Chapter 1

An introduction to the fluvial geomorphology of Britain

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INTRODUCTION

Scenery in Britain is closely associated with rivers. Because no area is very far from the sea there are no very large rivers, but since the country includes areas with more than 1000 mm of precipitation annually (Figure 1.1), there are large numbers of rivers and streams. The Thames has the largest drainage basin with an area of 9950 km^2, but this is only 0.14% of the area of the world's largest river basin, the Amazon. Although the Thames is the largest British river, according to drainage basin size and also according to length of the main river (239 km), it is not the largest British river according to mean annual flow. The Tay in Scotland has a mean flow 2.26 times greater than that of the Thames, and the flows of the Trent, the Ness, the Tweed and the Wye are also greater than that of the Thames.

The prominence of rivers and streams in the British landscape has been echoed by landscape painters such as Constable and Turner, and it has been emphasized in prose and in poetry for example by Ted Hughes (1983) in his book '*River*'. Rivers have also been regarded pragmatically as an integral part of the rural environment and they have played an important role in the location of sites vital for industry. Rivers in the British landscape have often been associated with leisure, and Isaak Walton's book the '*The Compleat Angler*', first published in 1653, has run to 300 reprints.

A vision of rivers and streams in the British landscape as constant and unchanging is perhaps an unfortunate perception because, although British rivers are not subject to violent changes, they have been affected by significant variations in the past. Fluvial geomorphology is the branch of earth science that is particularly concerned with rivers and with their present behaviour, the effects that they have in contemporary scenery, and the ways in which they have developed in the past. An understanding of rivers past and present can provide an indication of how rivers might change further in the future. The development of fluvial geomorphology provides a background to the Geological Conservation Review (GCR) sites described in this volume.

In the scientific study of scenery, rivers have enjoyed a prominent role. Until about 1830 the traditional view was that one sudden, violent and extraordinary event – the Noachian flood – had fashioned most of the Earth's scenery, and this was the simplest version of diluvialism which has recently been analysed in detail by Huggett (1989). This diluvial view was succeeded by a more uniformitarian interpretation of landscape development, to which Charles Lyell was a particularly significant contributor, and which is associated with the notion that the present is the key to the past (Lyell, 1835). Key points in the uniformitarian approach to the shaping of scenery were the facts that rivers are sustained by the precipitation falling over their drainage basins and that the basin is the unit for calculating a water balance. Although these ideas had been established by P. Perrault (1674) for the Seine basin in France, it was only during the 19th century that their significance gradually became registered. Thus George Greenwood (1857) in his book '*Rain and Rivers*' suggested how rain and rivers shaped the scenery of Britain and of other parts of the world.

An American geomorphologist, William Morris Davis, at the end of the 19th century and during the first part of the 20th century, proposed an approach to the study of scenery that had a very significant impact. He suggested that rivers were the central part of the normal cycle of erosion, that the scenery of an area could be interpreted in relation to its geological structure, the processes operating, and the stage of erosion that had been achieved or the length of time over it operated, and that the cycle of erosion proceeded in stages from youth to maturity and thence to old age. His 1899 paper related his ideas to British river development and these were explored in research during the next 50 years. Contributions from this research centred on the evolution of river systems, including the early origins of major eastward-flowing systems (Figure 1.2), the association of stages of river development with remnants of older land surfaces or planation surfaces, and the Quaternary development of river valleys reconstructed from the remnants of former valley floors and deposits still preserved on valley sides.

Although the importance of understanding river processes had been acknowledged since Davis, there had been few quantitative investigations of the controls upon river and stream behaviour. Although Gilbert (1887) had developed what later came to be recognized as the potential basis for an approach to geomorpholo-

