Chapter 2

Review of field studies

2.1 Introduction

This chapter reviews previous field based studies which have examined the relative affects of land use and climate change on fluvial systems. From this review current issues and problems will be identified, allowing more detailed model objectives to be drawn.

2.2 Agents of change

River catchments have been shown to respond in a variety of ways to changes in the environment. Knox (1995) succinctly categorised these agents of change into five groups.

1. climate;
2. vegetation;
3. tectonic and eustatic base level change;
4. anthropogenic factors;
5. geomorphic factors intrinsic to a given watershed.

However, assessing the individual importance of these factors is complicated by interactions between them. For example, vegetation is strongly dependant upon climate, and both can be influenced by man. Furthermore the relative effects of these factors will vary strongly between different catchments and environments.

As this study focuses on upland UK catchments over the Holocene, some of these factors are more relevant than others. In the UK, over the last 8000 years, humans have had a massive effect on vegetation, reducing the forested area from 95 to 5% of the country (Ballantyne 1991). Furthermore, aside from late Holocene mining there has been little direct human influence on upland river systems. There is an increasing body of evidence describing Holocene climatic fluctuations and their effects on river environments, although the impact of this on vegetation levels is uncertain. Tectonically the UK has remained relatively stable during the Holocene, with the

Yorkshire Dales lying close to the hinge line with zero isostatic rebound. Whilst there has been 40-50m of sea level change over the last 10 000 years (Long *et al.* 1998) it is unlikely that river base level changes will have effected the uplands. Therefore for the UK's uplands in general, Knox's five categories can be reduced to two, anthropogenic vegetation cover change and climate. These two factors are discussed in greater detail below.

2.3 Vegetation cover change

Vegetation cover exerts important controls on sediment supply and catchment hydrology, reducing surface runoff and protecting the underlying soil from the erosive effects of raindrop impact. It further reduces surface runoff and erosion by enhancing the infiltration capacity of the soil and increasing frictional resistance, thereby reducing overland flow velocities and thus erosion. Furthermore, tall vegetation, especially forest cover, significantly alters the hydrology by increasing the evapotranspiration and reducing the flashiness of storm hydrographs. Therefore, the removal of protective vegetation, in particular deforestation, can result in substantial increases in soil erosion, channel extension and gully formation, all of which increase sediment delivery to the fluvial system. In temperate environments such as the UK, the most important effects are the changes to the hydrology with greater flood total flood volumes and more flashy hydrographs. For example, in temperate US catchments, Knox (1977) estimated that the removal of tree cover increased the number of floods with a five year return period by a factor of 3-5.

2.3.1 The history and influence of upland vegetation cover change on valley floor development

As mentioned in 2.2, in the UK the largest Holocene influence on vegetation cover has been anthropogenic deforestation for land clearance, fuel and housing. However, as the colonisation of the UK's uplands progressed at a slower rate than lowland areas, deforestation occurred much later, and by 2000 BP most upland forests had been stripped (Ballantyne 1991). These areas have largely remained deforested, with agriculture and grazing preventing the return of woodland. In the Yorkshire Dales there are several palynological records describing such anthropogenic ingress, with pollen cores from near Malham Cove showing human activity from 5000 BP (Smith

1986). Significant deforestation occurring during the Beaker period of the early Bronze Age (Tinsley 1975) and studies from nearby Nidderdale indicate that the late Iron Age - Roman period from 2350 BP onwards was a period of intense agriculture (Smith 1986, Tinsley 1975). Subsequently, there was abandonment, with some regeneration of tree cover, and the spread of heathland around Malham. As corroborated by early historical records, 1150-1350 AD was a period of increased arable activity before a decline associated with the Black Death in the 14th century. Smith (1986) suggests that the valleys were also the sites of major settlement from the earliest prehistoric periods.

Several authors have linked such records of vegetation removal to geomorphic change. Tipping and Halliday (1994) examined the development of an alluvial fan in the Tweed valley, southern Scotland. This fan overlies peaty deposits ^{14}C dated to the 11th Century AD. This was unusual as there is no other evidence of alluviation of the main valley floor, and it occurred at a time of relative stability during the Medieval Warm Period. This, combined with archaeological evidence, suggests that the deposit may be associated with the introduction of agriculture, but the authors conclude there are too many uncertainties to show a clear causal link. Harvey and Renwick (1987), studied alluvial fan and terrace formation in the Bowland fells, NW England. Using ^{14}C dating at several sites, they described two main phases of fan accumulation alternating with fan dissection. The first occurred between 5000 and 2000 BP and the second after 1000BP, the latter suggesting a linkage with local Viking settlement. Harvey (1996) also suggests that widespread gully development in the Howgill Fells, Cumbria, initiated from 800-900 BP, in response to changes in the catchment hydrology induced by anthropogenic vegetation change. He argues that the change of erosional thresholds increased hillslope gullying and overloaded the upland fluvial system with sediment, creating alluvial fans. Harvey also suggested that in steep upland systems like the Howgills, where the slopes are close to erosional thresholds, human induced vegetation change may be a sufficient trigger for the initiation of gullying. Similarly, Macklin *et al.*(1992 a) suggested that vegetation clearance may have caused gullying of upland areas in the Northern Pennines at the beginning of Roman times. Ballantyne (1991) synthesising his own and other peoples work, concludes that there was increased solifluction, vegetation stripping and soil erosion in upland Britain throughout the late Holocene. He links this to forest clearance and increased grazing pressures.

Location and authors	**Inferred cause**	**Date**
River Tweed (Tipping and Halliday, 1994)	Possible agriculture change	1100 AD
Bowland Fells (Harvey and Renwick, 1987)	Possibly linked to local viking settlement.	3000-200 BC and 900 AD
Howgill Fells (Harvey, 1996)	Vegetation change	1000-1100 AD
Upland Britain (Ballantyne, 1991)	Forest clearance and grazing pressures	0-1500 AD

Table 2.1 Studies linking upland Holocene change to land use variations

Table 2.1 summarises the few studies linking upland land use alteration to geomorphic change, and shows little correlation between significant dates. There seems to be a slight grouping of dated changes to medieval times but the record is confused by the diachronous impact of human intervention.

