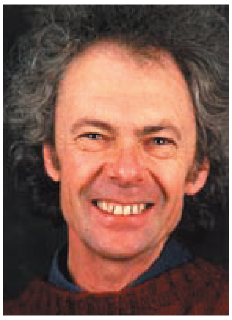
Long-term fluvial behaviour through the later Pleistocene in lowland NW Europe



Philip L. Gibbard, BSc PhD Dosent
plg1@cam.ac.uk

University of Cambridge
Department of Geography
Cambridge Quaternary
CAMBRIDGE CB2 3EN, England
Tel: +44-1223-333924; Fax: +44-1223-333392

und

Universität für Bodenkultur
Department für Bautechnik und Naturgefahren
Institut für Angewandte Geologie

1 Introduction

Northwest Europe can be regarded as a unified geographical region which has undergone a broadly consistent geological and climatic history over the past few million years. Today the region lies in the temperate climatic and vegetational zone but during the recent past it has been subjected to climatic change that has given rise to long periods of periglacial (non-glacial) and even glacial conditions. In coastal areas, sea-level change, largely driven by glacial eustasy, has caused intermittent regressions and transgressions; in and adjacent to glaciated regions, isostatic and forebulge effects have also caused major land- and sea-level variations. All these variations are superimposed on longer-term trends in climate and tectonic evolution of the continent.

2 The period of Cenozoic

The drainage system of northwest Europe has evolved in response to the development of the continent during the late Cenozoic. The position of the region at the margin of the Eurasian continent has been crucial in determining the events that have influenced its geological evolution. By their nature, rivers owe their existence to, and are strongly primarily influenced by, tectonic activity and climatic variability. The interplay of these two major driving-factors is responsible for determining the form of the modern river system, which should be considered as the product of continual remodelling.

Because river valleys are major zones of terrestrial deposition, an understanding of their detailed geological record will provide a calibration of the geological evolution of the North Atlantic region as a whole throughout the past few million years. As will be demonstrated, there is considerable evidence of palaeoclimatic significance in river-sediment sequences; from this evidence it is clear that the northwest European rivers have functioned as an integrated system.

The rivers generally adopted braided or wandering courses during cold climate periods.

The deeply incised modern valley system has developed largely as a result of rapid climatic changes over the past 2.4 Ma, but in particular, to the development of the severe glacial climates of the last *c.*1 Ma. This appears to result from the greater amplitude, and longer duration of climatic oscillations with the change to the 100 ky cyclicity when climates in the region were markedly dominated by frost.

Throughout this period the river system has undergone repeated adjustments in response to continental glaciation, and glaciation of mountain massifs, including in particular the Alps. By contrast, temperate climate events (interglacial) interspersed between the cold-climate periods are characterised by sedimentation that comprises predominantly fine-grained, often fossiliferous sediments with rivers normally adopting single-thread channels.

This pattern is particularly well established for the Late Pleistocene where numerical dating has allowed the detailed response of rivers to the frequent climatic changes to be partially unravelled. The varied scale of these climatic changes, now identified from the marine and ice-core records from the North Atlantic region, have differing scales of responses, some of which can be seen in river systems. Of particular significance however, is the 'lag-time' that is repeatedly seen between the timing of the climatic change and the response seen in the fluvial systems. These points are discussed below.

3 Climatic and palaeohydrological events in the Late Pleistocene

In lowland regions fine, inorganic sedimentation begun late in the last interglacial (Eemian, Ipswichian) and continued into the Early Weichselian (Devensian, Marine Isotope Stage, MIS 5), ultimately filling the valleys to a depth of several metres. These 'late interglacial – earliest glacial' sediments are poorly fossiliferous because of their increased inorganic component that arose as a consequence of progressively deteriorating climatic conditions. Higher discharges and sediment loads involving increased channel size and lateral erosion/accretion along the course of previously quiescent channels removed much of the evidence for prior channel activity. Decreasing channel accommodation space led increasingly to sheet-like vertical accretion of deposits particularly during flooding events. The fine-grained character of these early glacial deposits means that they have a low preservation potential and they are therefore probably rapidly removed in all but very protected places during subsequent events.