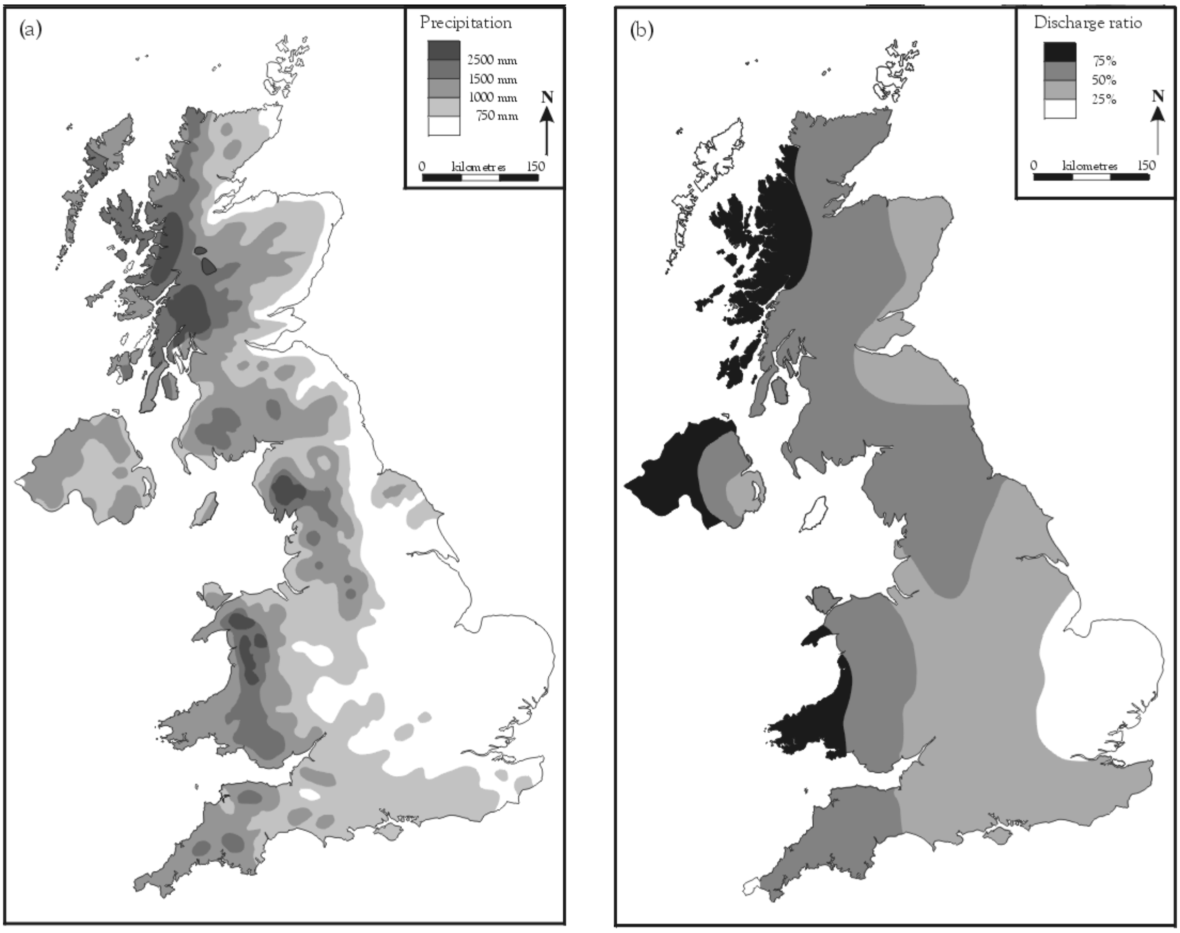


Figure 1.1 (a) Annual precipitation for the whole of Britain (after Ward, 1981). (b) The discharge ratio for the whole of Britain (after Ward, 1981).

gy founded upon analysis of processes, this could not be adopted as easily as the approach advocated by W.M. Davis (1899) and so was not pursued until the mid-20th century. Therefore, since the 1960s, greater attention in research has been accorded to fluvial processes and initially to studies of small drainage basins (Gregory, 1978). Improved understanding of river processes has also provided a basis for analysing the impact of human activity on rivers and their basins. In addition, it has been possible to improve understanding of past river systems, and palaeohydrology has been developed as an investigation of the hydrological records (Gregory, 1983). Research has therefore provided a basis for understanding river mechanics in the future against the background of the analysis of contemporary and past river behaviour. Thus, much of the early phase of modern fluvial geomorphology was based on using scientific principles and fundamentals to understand fluvial processes and their operation in a system. Much work was aimed at identifying regular and systematic variations and was based on an assumption of equilibrium between form and process. For a time, there was a phase of intense concentration on small-scale and short-term processes, with use of instrumentation being a key component. Since then, analysis of changes at various timescales, including that of human impact, has gained significance and the link between forms and processes has been re-emphasized. The evolution of ideas gives a basis for an outline, below, of **river processes**, an indication of how **river history** has been deciphered, and suggestions of the **types of river system** that have now developed in relation to the pressures that river systems have to sustain.