2.4 Climate change

Climate is of great importance to alluvial systems with precipitation being the primary source of water for floods and thus fluvial change. Climate also determines the water balance, the relationship between evapotranspiration and runoff, and there are long term interactions between climate and vegetation as shown by Langbein and Schumm (1958) (Figure 2.1). However, it is the intensity and duration of storm precipitation, and its frequency distribution that has the greatest impact on runoff. Fluvial responses to increased precipitation include channel widening, incision, stream head erosion and the expansion of the drainage network (Kirkby 1994). Additionally, increased rainfall generates sediment from slopes via overland flow, and soil saturation lowers the landslide threshold of slopes. Furthermore, there is evidence that river systems are especially sensitive to small changes in climate. Knox (1993) showed in the Mississippi that a 1-2 ^{o}C fluctuation in average temperature was sufficient to switch between periods of aggradation, degradation and alluvial instability.

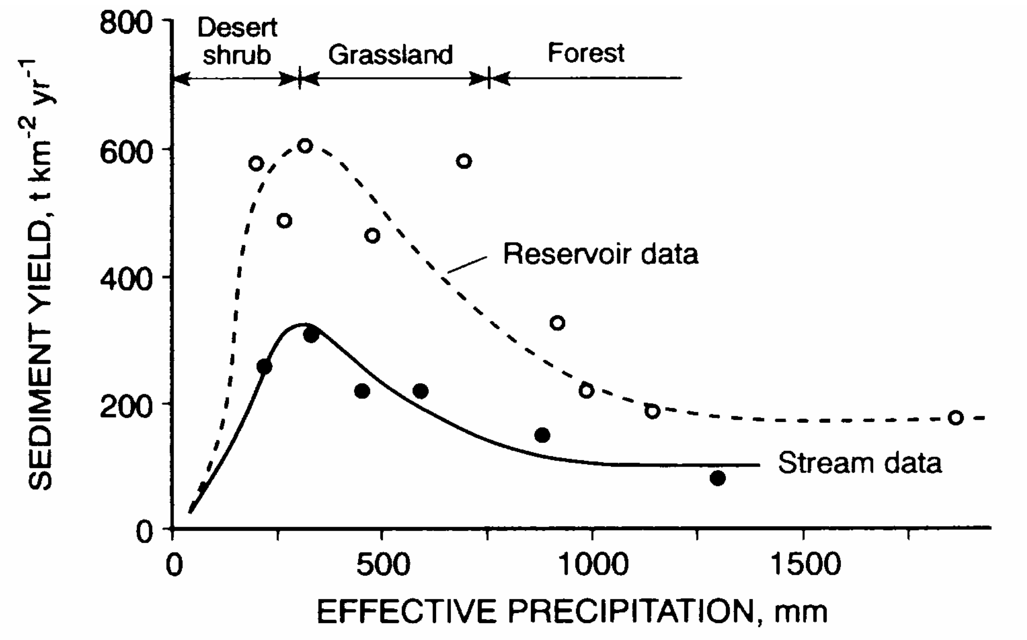


Figure 2.1 Relationship between vegetation, precipitation and sediment yield, after Langbein and Schumm (1958).

2.4.1 Impacts of climate change on valley floors

Over the last ten years, aided by improvements in proxy climate records and sediment dating techniques, workers have linked climate change to variations in fluvial activity recorded in stratigraphic records. Macklin and Lewin (1993) completed a countrywide review of such stratigraphic records, which when combined with their own data showed a series of regional and national correlations. They identified major periods of aggradation in 9600-8400 BP in lowland Britain, 4800-4200 countrywide, 3800-3300 and 2800-2400 largely in southern Britain, 2000-1600 and 1200-800 countrywide and 400-present in upland catchments (Figure 2.2). A lack of units dated between 8000 and 5200 BP implied a period of relative channel stability and incision. Unlike previous studies linking change solely to anthropogenic factors, Macklin and Lewin (1993) concluded that such national synchronicities of aggradation indicated that climate was the major driver of change.