The re-activation of gravel transport, but lacking the full loading of glacial inputs, resulted in valley incision, removing pre-existing fine alluvium *en masse*. It is as yet not clear *precisely* when gravel transport is re-activated. However, deposition of Early Weichselian (= late MIS 5, *c*. 90 ka) gravel and sand sequences, followed the downcutting interval; the sedimentary facies are comparable to those of a braided-river regime and therefore are of cold-climate origin. This accumulation is rare in valley systems, its limited occurrence probably reflecting the intensity of subsequent fluvial incision. However, MI Stage 4 was mainly a time of intense fluvial downcutting.

Gravel-bed braided rivers, with abundant coarse sediment supply from drainage basin slopes by solifluction dominated during MI Stage 3 in river valleys in the higher-relief areas underlain by harder substrates. In the British fluvial successions, permafrost may have been continuously present.

Although there is evidence from the ocean sediment and ice-core records of several temperature oscillations (7-8 interstadials) during MI Stage 3, warm episode records in coarse fluvial sediment sequences are rarely found, especially in the coarse detrital sequences associated with normal lowland conditions such as in southern Britain, Germany and France. This contrasts with the situation in the Netherlands and Belgium where the low-energy sand-dominated river systems preserve organic channel-fill and related sequences that reflect multiple 'interstadial'- climate accumulations.

The implication of this observation is perhaps that for the rivers to change their form and depositional patterns recognisably, any particular climatic oscillation must be of significant magnitude both in duration and temperature. For example, the main fluvial response to the Hengelo Interstadial and its equivalents was a reduction in seasonal flood intensity, possibly with flow being distributed more evenly throughout the summer months. This presumably resulted from increased vegetational productivity, as discussed above, accompanied by increased or complete surface plant cover; these factors together would have reduced surface run-off and increased attendant slope stability, in turn restricting the supply of coarser debris. This initiated vertical accretion in response to flooding, rather than substantial lateral shifting, which typifies the peaked-flood discharges and high sediment yields of the cold, stadial period rivers. The Hengelo sediments regularly show this type of evolution while still retaining characteristics of stadial type sedimentary successions, i.e. fine-grained sediments interlaminated with coarser sands indicating that annual, possibly nival-type floods still regularly occurred. These successions are of a type one might associate with a cool continental, rather than maritime climate, where cold winters result in marked nival-flood events in spring following snow-melt. Interglacial-type temperate fluvial sediments from lowland areas generally lack this regular flood-cyclicity.

Thus if an 'interstadial' event of lower magnitude or shorter duration than the Hengelo (i.e. 4–5 ka) occurred, it would very likely be recorded only in 'normal' cold, stadial-type sediments and therefore its preservation potential would be no higher than that of other stadial-type fine sediments. In other words, the minor 7–8 interstadials in MI Stage 3 must have been marked by shorter durations and or climatic conditions that failed to cause the river systems to cross important process thresholds. These warmer events were accommodated by the rivers making minor internal adjustments and in consequence failed to initiate a response that can be identified in the preserved sediment sequences. The low preservation potential of these events is exacerbated by the coarse-grained nature of MI Stage 3 deposits. Therefore, for example, the British record is considerably more fragmentary than those of the lower energy, sand-dominated regimes of the Netherlands and Belgium. This fragmentation and constant reworking of the sediments will be relatively far greater in situations where the river is restricted to a narrow valley by steep, often bedrock-controlled slopes, in contrast to where it is unrestricted and able to increase the valley width on non-cohesive or unresistant substrates.

The maximum period of aggradation in MI Stage 3 seems to vary significantly, with aggradation at some sites beginning before c. 40 ka. However, radiocarbon-dated organic sediments in the basal parts of the succession may give dates as young as < 30 ka, in places. This suggests that incision, or at least non-aggradation, may have continued in some valleys into the early part of MI Stage 3. Having been initiated, aggradation also continued to various times in different valley systems, but the paucity of dates from after c. 20 ka suggests that almost all the streams were either incising, or at least had virtually ceased depositing sediment by this time.