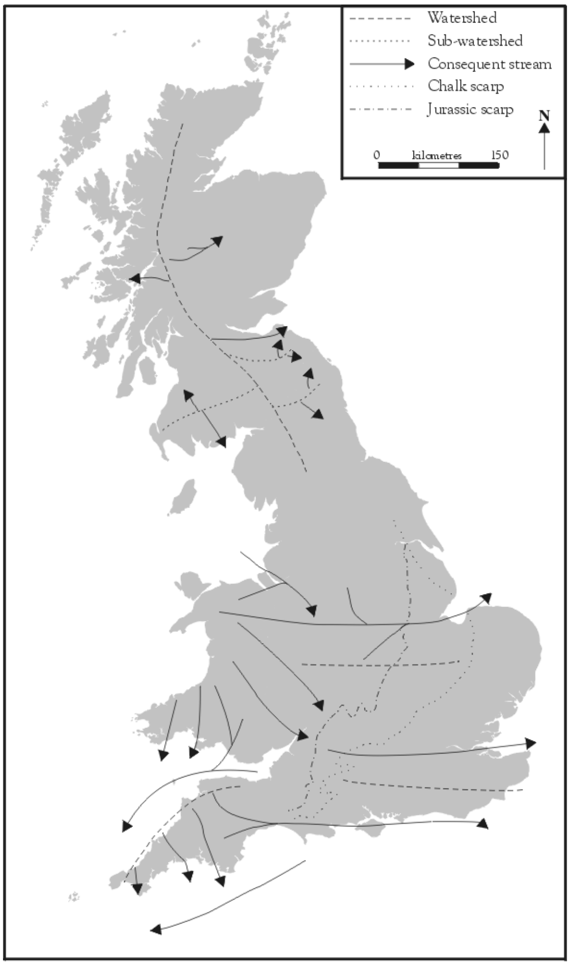


Figure 1.2 The original drainage pattern for England and Wales as initiated by Early Tertiary uplift of the late Cretaceous sea floor (Brown, 1960), and the initial watersheds and initial drainage of Scotland (after Sissons, 1967).

RIVER PROCESSES

Rivers and streams act like a conveyor belt, which is critical for the development of scenery. The network of river channels that makes up the fluvial system is really a series of linked conveyor belts because water and sediments do not progress continuously through the system. Storage of water in lakes or in the deeper pools of river channels occurs for relatively short periods of time, but sediment and solutes can be stored in or adjacent to river channels for much longer periods of time.

River discharge (Q) derives from precipitation (P) and these can be related in a simple hydrological or water balance equation in which

$$Q = P - E \pm S$$

where E is evaporation from land and water surfaces and S represents changes in storage of ground water and soil moisture. The amount of evaporation can be greater than 50% of the precipitation received in southern and eastern England, although in the Highland zone it can be less than 25% of total annual precipitation. The proportion of precipitation that eventually reaches the river channel can follow one of two general routes. **Delayed flow** is water that infiltrates through the soil and rock to reach the groundwater table and subsequently emerges from springs to provide a base flow component of river discharge. **Quick flow** is that portion of precipitation which either flows over the ground surface as overland flow, falls directly onto the stream channel, or infiltrates into the soil or into the rock above the water table and then flows laterally beneath the ground surface towards the river or stream channels. Water can follow a variety of pathways: these range from matrix flow, where the water flows through very small spaces in soils, to flow through soil "pipes' which are often 10 cm in diameter and sometimes much larger. Flow can also occur at different levels, through the soil as throughflow, or through the unsaturated part of the rock as interflow.

Whenever precipitation falls on a drainage basin, the amount of water that will flow through the basin and the routes that it follows will be determined by the characteristics of the basin, including the rock type, soil, topographical shape, and land use and vegetation, and also by the preceding weather conditions. If the ground water levels are high, then a different pattern of flow routes will be used from the one that will operate when ground water levels are low after a dry period. In essence, this is the basis for a dynamic view of river discharge production that is now an integral part of hydrological models of river flow through drainage basins.

