle Trent have employed several of these techniques including simple slope-area calculations of discharge from channel dimensions, HEC-II flow modelling and palaeohydraulic calculations based upon transported and non-transported clasts (Brown and Salisbury in prep.). The sedimentology, the archaeology and the pattern of palaeochannel fragments suggest that the reach was highly unstable during the Holocene and especially the last thousand years. The sedimentology suggests relatively shallow unstable channels eroding and depositing sand and gravel. The predominant sedimentological features, horizontal and low angle bedding with shallow channels suggests a locally braided river and this is in agreement with the low sinuosity of the channels during the early Medieval period. However, the preservation of old palaeochannels and archaeological features (such as the mill and bridges) and the avulsion of the channel sometime between the 15th and 16th/17th Centuries suggest that the river underwent a braided and anastomosing phase before returning to a single-channel meandering form. The typical form of both braided and anastomosing reaches has been used in a generalised geomorphological model of the reach from the 8th-19th Centuries (Figure 3.5). It is impossible to accommodate both the archaeology and the palaeochannels unless the reach has at least two (preferably three) functioning channels. The evidence suggests that channels migrated eastwards leaving a Prehistoric meander core, but that a functioning westerly channel (even if small) until an avulsion sometime between the 15th and 16th/17th century led to the abandonment of the easterly channel (Old Trent) and conversion of the westerly channel into the only permanent channel in the reach. Associated with the increase in channel numbers is a drop in main channel sinuosity as would be expected during a period of braiding and high bedload movement through the reach. This model therefore suggests that this reach of the Trent went from being a meandering single-channel river in the early medieval period (6th-9th centuries) to a braided river in the 10th-11th centuries back to a single-thread meandering river by the end of the 17th century probably passing through an early wandering gravel-bed phase and a later transitional anastomosing phase. This is a classic example of medium to long term metamorphosis of a river channel and floodplain. The processes responsible for this change are large floods, particularly those generated in the Pennine uplands and an increase in the transport of bedload into and through the reach. The trigger for this remains unclear but may have been floods, probably rain on snow, that occurred during the 11th-13th centuries, a period which has been labelled the `Crusader cold period' and is part of the Late Medieval Climatic Deterioration. The cycle of channel change is clearly related to abundant bedload supply and high sediment transport rates, and can be viewed as channel adjustment to a pulse of sediment which was - through channel metamorphosis - deposited into floodplain storage. The nature of the reach (shallow channels) was taken advantage of for the construction of bridges, the builders being presumable unaware of the transitory nature of the channel conditions or constrained by the geography of the route. The climate changes of the Late Medieval period and early modern period are now considered to have probably been the most dramatic in the Holocene (Rumsby and Macklin, 1996) and the Middle Trent is particularly sensitive to changes in hydrometeorology. This is not to say that there were no human impacts on these events, as deforested uplands are far more likely to produce large rain on snow events due to the increased depth of the snowpack that can accumulate over grass as opposed to tree cover. Likewise there is little doubt that runoff generation times have been decreased, and therefore peak flows increased, by drainage and land-use change (Higgs, 1987).

Irrigation structures should also reflect the prevailing hydrological conditions. Gale and Hunt (1986) attempted to use floodwater farming structures in Libya to reconstruct water supply during the Roman period. They used the Darcy-Weisbach equation and an expression for roughness in turbulent flow in rough channels. Drainage and artificial channels used in mineral processing should also reflect the prevailing hydrological conditions. Bradley (1990) has attempted to use the dimensions and slope of tin streaming (alluvial mining) channels to estimate late Medieval stream powers and used this to support the observation that downstream floodplain and channel sediments were relatively enriched in cassiterite content of the >63 microns particle size fraction which in this case is part of the active transport of mining debris. Bridges provide the most obvious evidence of channel change in either the case of bridges over palaeochannels or over contemporary channels. There is of course a conceptual problem with channel evidence from bridges. First, bridges may not be randomly located along channels. Second, most bridges replaced fords and in many cases were clearly located where the channel and floodplain was constricted and a terrace or high bank could be used in construction. The second factor will also depend upon the state of bridge technology; early bridges with restricted single spans restricted to narrow or divided channels and later bridges requiring solid foundations on terraces or bedrock. However, the geographical location of a bridge depends upon the population pattern with routes linking towns or villages by the shortest or most practical route. So bridge *site* is fundamentally controlled geomorphologically whilst bridge *location* is generally dictated by routes linking centres of population, at least in lowlands. It has also been argued that bridges prevent channel change. Whilst this is certainly true in the case of lateral migration where it depends upon continued capital investment in the structure, it is not true where avulsion is a major cause of channel change.