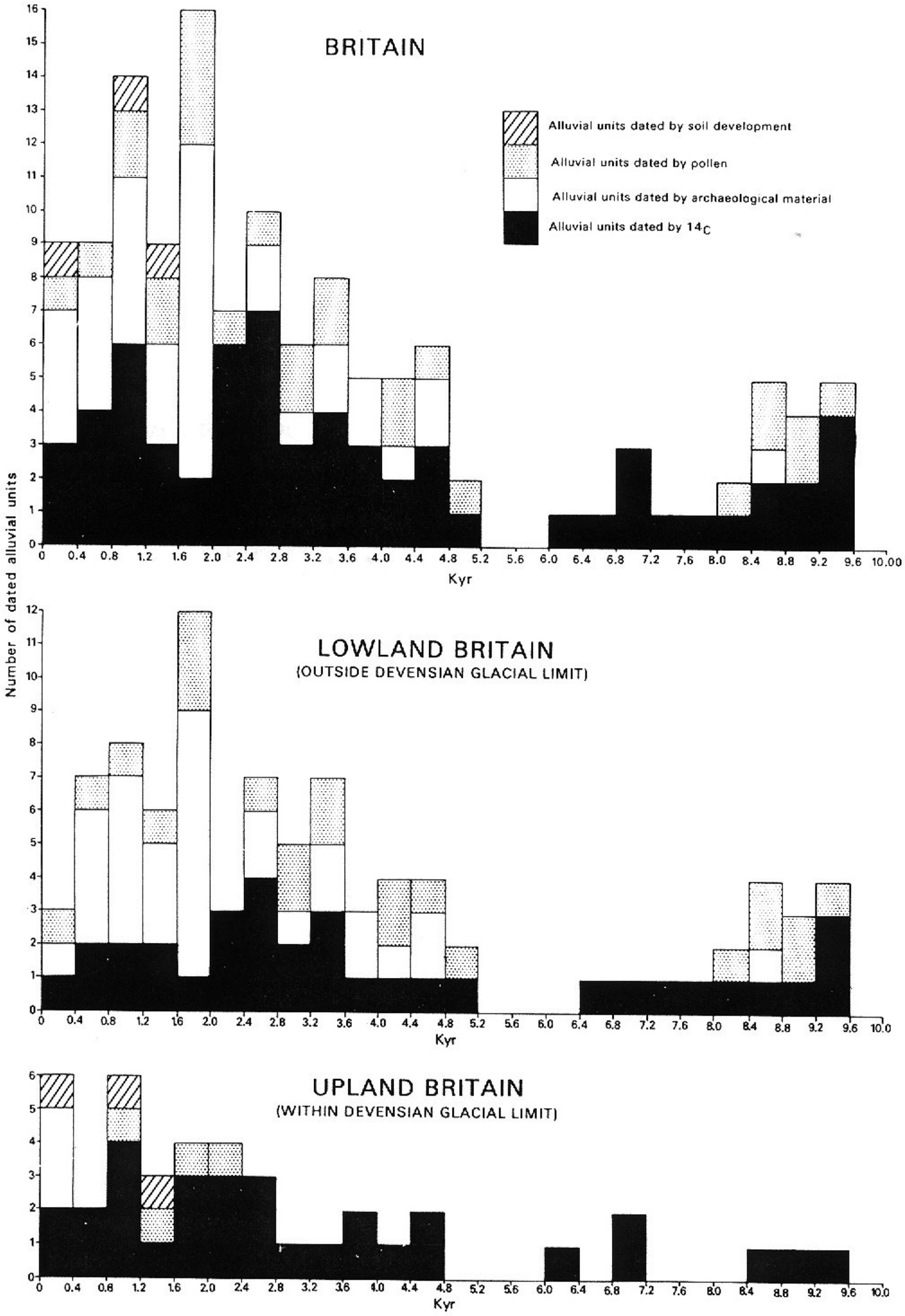


Figure 2.2 Dated Holocene alluvial units for the UK from Macklin and Lewin (1993).

Investigating the same period, Knox's (1993) reconstruction of a 7000 year history of flooding in the Mississippi basin (Figure 2.3) supported Macklin and Lewin's (1993) claims. This showed a warm and dry period from 5000 to 3300 BP followed by a shift to wetter and cooler conditions which increased the incidence of large floods of a magnitude to be classed today as 500 year events. Even larger floods dominated the period between 650 to 450 BP during the transition from the warm Medieval period to the Little Ice Age (LIA). Not only were there similarities between the USA and the UK, but this link between Holocene alluviation and climate change was reinforced by a synchronous response across Europe (Rumsby and Macklin 1996), and at a global scale (Macklin 1997).

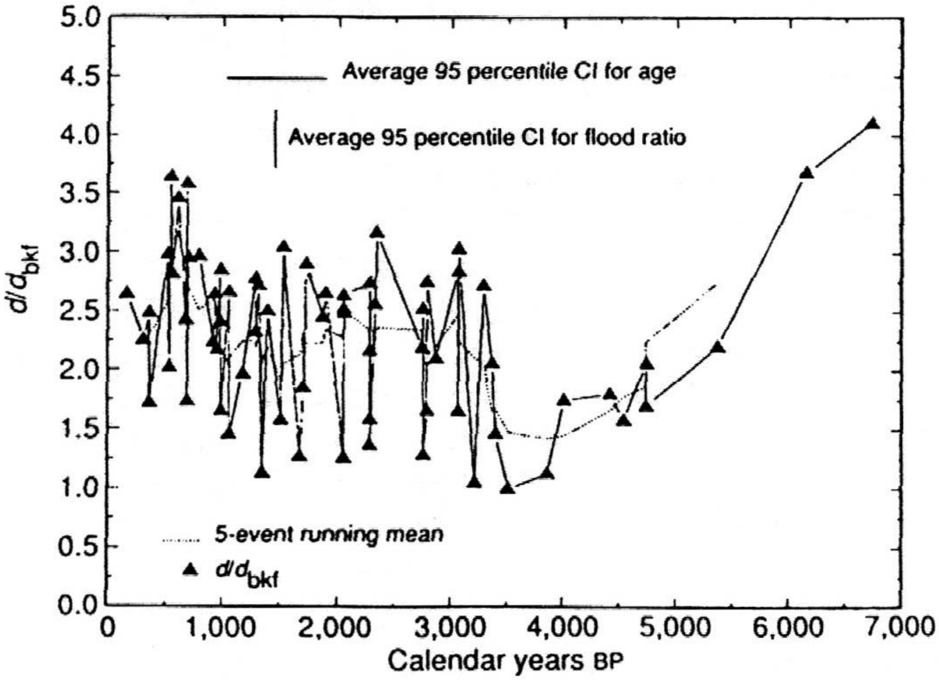


Figure 2.3 Dated flood magnitudes for the upper Mississippi (After Knox, 1993)

2.4.2 Impacts of climate change on upland catchments

The steep gradients in upland catchments can drive rapid deposition and incision episodes, providing an ideal scenario for the preservation of alluvial flood units. Several studies have linked such units to records of climate change. Macklin *et al.* (1992a), examined flood alluviation and entrenchment in three upland catchments in the Northern Pennines, focusing mainly on Thinhope Burn. Using ^{14}C dating and lichenometry, they dated deposits from 21 large floods from the last 2000 years, re-constructing the history of aggradation and incision. This showed up to 8m of incision over the period, with the first phase starting after 1577 BP. Subsequently there was gradual re-filling of the valley floor with fine grained alluvium to a level of 4m above the present stream. This was followed by a major period of incision commencing in the late 17th Century AD and continuing to the present day, eroding through the deposited alluvium and up to 4m into the underlying bedrock. Macklin *et al.*(1992b) found that these periods of incision corresponded with wetter and colder periods in climate records, and postulated that incision was triggered by higher flood discharges and stream powers. An increase in land drainage in the early and mid 20th Century sustained this incision and increased the stream network density by 47%. Furthermore, by using the sizes of the largest boulders as a proxy for flood magnitude, they showed a decrease in boulder size and hence flood magnitude over the last 250 years (Figure 2.4). However they pointed out that this may also be caused by a reduction in large sediment availability.