The 'conveyor belt' also transports solid material, which is rolled or jumped along the bed of the channel as bedload, or carried as sediment suspended in the stream flow. Some materials dissolve in the water and are transported in solution. Such solutes are derived from a great variety of sources since they can be present in the precipitation that falls over the basin, they are obtained from vegetation from the surfaces of leaves for example, and they are derived from soils and weathered rock and also from the rock types which underlie the drainage basin. At the other extreme, bedload is obtained largely by erosion of the river bed and the banks of the river channel. The size (calibre) of the bed material available to the river may reflect the legacy of glaciation, if glacial deposits provide a source of bedload for the river. During downstream transport of the bedload, considerable differences exist in the size of the material, which decreases downstream; in the roundness of the material, which rapidly increases to a particular level and is then maintained; and in the composition of the bed sediments because some survive longer than others. Intermediate in character is the suspended sediment, which can be derived from channel bed and banks, but also from slopes, pipes and cultivated areas.

Measurements of material transported as solutes and sediment have been necessary to estimate the rates at which river scenery is being changed. There are many was of estimating rates of erosion and the rates deduced necessarily vary according to the size of areas investigated, with the highest values obtained from small, easily eroded basins with steep slopes and incomplete vegetation cover. Ranges of values obtained for rates of erosion in Britain include:

Accumulation of sediment in reservoirs:
  equivalent to 10–1000 mm lowering of the land surface per 100 years
Calculation of sediment transported by rivers in solution and suspension:
  equivalent to 2–10 000 mm per 100 years
Measurement of specific small areas:
  in gulleys – 16 000 mm per 100 years
  over slopes – 1400 mm per 100 years
  unvegetated moorland –- 3810 mm per 100 years
  erosion of cultivated fields – 60–1050 mm per 100 years

Some idea of rates of deposition in Britain has been obtained from measurements of floodplains in lowland Britain, where increases of 1–10 mm in the land surface occur per year.

If erosion was allowed to continue uninterrupted at the estimated present-day rates indicated above, then it would take several million years for the scenery of Britain to be eroded to siginificantly lower levels. In most rivers in Britain, the greatest amount of load, calculated by relating the amount of solutes and sediments transported to the water discharge available, is transported as solutes. However, although solutes are very significant in the general denudation of the landscape, sediments – particularly bedload – are the dominant components of contemporary channel features.

Sediment and solutes do not continue uninterrupted on the 'conveyor belt' throughout any drainage basin. It is the interaction between storage and transport of sediment and water which gives rise to characteristic forms of scenery, or "landforms', associated with rivers and their channels. For example, along the course of a river channel there is an alternation between shallow areas, called riffles, and deeper pools. The spacing of the pools and riffles is directly related to the size of the river channel. Similarly, the time for which sediment is "stored' in fluvial systems varies according to the particular location. Within a river channel, sediment may accumulate in bars and these are the temporary locations for material that is gradually being moved downstream by one storm after another. Longer-term storage of sediment can occur in the floodplain, which is the level area immediately adjacent to many middle- and lower-course river channels. The floodplain is built up of fine sediments which are slowly deposited from floodwaters that have exceeded the capacity of the river channel, and also of coarser sediment that has been deposited as channel bars and incorporated into the floodplain as the river channel has moved position. Over time, river channels gradually shift by erosion of one bank and deposition on the other, and in this way meanders can gradually be translated in a downstream direction. During this translation, the gravel bars accumulated in the channel as point bars systematically become incorporated within the floodplain sediments.

The 'conveyor belt' in the river basin is made up of streams and rivers which collectively make the drainage pattern. This pattern is dynamic in extent because, just as the river channels themselves have low flows for much of the time but can fill up to bankfull or greater levels, so also can the extent of the drainage network increase. Streams are perennial if they flow all year, intermittent if they flow seasonally when the water table is high, and ephemeral if they flow only during, or immediately after, rainstorms. Thus the drainage network in any basin expands and contracts according to the prevailing climatological conditions. Along the course of individual streams and rivers in the drainage network, it is possible to classify their pattern according to the way in which they would appear from the air. This river channel planform is usually divided into two major types, those that are single-thread and composed of a single river channel, which may be either meandering or for short distances may be straight; and those which have more than one channel, are multi-thread, and are described as "braided' river channels. The braided channels occur particularly where basin slopes are steeper, where supplies of sediment are readily available and where river flows vary quite significantly. Conversely, the single-thread meandering channels tend to occur where the sediment is finer, where the basin slopes tend to be lower and where there are no unlimited inputs of sediment into the fluvial system. River channel patterns are not always simply distinguished as meandering or braided, and in Scotland other classifications are used. River channel patterns are not always free to change, because in some locations they are confined by the valley sides and sometimes they may be strictly confined by human activity. For example, the development of the railway network in Britain often involved detailed changes to river patterns, or necessitated changing the river channel to stop erosion that might otherwise have jeopardized the railway line.