There may therefore be some longitudinal variation in response and sedimentary pattern in modern streams that should be considered in the following summary of late- and post-glacial floodplain evolution.

In contrast, a somewhat different regime seems to have occurred during the warm phase of the Late-glacial Interstadial. The climate of this period was complex with an early warm peak, followed by a cooler later part during which regional birch forest became established. River activity is considered during this period and concluded that the climatic amelioration caused rivers to reduce their activity as peaked discharge was reduced to a more regular flow pattern. The rivers therefore tended to adopt a single-thread mode, possibly actively meandering where stream energy and the local sediment supply was sufficient (e.g. in lowland Britain). They deposited pebbly sand, sands and silts, the latter with a high organic component. Shallow pools developed in inherited braidplain depressions and the resulting sediments contained little inorganic material. Rose attributed this marked change in flow style and sedimentation to regulation of sediment supply and run-off in response to increased vegetation cover, soil development and increased infiltration resulting from melting of permafrost. In spite of this increase in organic-rich fine sediment deposition, sediments from this period have rarely been described. If this is a consequence of non-preservation, the cause could have been later removal by the rejuvenated, energetic and destructive rivers of the subsequent Younger Dryas (Loch Lomond) Stadial. This stabilisation/ incision response parallels that noted above during the Middle Weichselian Hengelo Interstadial event.

The change from the Younger Dryas Stadial to the Holocene is marked throughout the region by a profound change from gravel-dominated flow regimes to predominantly fine-grained sedimentation, comparable to that seen in the Late-glacial Interstadial. This change took place in response to the abrupt climatic amelioration, the latter having occurred in less than 50 years.

Such a change would have been too rapid for streams to adjust their channels and so the channels occupied during the latest Late-glacial would have persisted into the early Holocene. The initial reaction was a reduction in number of flow channels, a process that continued by siltation of secondary channels throughout the Holocene. There was therefore a ‘metamorphosis’ from multiple shallow gravel-bed channels to a network of fewer, deeper and narrower channels enclosed by cohesive banks that resulted from vertical accretion of predominantly fine sediment on floodplain surfaces. As this author notes, this transition is marked in the valleys by increased channel abandonments, as indicated by basal C14 dates in channel fills. These abandonments are accompanied by the exposure of the higher areas of the pre-existing braidplain surface to subaerial processes, including soil development and vegetational colonisation.

Two things are important in determining the preserved alluvial record of the early Holocene. First, anastomosing or more stable meandering alluvial styles are intrinsically different in type and rate of alluviation. Lateral accretion rates are low and the zone occupied by migrating channels is restricted. Floodplain zones liable to overbank mineral sedimentation and organic growth for extensive periods, albeit at low sedimentation rates, are much more in evidence. Thus for a given valley floor, such sedimentation styles are:

(i) spatially differentiated, with active lateral accretion on only a fraction of the floodplain (in contrast to braided environments) with the potential for long-term preservation of vertically-accreted channel fills and floodplain fines on much of the floodplain surface; and,
(ii) less destructive of prior alluvial units.

A second factor concerns the effects of the sequential change from braiding to meandering/anastomosing. The prior braidplain surface with a complex relief of bars and interlacing multiple channels directly conditions the location of lower energy channels depositing sediment. Alluviation in what might otherwise be a simpler channel and planar floodplain system is topographically steered, producing a distinctive transitional pattern type.