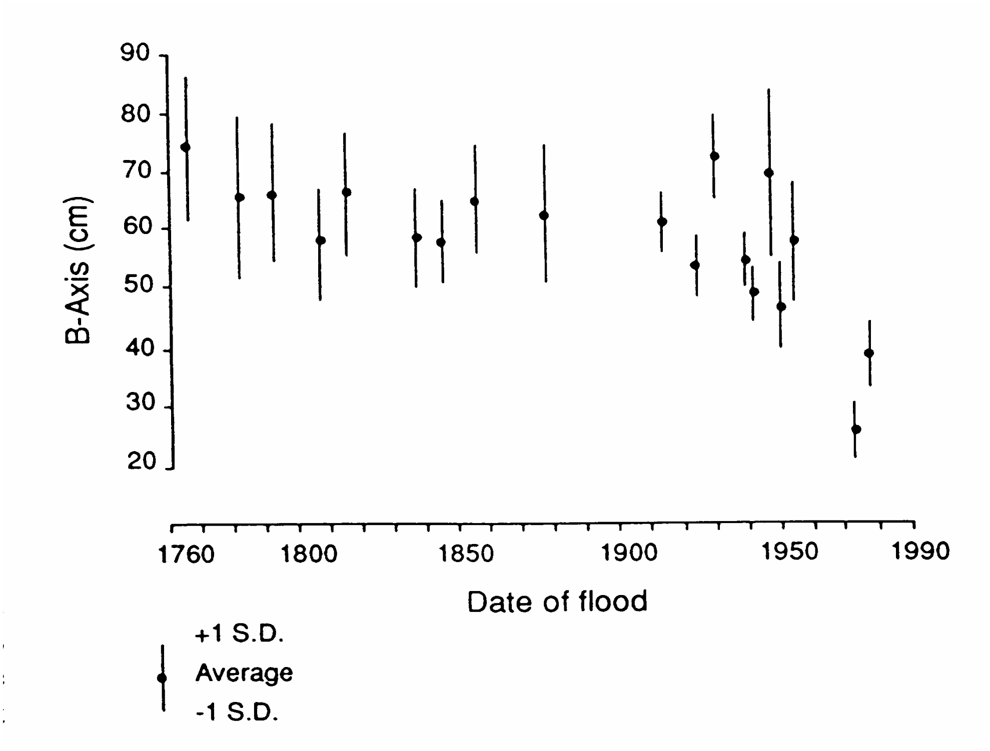


Figure 2.4 Boulder size/age diagram from Macklin et al. (1992b)

Using lichen growth to date boulder berm deposits in Coverdale, North Yorkshire, Merrett and Macklin (1999) again identified two major periods of enhanced flood magnitude and frequency in the 18th and 19th Centurys. During the first period (1750-1800 AD) sediment supply increased and led to valley floor aggradation. For the second phase (1870-1910 AD) there are also deposits, but associated with channel incision. They suggest that this is linked to climatic fluctuations as opposed to anthropogenic influences, because nearby pollen records show that deforestation occurred hundreds of years before. Furthermore, they postulate that the shift from aggradation to incision around 1870 may be caused by a decrease in sediment supply, or sediment exhaustion.

These studies, especially those in the uplands, all show a cluster of large floods in the 17th, 18th and 19th Centuries, coinciding with the Little Ice Age (LIA). Rumsby and Macklin (1996) examined the effects of the LIA upon the alluvial record across Europe, showing a widespread increase in alluvial activity from 1250-1550 AD with an especially active period at 1750-1900 AD. They showed that these alluvial episodes coincided with periods of climatic transition, a cooling after the glacial optimum and a warming in the latter stages. However, linking long term periods of climatic change with precise changes in precipitation is difficult. The main implication from their work is that periods of climatic transition may be associated with unusual weather, including periods of large floods.

2.4.3 Evidence of Holocene climate change

These studies show an apparent link between climate and river behaviour. However, to model the impacts of climate change, an accurate and relevant record of previous climates must be used. The lack of regular documented records before the 18th Century has encouraged the use of proxy sources to re-create these climates. Over the last ten years there has been an increase in the precision and variety of available techniques for paleoclimatic reconstruction, with amongst others, tree ring growth, varves and $^{18}O/^{16}O$ isotope records from ice cores. From the GRIP Ice core, Stuvier *et al.*(1995) extracted a oxygen isotope temperature index back to 16000 BP with a 20 year resolution and from 818 AD with a one year resolution. This clearly shows the warming after the Younger Dryas, and the cooler spell of the Little Ice Age (Figure 2.5). Mayewski *et al.*(1994) also examined GRIP2 ice core records (Figure 2.6) together with sea-salt and dust concentrations which can also be used proxy for colder conditions of change, indicating with a cold spell around 6000 BP and during the Little Ice Age.

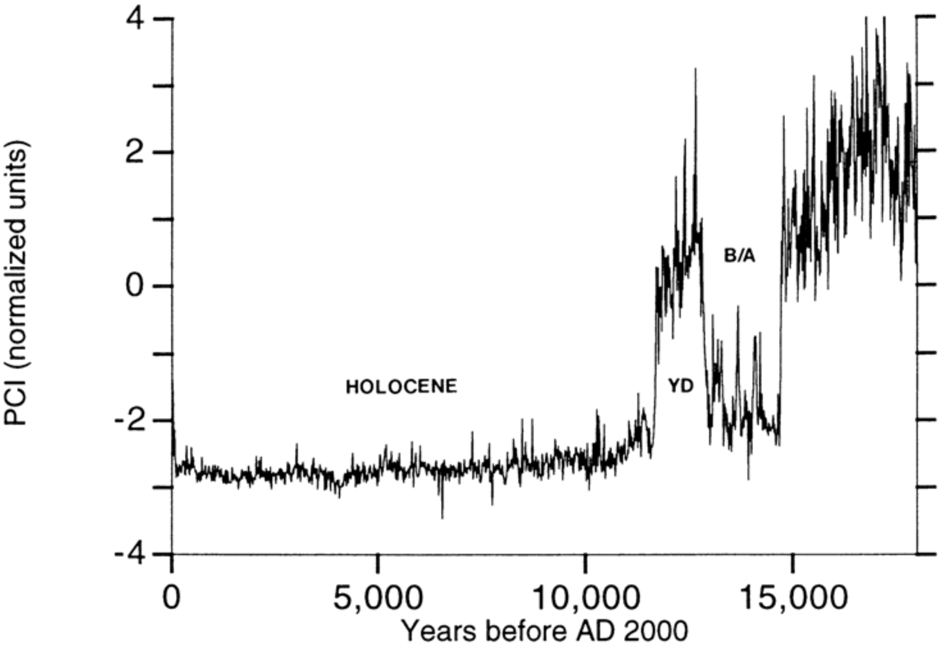


Figure 2.5 Ice core record from Stuvier et al. 1995.