The size and character of any river channel is related to the position in the basin and to the characteristics of that basin. Thus there is a simple relationship between the size of river meanders and the drainage area, and there is also a relationship between the area of the cross-section of the river channel and its position in the drainage system. The size of a river channel cross-section reflects the discharges that flow along it, the sort of sediment into which the channel is cut, and the local characteristics of slope and vegetation that also exert an influence. Simple relationships established between river channel dimensions and the discharges of British rivers can be used (Wharton *et al.*, 1988) to estimate river discharge from natural river channel dimensions. Thus river channel width (W in metres) can be used to give an approximate indication of the discharge $Q_{(1.5)}$ in cubic metres per second, which is the flow that would occur in the river channel at least on average once every 1.5 years, using the following equation:

$$Q_{(1.5)} = 0.217\, W^{1.76}$$

The general relationship that exists between the form of river channels and river landforms with fluvial processes should not lead to the assumption that all morphological features are produced by events that occur on average once or twice each year. It has been realized that rare flood events can have significant impacts in shaping river channels and drainage systems in Britain. Although Britain does not receive the extreme precipitation or flood events that occur in some parts of the world, nevertheless extreme events are experienced, and the effects of such floods at more than 70 locations over the period since 1686 have been recorded in the literature. For 39 of those events it has been possible to derive an estimate of the rainfall that produced the flood, and the large events are plotted in Figure 1.3 in relation to the line of maximum known falls in the Britain and a higher envelope line showing the maximum world falls. This inventory of flood events was compiled using those recorded by Beven and Carling (1989) as a basis, and the envelope curve for rainfall excesses was derived by Rodda (1970). The significance of such events is a reminder of the occasional impact of large floods: a number of the sites in this volume record aspects of flood events and are important because they offer results which are similar to a type of laboratory experiment. Subsequently it is important that we retain evidence of a particular flood event and also are able to analyse the rate at which that evidence is changed and assimilated into the fluvial system.

THE HISTORY OF FLUVIAL PROCESSES

There is no easy separation between what is present and what is past as far as the contribution of river activity to scenery is concerned. This is exemplified by flood events, since the impact of a recent large flood could be thought of as a rare event typical for present conditions,