3.4 Rivers and the Archaeological Record: Rivers as Artifacts of Human Activity

Human activities are intimately intertwined with fluvial processes. In early cultures and rural societies human impacts on fluvial systems are expressed primarily through the effects of land use on increased water and sediment production. Later and in developed areas, hydraulic channel works for irrigation, flood control, wetland drainage, navigation, and defense are common, and channel morphologic changes may show effects of local engineering alterations (e.g. Vischer, 1989). Local hydraulic effects of engineering works are beyond the scope of this chapter which examines the use of archaeological and fluvial data such as anthropogenic sediment to document environmental changes to watersheds.

Reconstruction of the interactions between cultural groups and their environment is a primary concern of geoarchaeology. Therefore, methods in fluvial geomorphology are needed that can elucidate contemporary palaeoenvironmental conditions, constrain them in time, and show environmental changes caused by or influencing human occupation and site abandonment. Similarly, archaeological methods may assist in the identification and correlation of a particular cultural surface on floodplains throughout a watershed. Evidence of climate or land-use changes may be preserved by fluvial forms in valley bottoms which can be studied to reconstruct changes in human societies. A common feature of floodplain stratigraphy is one or more buried soils representing surfaces that were stable prior to an episode of aggradation. These surfaces typically have distinct characteristics such as thick, dark A horizons (Happ, 1945, Knox, 1972; 1987). If a buried surface was the site of human habitation or cultivation this may be determined by testing soils for characteristic chemical residues for the region (Middleton and Price, 1996), elevated phosphate levels (Bjelajac. *et al*. 1996), pollen, organics, thin sections, or micromorphological features (Bryant and Davidson, 1996). Sediment overlying soil surfaces may be the result of human disturbances or it may represent an environmental change that influenced human habitation of the region. If anthropogenic sediment is sufficiently distinct, it may be possible to recognize and measure the extent and magnitude of valley bottom aggradation, and possibly to determine whether the event was human or climate induced.

a) Sediment Generation and the Role of Land Use

Understanding the ubiquitous nature of anthropogenic alluviation in modern floodplains is essential to efficient archaeological exploration. Modern floodplains are often covered by thick layers of historical alluvium so primary deposits containing older cultural features are typically found below the surface at depths that depend upon historic sedimentation rates. In addition, techniques in fluvial geomorphology allow the reconstruction of human-environmental interactions. Cultural activities in watersheds that reduce the vegetation cover decrease infiltration rates and increase runoff and sediment production. While Mesolithic cultures of Europe had less impact on runoff and erosion than their agricultural successors (Brown and Barber, 1985; Brown, 1997), they did open forests by burning which had an impact on soil erosion, particularly in fragile ecosystems (Simmons, *et al*., 1981). Perhaps their greatest importance is the role they played in establishing sites that were sequentially occupied by agricultural groups (Limbrey, 1983). Similarly, in the New World, sedimentation and burial of cultural sites by alluvium was occurring in the southeastern U.S. during the Archaic cultural period; that is, during the early Holocene long before cultivation was introduced (Delcourt, *et al*., 1986).