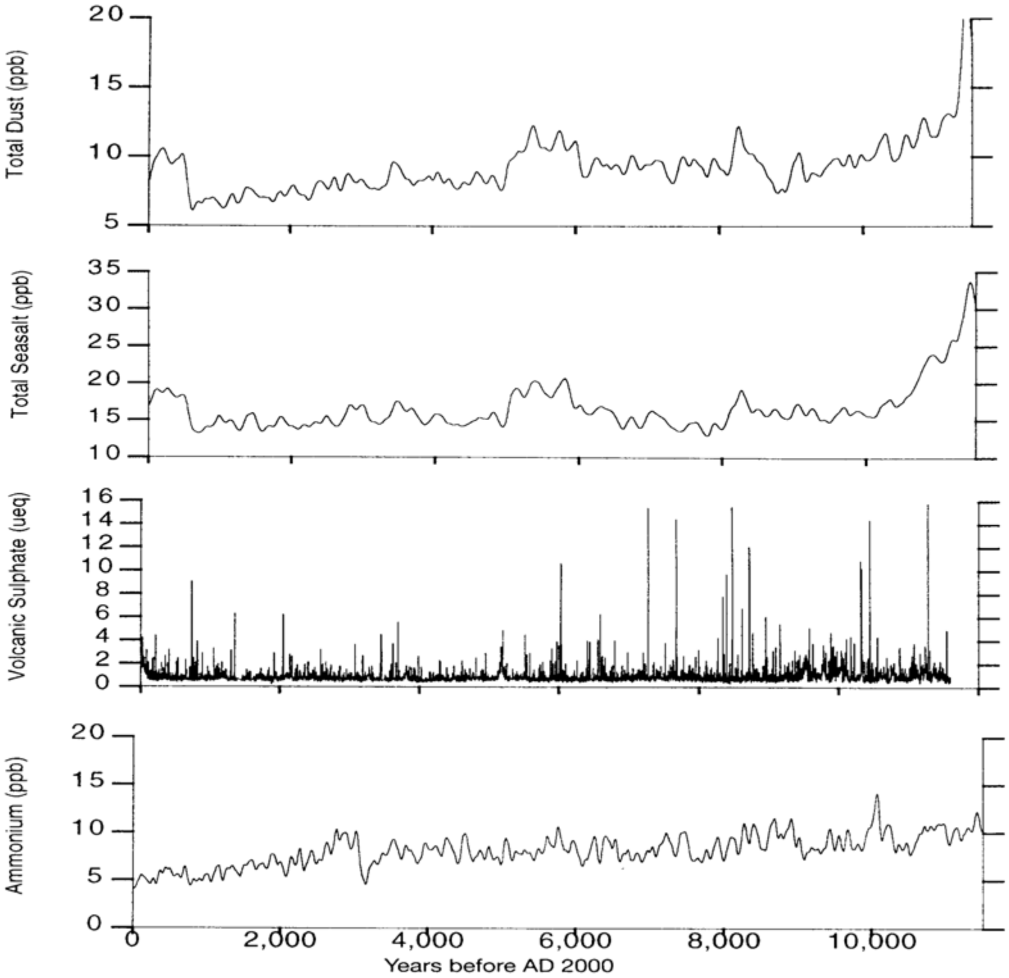


Figure 2.6 Ice core record of storminess from Mayewski et al. (1995).

Although ice cores offer a good indication of long term climate changes, for Holocene studies of the UK's uplands, their low temporal resolution allows only decadal trends or averages to be shown. Furthermore, indicators such as dust and accumulation rates can, at best, only give indications of global or hemispheric trends in storminess or precipitation. Palaeoclimatic reconstruction's derived from raised mires may prove more appropriate for the UK's Holocene record, as they are regional and provide a wetness index instead of temperature or storminess record. Barber *et al.* (1994) reconstructed a paleoclimatic record from macrofossils, carbon dates and peat analysis for a 5m peat core taken from Bolton Fell Moss, Cumbria, U.K. Using a multivariate analysis on the species found, a wetness index was constructed for the last 7000 years (Figure 2.7). Anderson *et al.*(1998) similarly reconstructed a Holocene wetness record from humification analysis on four separate peat cores in Northern Scotland (Figure 2.8), dating back to 9250 BP. These show a marked change from dryer to wetter conditions at ca 3500-3900 BP, which coincides with other paleoclimatic indicators such as lake levels and Alpine glacier advances. Whilst retaining some differences that may be caused by the slightly different techniques used and by regional variations, these two peat records show many similarities, including a dry spell from 8500-5000 BP, a rapid shift to wetter conditions around 3500 BP and the Medieval Warm Period.