Once the transition had occurred, it is uncertain whether more than a single channel operated at any one time. It is considered that the lack of channel migration, combined with the low width/depth channel ratio and the preservation of floodplain archaeological sites, indicates the presence of multiple reaches of sinuous channels of comparable proportions to those found in modern analogue localities (e.g. Khopersk National Park, Russia – personal observation). It is quoted an example from southern Ireland where a wooded anastomosing channel system, comparable to those expected to have occurred throughout southern Britain and northern Francew before human interference with channel systems, is found. It is characterised by a stable interconnecting channel pattern, small diamond-shaped islands, adjacent channels with different bed- and flow conditions, much deadwater at medium and high flow, floodplain scour often related to vegetation, debris dams and the silting-up infill of abandoned channels. Where shifts in flow channel take place, they principally occur by avulsion into neighbouring depressions. This behaviour is triggered by local channel deposition, resulting in locally-increased gradient or blockage of individual reaches by sediment. Avulsion typically occurs where an intrinisic threshold has been exceeded. Clearly the complexities of these systems in part reflect the inherited topography on which they formed and which they were incompetent to destroy.

The increase in floodplain surface and channel stability was greatly enhanced from the early Holocene by establishment of woodland both in the catchment in general, but particularly on floodplain surfaces. Riparian vegetation reinforced bank resistance. It has been observed, dense woodland would certainly retard channel migration, leading instead to the stabilisation of multiple small channels that shifted by avulsion. In addition, these small channels were highly susceptible to damming by vegetational debris.

In the later Holocene human interference in the landscape, principally through forest clearance accelerated the delivery of fine sediment to predominantly single channel systems.

Where sufficient stream energy and sediment were available and cohesive banks were lacking or destroyed, multiple-channel braided reaches and active channel migration continued in some areas, particularly in the Middle Trent valley. However, the latter is atypical of lowland Britain.

Precisely when alluviation occurred has been the subject of considerable discussion centred upon whether depositional episodes and interspersed incision are principally climatically or anthropogenically-driven. Attempts to determine this based on dated sequences have been collated for Britain. Figure 1 suggest that the early Holocene was a period of relative stability with slow sedimentation. This is followed by an apparent hiatus of around 1000 years at *c.* 6.0 ky BP (early Substage Fl II). This may be interpreted as a period of erosion resulting from minor climatic deterioration or one of low sedimen-

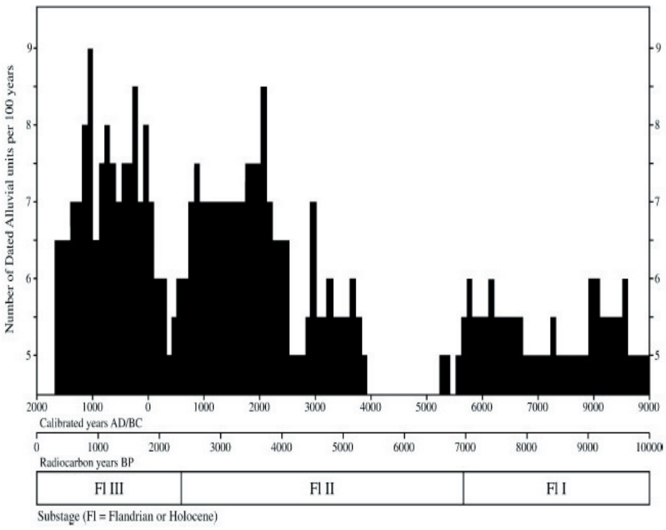


Figure 1 Radiocarbon-dated Holocene fluvial deposition in Britain

tation. Alternatively, a record of relatively small amounts of alluviation once present may have been removed by subsequent erosion. Recorded alluviation throughout the region began again shortly after 5.5 ky BP in the climatic optimum (the second half of Substage Fl II: *sensu* this article). Major fine inorganic sediments were laid down by increased overbank flooding, normally attributed to the anthropogenically-induced surface erosion following the Neolithic forest clearance. This clearance commenced at approximately 3-4 ky BP and continued virtually to the present (Fl III).

It is argued that the anthropogenic effects have served mostly to amplify or blur the impact of natural climate changes, whilst others consider that humans have been the controlling force for changes, particularly in the later Holocene. A third group conclude that a combination of the two have influenced fluvial systems.