Agriculture is the most widespread land use associated with soil erosion and valley aggradation, so the spread of cultivation – particularly when practiced in conjunction with forest clearance – has been associated with accelerated erosion and sedimentation. These effects dominated early forms of human impact on the environment. Archaeological evidence including a stone hand sickle and other farming implements indicates the earliest known agriculture occurred ca. 13,000 B.P. (before present) in Jarma of present northern Iraq (Troeh, Hobbs and Donahue, 1991). Other villages in the area dateing from 13,000 to 11,500 B.P. were upland sites, with silt loams that would have been easily tilled and farmed. Along the Tigris-Euphrates, lowland sites were occupied from 11,500-10,800 B.P. in present southern Iraq (Troeh, Hobbs, and Donahue, 1991). The complex relationships between land use, climate change, erosion, and sedimentation in the Mediterranean and western Europe are summarized by Blaikie and Brookfield (1987), Limbrey (1983) and Brown (1997). Limbrey (1987) describes historical changes in land use in the Severn Basin in which farming begins in the lowlands during the Neolithic by skilled and experienced soil managers, so fluvial sediment deposition was limited to local sites on low terraces and along valley margins. In the late Neolithic, however, farming and forest clearance progressed to above 300 m elevation and presumably sediment production accelerated. In the New World human cultivation and the manipulation of native vegetation began by ~4000 yr. B.P. in the southeast and ~1000 yr. B.P. in the northeast (Delcourt, *et al*., 1986). For the historical period in Europe, there are a number of studies of fluvial change based on documentary information (e.g., Petts, *et al*., 1989; Chapter 4 of this book). The relationships between land use and sediment production can be understood through study of modern analogues and through field and historical-stratigraphic reconstructions. Modern erosion rates can be modeled and applied to past conditions based on theoretical or empirical relationships of sediment detachment and transport (Lal, 1988). Empirical models such as the USLE (Wischmeier and Smith, 1965), RUSLE (Renard, *et al*., 1991), or WEPP (Foster and Lane, 1987). Application of this approach to paleolandscapes requires the estimation of contemporary land uses and land covers. Historical methods of reconstructing land-use changes and soil erosion include field, laboratory, and documentary procedures that fall in the various fields of archaeology, geomorphology, history, and geochemistry. For older periods, documentary records are lacking and empirical evidence must be derived from upland field studies including archaeological digs and measurement of geomorphic features such as gullies and soil characteristics. Trimble (1974) estimated post-European contact soil erosion in the Southern Piedmont of the eastern U.S. by examining present soil A horizon thicknesses as noted in county soil surveys. Additional sediment production volumes produced by gullies may be estimated by cross-section surveys and dated by denrochronologic methods. A relatively recent method of estimating soil erosion from agricultural fields by using 137Cs fallout is not only a powerfull geomorphological tool (Quine, 1989; Ritchie and McHenry, 1990) but also has potential in the assessment of the rates of destruction of archaeological sites (Jones, 1998).

b) Floodplains, Alluviation and Landuse Change

Numerous studies document historical valley alluviation in Europe, Great Britain, and North America. For the historical period in Europe, there are a number of studies of fluvial change based on documentary information (e.g., Petts, *et al*., 1989; Chapter 4 of this book). Based largely on field evidence, historical sedimentation and channel changes are documented on the River Severn (Lewin, 1987; Brown, 1987) and the River South Tyne (Macklin and Lewin, 1989) in Great Britain. Happ, *et al*. (1940) describe sediment components of a facies model (Table 3.3) for historically aggraded floodplains of meandering channels. Knox (1972) described a laminated silt loam deposited in midwestern U.S. floodplains by overbank sedimentation and related these deposits to 19^{th} century land-use changes following the introduction of agriculture. Costa (1975) describes similar deposits in the Atlantic Coastal plain of the eastern U.S. and noted that only 34% of the sediment had left the upper watershed. Jacobson and Coleman (1986) identified three sedimentary units in Maryland Piedmont floodplains. In addition to a thick, fine historical overbank unit, they describe lateral accretion deposits associated with post-agricultural decline of sediment yields.