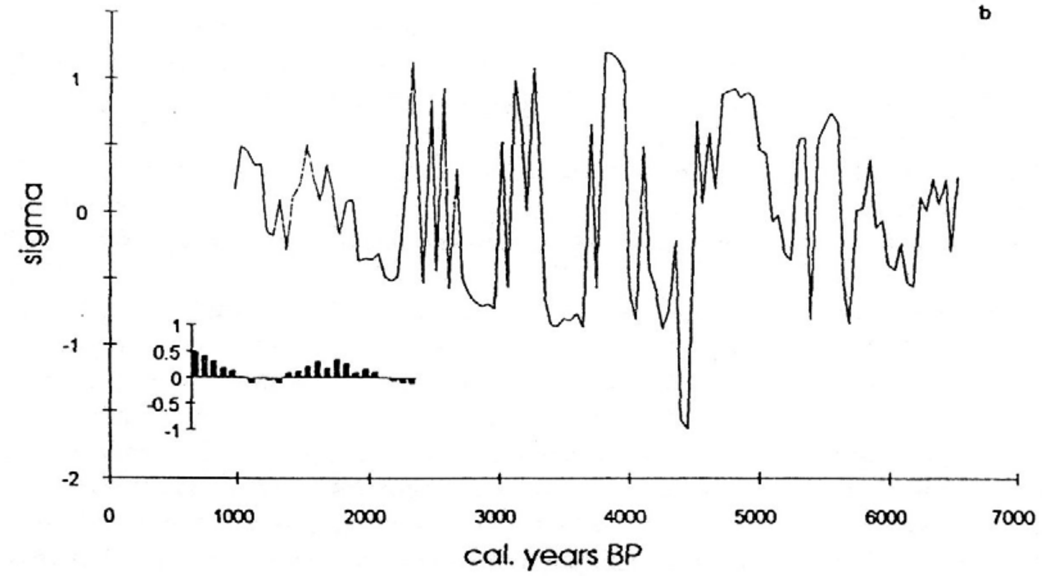
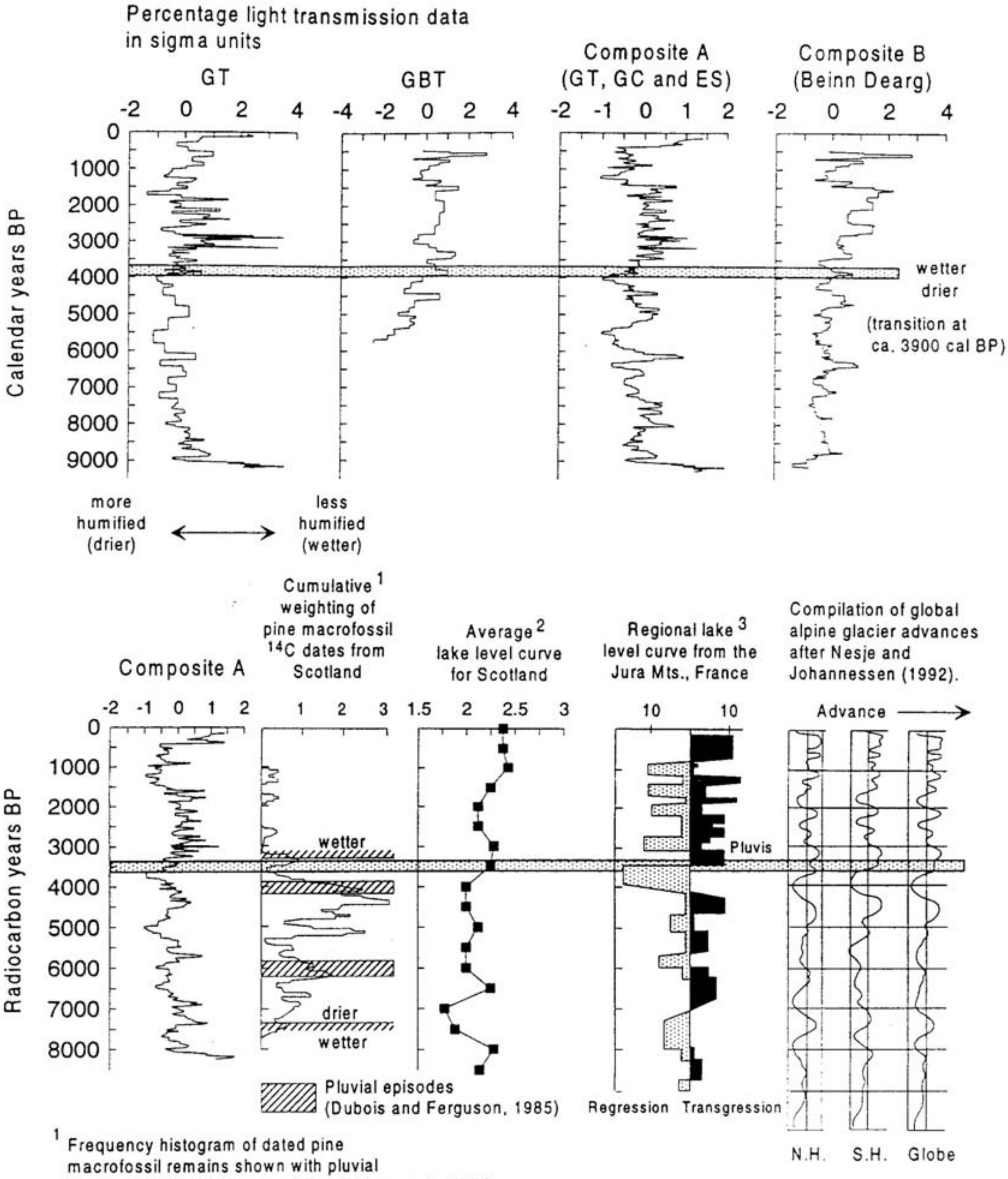


Figure 2.7 Palaeoclimatic wetness index derived from peat cores, from Barber et al. (1994).



[1] Frequency histogram of dated pine macrofossil remains shown with pluvial episodes in the Cairngorms (after Bridge *et al.*, 1990).

[2] The average lake level curve for Scotland is constructed using data from 9 lochs compiled by Yu and Harrison (1995a). Codes range from 1-3, low to high.

[3] Histogram modified from Magny (1992) showing number of lakes in the Jura and northern subalpine ranges with evidence for transgressions and regressions. In *Boreas* 21, 319-334.

Figure 2.8 Peat core climate record, from Anderson et al.(1998). The top half of the diagram details wetness indices from four separate peat cores and the main composite record (A) constructed from them. In the lower half this composite A is compared to lake levels from Scotland and France, as well as records of glacial advances.

2.4.4 Recent climate change

The last 2000 years are of special interest, containing a period of climatic instability c. AD 1300 to 1900, termed the ‘Little Ice Age’ (LIA) (Lamb 1977). Its recent occurrence means fluvial deposits will be better preserved, and there are a large number of surviving documented records. These describe a widespread cooling across Europe in the second half of the 16th Century coupled with an advance of the Alpine glaciers. This continued until a warmer phase in the early 18th Century, which was followed by a second cool phase in the late 18th and early 19th Centuries (Lamb 1977). During the LIA, there are numerous accounts of unusual weather, frost fairs on the River Thames, droughts and marked seasonal contrasts in temperature and precipitation. Although it is difficult to draw precise conclusions for precipitation, the period 1700-1850 AD was characterised by a cooler and wetter climate, and the 19th Century by cool-warm-cool oscillations (Rumsby and Macklin 1996). This climatic perturbation may have had a large effect upon our alluvial environments as will be discussed later.