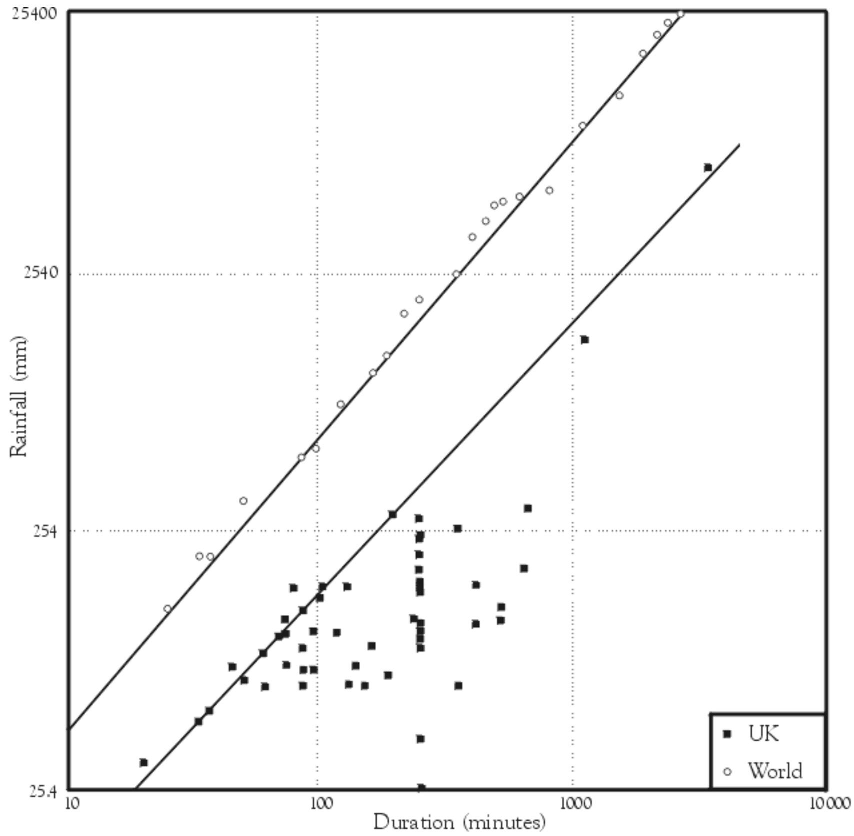


Figure 1.3 Rainfall magnitude–duration relationships for the world and the UK. The largest falls (from Rodda, 1970) and magnitude–duration relationships of geomorphologically significant UK floods, where shown, are given.

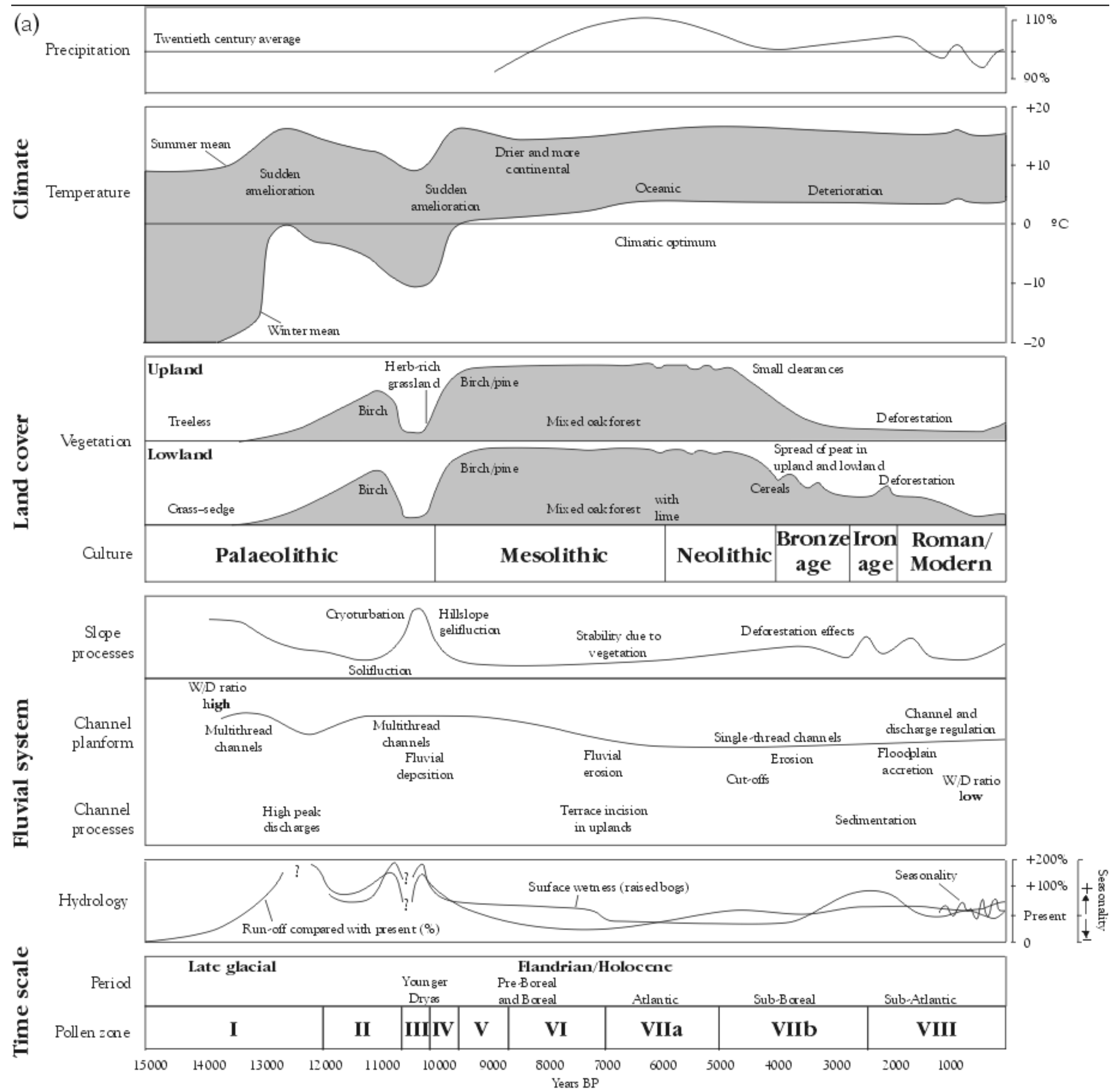
or it could be envisaged as an example of a type of flood that occurred in the past. Thus the Lynmouth flood, that devastated Lynmouth and the East and West Lyn river channels in 1952, was the sort of event that could happen on average once in 500–1000 years under present climatic conditions. Furthermore, it is not easy to separate the present from the past because of the way in which human activity has slowly and progressively changed the landscape of Britain. Although the direct effects of human activity may be obvious, for example in the engineering of river channels, other changes are often much more difficult to decipher. Thus the river channels that today are bordered by woodland show how river channel processes are significantly affected by trees and organic debris (Gregory and Gurnell, 1988), and these vegetation influences were much more extensive in the past when many more rivers in Britain were flowing through woodland basins.