Table 3.3 Genetic types of fluvial sediment associated with floodplains. (Happ, *et al*., 1940)

Channel-fill deposits
Vertical accretion deposits
Flood-plain splays
Colluvial deposits
Lateral accretion deposits
Channel lag deposits

These geomorphological studies and geomorphological studies of archaeological sites have shown how, but to a variable extent, contemporary floodplains can be regarded as artifacts of human activity. From the Bronze Age onwards in the lowlands of North West Europe, floodplain and fen-margin sites reveal evidence for increased flooding and alluviation. The picture is much less clear for upland sites (Richards, *et al.*, 1987). This is partly due to the lack of preserved archaeological sites on the valley floors and the more dynamic response of upland rivers to individual storms and changes in flood frequency and magnitude (Macklin, 1999). Before describing some of the evidence for lowland alluviation, it is worth considering the types of data that may indirectly reveal floodplain accretion, other than a dated increase in overbank-silt deposition. Firstly, pedological data: a lack of soil development and soil structure, caused by a lack of bioturbation and soil development. Soil micromorphology frequently reveals a decrease in pedological fabric and an increase in un-bioturbated sedimentary micro-features in soils developed on young historical sediment (Limbrey, 1992). This reflects rapid vertical accretion which could be caused by an increase in flood frequency or an increase in the sediment loading of individual overbank flows. [The former is probably more important than the latter as fine sediment is supply rather than transport-limited although both may be the result of climate and land-use change. {It does not seem clear to me that this last sentence is necessary or central to the point. Increased sediment loads often accompanied increased flood frequencies. The anthropogenic causes of increased flood frequencies - gullying, increased drainage densities, and loss of vegetation and permeable soil epipedons – all also correspond with increased erosion, so not as limited in supply as at present. A second, more ambiguous, data type is the existence of an *in situ* peat horizon or tree stumps, which may result from a rise in the floodplain watertable, which may, or may not, be accompanied by increased alluviation (Robinson, 1992). A third data type is, a coarsening up sequence, especially a band of fine gravel or coarse sand, traceable laterally across a site and lastly, the partial destruction of a site by channel change or catastrophic flooding. Just as the nature of the evidence varies, so does the nature of the hydrological change implied; from the lumped hydroclimatic response of watertable variations to the episodic response exemplified by flood sediments. In this context, we have to remember that one flood does not imply hydrological change, in contrast to evidence of a permanent rise in floodplain watertables which does. Variations in the frequency of flooding and rates of alluviation change the floodplain environment; for example, floodplain "islands" or terrace remnants may disappear - as alluviation raises the floodplain around them and it may even bury them completely.

The Thames basin, England provides two sites which show good evidence of floodplain change in Later Prehistory. These are the Neolithic-Late Bronze Age sites at Runnymede, near Egham (Needham and Longley, 1980; Longley,1980; Needham, 1985; 1992) and further upstream, the Iron Age site at Farmoor near Oxford (Lambrick and Robinson, 1979). The Runnymede site is particularly interesting, as the interstratified alluvial and settlement record is unusually detailed and well recorded. In 1978, some 80 m of excavations revealed a silted-up river channel with a double row of pile-driven timbers, interpreted as a wharf, and a Prehistoric land surface behind it. The position of the wharf and the evidence of channel erosion may be reconciled by the existence in this reach of an anastomosing channel or simply a main channel with some smaller secondary channels. The Runnymede sites also display evidence of increased flooding at the beginning and towards the end of the Bronze Age. There is evidence from an overbank gravel spread of a large flood at *c.* 4,000 BP. Similar flood layers have been dated to *c.* 3,000 bp from the river Stour in the west Midlands (Brown, 1988). The identification of discrete events is relatively rare in predominantly silt and clay alluvial systems, probably because they result from a combination of an unusually large flood event (cf. mega-flood) and continued floodplain aggradation, preventing the pedological reworking of the flood layer. The Bronze Age channel at Runnymede into which piles had been driven silted-up, and more significantly, a blanket of archaeologically sterile brown alluvium about a metre thick began to be deposited over the entire site. However, whether the site abandonment was due to socio-economic factors or repeated flooding is still not clear.