2.4.5 Evidence for future climate change

There is growing evidence of global warming exacerbated by anthropogenic inputs. Recent simulations using general circulation models (GCM’s) have predicted how the UK’s climate is likely to change if there is continued global warming (Conway 1998). These show a warming over the UK with a likely increase of 3 to 3.5^{o}C by 2100 and an increase in precipitation which is stronger in winter and in northern Britain (Figure 2.9). This may represent as much as a 25% increase in rainfall (average per day) and may be associated with a decrease in the number of rain days and increase in precipitation per rain day. Furthermore, Rumsby and Macklin (1996) indicated that changes in temperature and rainfall recorded during the LIA are of a similar magnitude to those predicted for the next 40 years (Rumsby and Macklin 1996).

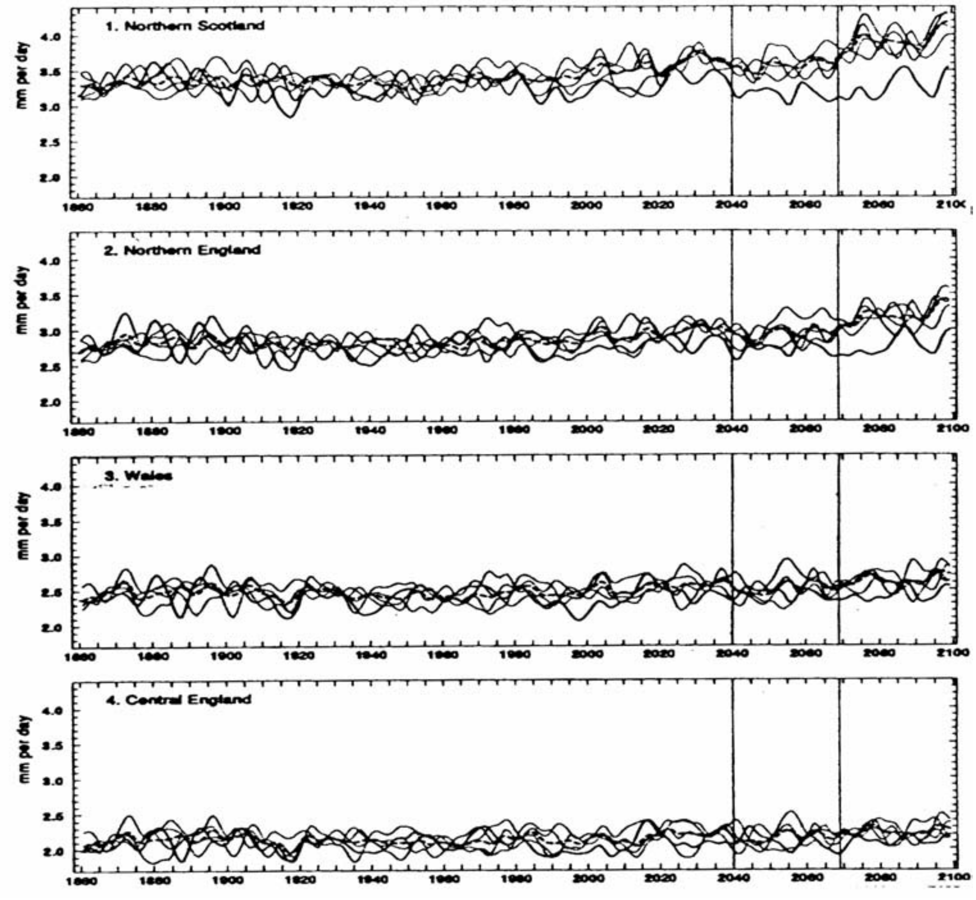


Figure 2.9 Predicted precipitation increases from GCM's (from Conway, 1998).

2.5 Flood frequency, magnitude and extreme floods

As shown in the last two sections, climate and vegetation changes through altering flood frequency and magnitude exert a significant influence on catchment development. However, uncertainty still surrounds the role of single extreme floods (catastrophism) compared to the effects of longer periods of more moderate flooding (uniformtarianism). When studying alluvial deposits in valley floors, the evidence of large floods is usually best preserved, tending to suggest that these events are dominant. But, the discussion of geomorphic magnitude and frequency by Wolman and Miller (1960) suggests that channel geometry is adjusted to relatively frequent floods of a moderate magnitude, as there are definite empirical links between channel geometry and channel discharge statistics.

Large individual flood events have a significant effect upon the fluvial system and can cause much damage to life and property. Evans (1996) recorded the effects of a severe storm on the headwaters of Wycoller Beck, Central Pennines that caused a 'wall of water several feet high'. Local rain gauges recorded rates of 48 mm and 193mm in two hours, which are some of the highest intensities on record in the UK. There was much damage to the stream network, widespread incision, movement of large boulders and the removal a stone slab bridge, considered to be 1000 years old. The damage was restricted solely to this catchment, suggesting the flood was triggered by an isolated, intense storm cell. Evans surveyed the reaches and produced a sediment budget for the storm, as detailed in Table 2.2

Volume eroded (m^3)	Volume deposited (m^3)	Erosion minus deposition	% transported downstream.
2177.81	1826.37	351.44	16.1

Table 2.2. Sediment moved during Wcyoller Beck flood (Evans 1996).

Evans suggested that the widespread change in the catchment was caused by the exceedence of a rainfall intensity threshold of 50mm/hr.