Robinson and Lambrick (1984) have integrated the evidence of alluviation in the Upper Thames from several sites, including Farmoor. Their conclusion is that extensive alluviation is largely restricted to the last 3000 years and that it was particularly severe during the Late Iron Age-Roman period and during the Late Saxon-Medieval period. Other evidence of Roman and Medieval alluviation will be discussed in more detail later in the next section. Largely on the basis of waterlogged ditch deposits, Robinson and Lambrick (1984) also argue that there was a rise in the floodplain watertable which preceded alluviation as early as *c.* 2,500 years bp. There is also evidence of a lagged alluvial response from the river Nene, but during the late Neolithic-early Bronze age (Brown and Keough, 1992). Although it is clearly diachronous, even within a reach, due to the uneven nature of the floodplain topography, all sites investigated by Brown, *et al.*, (1994) were subject to alluviation by 2,500 years bp. Another cause of diachrony can be the timing of land use change in different sub-catchments and in order to resolve this there have been several studies of the alluvial history of small catchments in the British Isles (Brown and Barber, 1985; Macklin, 1985) and mainland Europe (Bork, 1989). Bork (1989) also provides an excellent example of the combined use of geomorphic features, in this case infilled gullies, with documentary sources in a study of accelerated agricultural erosion caused by severe storms in Medieval Saxony, Germany. The phases of alluviation recorded predominantly in southern England at 3,800-3,300 bp, 2,800-2,400 bp almost certainly reflect changing land-use controls in increasingly agricultural catchments coupled with erosive storms. The spatial distribution of alluviation in response to climatic deterioration is at the regional scale, catchment dependant and so reflects the spatial distribution of erodible soils and erosive land uses. Land use change such as deforestation, the conversion of pasture to arable and drainage alters storm response not only by increasing sediment supply but often by increasing the volume and peak height of the flood hydrograph, especially in headwater catchments (Hollis, 1979). Archaeological data are invaluable in studies of the processes and controls of alluviation, at least at the catchment scale.

c) Artifactual Evidence of Floodplain Deposition and Erosion

The rate of floodplain sedimentation has been estimated in Ardennes rivers using stratigraphical markers identified by Henrottay (1973). These consist of scoria (up to 105 mm) produced by the previous metal industry set up in Ardennes valleys from mid 13th century . The debris from these factories was deposited in the rivers so that the presence of microscopic scoria in alluvial deposits affirms that the floodplain was accreted after the 13th century. As shown by Figure 3A, dealing with the River Ambleve, the whole floodplain contains microscopic scoria deposited after the 13th century. The thickness of recent flood silt generally exceeds 1 m and frequently reaches 2 m which gives a rate of accumulation of 28 cm per century. Henrottay (1973) has examined different rivers of the Ourthe basin and the River Meuse downstream of Liege (Table 3.4). The rate of sedimentation exceeds generally 20 cm/century. Everywhere the thickness of silt deposited since the 13th century is greater than the thickness of old silt without scoria. Human activities (deforestation and enlargement of tillage in the catchments) have probably played a preponderant role in the silt accumulations in the valleys. The same technique has been used in the south of the Ardenne by Sluse (1995). The rates of sedimentation are slightly less than in the north of the Ardenne (Table 3.4). Two reasons explain this difference. The forest clearings in the south-Ardenne catchments have been less important and the present land use in these watersheds is still dominated by forests and pastures, so that soil erosion is less than in the northern part of the Ardenne. Furthermore, the loess deposits are less thick in the south-Ardenne so there is less material to erode.

Table 3.4 Sedimentation and erosion rates determined using microscopic scoria deposited in floodplain sediments.