McEwen and Werritty (1988) examined the long and short term implications of two flash floods in 1956 and 1978, in the Cairngorms, Scotland. This allowed them to assess the impacts of various types of flood, the timing of consequent floods and recovery periods. They noted that the sequence of large floods was important in both sediment supply and valley floor re-working. Where slopes and toe deposits were given time to stabilise after a large flood then the impact was less than when the sediment was still available for re-working by second large flood such as that of 1978. As the thresholds for channel change progressively decrease downstream the 1956 flood is well preserved in upstream deposits. The authors state that the deposits and channel change from these large floods show that for the lower reaches only relatively rare floods with a return period exceeding 50 years are major formative events. This contrasts to the uniformitarian channel response observed in more humid fine grained, lower gradient channels (Wolman and Miller 1960). Furthermore, McEwan and Werritty (1988) note a dependence upon the timing and magnitude of successive large floods. One massive flood will re-work the valley floor, whereas smaller floods will results only in a partial modification. Sediment supply is also important, as the movement from supply (slope) to transfer (channel) to deposition (alluvial fan) is self sustaining until the supply of coarse sediment is exhausted. In the Cairngorm floods, sediment is derived from glacial deposits which locally show this exhaustion effect.

Newson (1980) described two floods in the Plynlimon catchment in August 1973 and August 1977, respectively caused by rainfalls of 72mm in 6 hours and 86 mm in 80 minutes. Despite being of similar magnitudes the two floods had very different effects. This led him to propose a theory of flood effectiveness in which slopes and channels have a strong interrelationship, each potentially controlling the other. Thus slopes influence channels through the grade and availability of sediment, and channels effect slopes by limiting sediment export. There is therefore no simple linear relationship between flood size and sediment discharge, and floods should be classified by the effectiveness of erosion or transportation rather than their magnitude alone.

The spatially heterogeneous nature of precipitation further confuses the impact of flood frequency and magnitude, as different size storms have different effects upon catchments of various sizes. For example, a localised intense storm cell will have a minor impact when averaged out over a large drainage basin, but may have a dramatic effect on a small catchment. Conversely, sustained periods of more moderate rainfall or snow over a large area associated with frontal weather systems or anti-cyclones will have a minor impact on a small catchment but cumulatively may cause large floods downstream. Furthermore the return periods of a 100mm/hour rain storm will be very different for large and small catchments. Because this thesis focuses on fluvial problems in small upland catchments, the most formative events are likely to be those caused by small, intense, convective thunderstorms. Newson (1980) has shown from his review of the literature on upland floods that most occurred not in the wetter winter months but in August, caused by '*thundery cyclonic weather'*.

2.6 Problems of field based studies

Despite the number of studies, both climate and landuse perspectives are based upon inferences. Unfortunately, the alluvial chronologies are not precise enough to unequivocally establish a direct response between short term climate or vegetation change and river response. Therefore, a causal link is inferred between dated flood units and historical or archaeological evidence of floods or land use change. There is wide scope for errors, for example the climate records, which whilst largely in agreement, are all based upon proxy sources, and the records of deforestation are inferred from pollen sequences. Even the dating methods are prone to error, ^{14}C isotope dating does not give a precise date and it is assumed that the dated carbon has not been re-worked. Lichen growth curves contain a fair amount of scatter although the large number of samples now gathered adds robustness. Therefore, if the error margins are incorporated for both the dating methodologies and the landuse/climate records it is generally impossible to prove synchronicity for any particular case. Relationships do appear to exist, but it is hard to deduce definitive conclusions due to the coarse temporal resolution of the data. As Macklin *et al.*(1992a) states ‘ *dates for initiation and cessation of alluvial episodes are relatively imprecise’.* Werritty and Ferguson (1980) also contribute *‘The lesson is that palaeo-environmental inferences from coarse fluvial deposits must be made cautiously and with due regard for the considerable short-term and small scale variability of the braided river environment’.*

As well as these temporal inaccuracies, the spatial resolution of these studies can also be criticised. Most of the previously described studies, especially the archaeological, are restricted to a single reach or section of the river. As Macklin *et al.* (1992a) showed, there seems to be different fluvial responses in different sections of the drainage basin. Many of these studies are therefore site specific in nature. For example, Harvey (1996) finds a period of Medieval gully development and valley floor activity in the Howgills that contrasts with a period of inactivity found by Macklin and Lewin (1989) in the Tyne. Palynological cores are generally taken from the immediate vicinity of the study area, but pollen can travel long distances, creating the possibility that they may record land use changes from outside the study area.

As noted by Knox (1995) in section 2.2 (point 5), no two reaches or catchments are the same. Whilst many are similar and can be grouped, a inherited topology history and lithology may lead to different responses. Thus it is dangerous to infer general conclusions from individual sites. In addition, there are internal sources of change, termed intrinsic thresholds by Schumm (1973) and discussed by Knox (1995). These are caused by instabilities operating within the fluvial system, causing thresholds to be exceeded. For example, at a minor scale a river bank may become undercut until it reaches a critical point and collapses, releasing sediment into the channel. Thus, the response to change is difficult to predict. The channel may absorb the changes and return to its prior state, it may remain in its new state, or the new state may initiate a sequence of positive feedback's causing more change. An example of such a complex response at a catchment scale us provided by Brown (1996) where aggradation at the top of the stream has caused incision downstream. Similarly Knox (1977) showed different upstream/downstream channel reactions to land use change. The existence of such instabilities undermines our ability to interpret alluvial features, particularly if data is only available for a small number of sites within a catchment.

Given these differences one might express surprise that any similarities or relationships have been established. This may attest to the strength of the factors involved, allowing these relationships to stand clear from the noise. It is clear moreover that although dating techniques and palynological practices may be susceptible to error, as the number and precision of data continues to improve, that the quality of the debate and the inferences are benefiting in proportion.

2.7 Modelling aims

This thesis aims to answer the questions and uncertainties raised in chapter one and discussed here in more detail. Therefore, in order to address the three aims previously outlined (1.2), the model should be created to examine an entire catchment and combine as many processes as possible that are important to its evolution. For example; slope processes (creep, mass movement), important fluvial mechanisms (erosion, deposition, armouring, grainsizes) and vegetation change (hydrological changes and cohesive properties), within a framework that can model time periods of up to 10 000 years. Furthermore, to make this model relevant to our current interpretations of field evidence, it should be capable of generating the landforms that we currently use to determine geomorphic change, e.g. alluvial fans, terrace sequences, berms, overbank deposits and landslides. A model of this detail may then be validated against alluvial sequences found in the field, which would allow the simulation of future climate and landuse change with relative confidence.