River	Catchment area (km^2)	Date of Ironworks	Sedimentation rate (cm/century)	Lateral erosion rate (m/century)
North Ardenne (from Henrottay, 1973)				
Amblève	1044	1250	23.5	14.6
Ourthe	1597	1250	28-33	6.3
Ourthe	2691	1250	28	-
Somme	38	1400	8-18	3.9
Meuse	20802	1250	21	42
South Ardenne (from Sluse, 1995)				
Rulles	96	1540	14.4	5.5
Rulles	134	1540	9.1 (6)	4.4
Mellier	63	1620	19.6 (5)	5.4
Rulles	220	1540	24.9 (5)	18.0
Semois	378	1540	19.8 (5)	33.0

The microscories also allow evaluation of the importance of lateral erosion of these rivers (Henrottay, 1973). As shown in Figure 3A, the silt deposited on the River Amblève floodplain contains microscopic scoria and was thus deposited after the middle of the 13th century, along all the width of the floodplain. Silt without scoria (before the 13th century) has been eroded which implies that from that time, the river has swept away, at least once, all its floodplain across a width of 100 m. This indicates average lateral erosion rates close to 15 meters per century. Contrary to the River Amblève, the Ourthe has not systematically swept its entire floodplain since old silt rests under the recent silt (Figure 3.6B). Nevertheless, lateral erosion of at least 45 m occurred at rates similar to south-Ardenne rivers (Table 3.1). This method provides minimum rates of lateral erosion because the river may have passed several times where the old silt is eroded. Yet, these rates agree with rates determined from old maps (Petit, 1995

3.5 Conclusions

Archaeological phenomena – including cultural artifacts and methods for their study – have led to the development of a set of tools that can be used by geomorphologists to study alluvial histories and fluvial processes. Conversely, fluvial geomorphology provides a series of tools that can be used to study both the timing and environmental context of cultural features. The explanation for such strong linkages between archaeological and geomorphic methods arises from interactions between human societies and fluvial landforms; i.e., river channels and floodplains. These interactions include anthropenic alterations of fluvial processes and magnitude-frequency relationships as well as the incorporation of human relics in alluvium. This chapter emphasizes the use of archaeological evidence such as anthropogenic tracers in the development of alluvial histories and channel changes.

In Europe, Asia, and Africa substantial anthropogenic environmental disruptions were diachronous and began in the Middle to LateHolocene and the clear cultural record allows the application of these tools over a relatively long period of time. In the

Americas and Australia, the early cultural record is subtle, and extensive agriculture and deforestation came much later, leaving an abrupt boundary late in the stratigraphic record. There are advantages to both situations. In the Old World we can learn about long-term and the effects of multiple intermittent anthropogenic perturbations, while in the New World we can study the effects of the sudden introduction of environmental exploitation. Both of these lessons are essential to an understanding of the future potential for human impacts on the envrironment and global environmental changes. It is unfortunate that one of the driving forces of increasing links between archaeologists and geomorphologists has been the relentless drift of funding towards applied and short-timescale studies in geomorphology. While such process-oriented studies are important, they cannot replace the need for an empirically based understanding of Earth-surface processes over millennial time scales.

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Figures

Figure 3.1 Hydraulic gold-mining sediment deposited in Greenhorn Creek, northern California, 1862-1880. Subsequent incision left high terrace (middle background) ~15 m above channel. View upstream, ca.1990.

Figure 3.2 The along-stream distribution of plutonium in Acid, Pueblo, and Los Alamos canyons. From Graf (1994) with permission of Oxford University Press.

Figure 3.3 The distribution of Sn mining and Sn profiles of rivers draining Dartmoor in SW England. Note that the sedimentary profile from Taw Marsh is derived from a terraces exposure and so rep

Figure 3.4 A. Evolution of the mean diameter of the 10 biggest slags measured by the b-axis, along the Rulles river and the Semois river, using a cumulative distance from the most downstream iron factory located on the Rulles. The arrows on the x-axis locate the junctions of the tributaries where ironworks were located, bringing slags into the Rulles river. The star symbol in the x-axis locates the upstream site where no slag has been found in the Semois.

B. Trend of the mean diameter of the 10 biggest slags measured by the b-axis in relation to the distance from the closest ironworks, all sites together.

Figure 3.5 Late Holocene channel changes of the river Trent at Hemington postulated from the analysis of both sedimentary and archaeological data.

Figure 3.6 Transverse profile of the Amblève river (A) and the Ourthe river (B): the presence of microscopic scoria in the floodplain allows an estimation of the sedimentation rate since the 13th century; (1) gravel, (2) silt with scoria.