Reconstruction of the way in which scenery was fashioned can use evidence from morphology and landforms, from sediments and from deductions about the way in which processes operated in the past. However, for past environmental situations sufficient information is rarely preserved and Lewin (1980) has drawn the analogy with a series of windows in time that allow us to see fragments of the former landscape. It is those fragments of morphology and sediments that can be used to deduce what processes were like in the past and so to reconstruct how changes occurred. British scenery still contains many legacies that were produced under rather more dramatic conditions than those of the present time. Some of these previous conditions were associated with rivers and others were associated with environments affected by glaciation and deglaciation.

It is imperative that we identify and conserve evidence of former environmental conditions because these provide the fundamental basis for interpreting the history of our scenery, and a number of the sites in this volume contain vital evidence of this kind. Particularly dramatic landforms created under past conditions are large meandering valleys, now occupied by small underfit streams, which were produced when river discharges were much larger than those of the present time. In some cases river valleys that received water from glacial drainage channels, which were created by meltwater from melting glacier ice, or draining from lakes impounded by ice, were a feature of the Quaternary environments of northern and western Britain. In the headwaters of drainage basins, particularly on limestone and sandstone rocks, there are extensive networks of dry valleys, and examples are included in the Quaternary GCR Blocks. These valleys, without any trace of stream channels at the present time, were also produced when the hydrological cycle of the past involved greater amounts of surface runoff.

Some features were produced by changes in sediment distribution and, for example, along some small rivers in upland Britain, there are sequences of deposits laid down as alluvial fans which have now been abandoned and dissected by present streams. Abandoned channels survive along many rivers as remnants that may be dated from the organic deposits which infill the old channels. Many of the river systems of Britain are still endeavouring to recover from the most recent glacial and cold phases, which produced vast quantities of sediment. Materials from glacial deposits are still being released into the fluvial system. In many parts of Britain, such as Scotland and north-east England, the present fluvial system clearly records the legacy of recent and of earlier glaciations. We therefore have a landscape today in which river systems are still recovering from the impact of different processes in the past.

Three main reasons explain the differences between the past and present conditions. The most obvious is the impact of changes of climate. Not only did the Quaternary bring a series of glaciations that affected much of the northern parts of Britain, but to the south of such glacier ice were climatic conditions that resembled the contemporary Arctic climates of northern Canada or the former Soviet Union. This meant that the regimes of rivers were typically very seasonal, with little or no flows during the winter months and very large floods before and immediately after the spring thaw, followed by lower flows for much of the summer. Under such conditions, when the ground was frozen so that infiltration was not possible, extensive networks of valleys were produced, later to become dry valleys, and larger river discharges characteristically occurred along river valleys compared to those of the present time. Secondly, there have been changes along river valleys instigated by sea-level change. Such sea-level changes have affected the levels to which river activity could work and so allowed the destruction of original valley floors, remnants of which now remain as river terraces. In some cases the development of incised meanders occurred after significant lowering of river levels. A third difference between the present and the past is that the influence of human activity today is very substantial, whereas in the past it was often less significant. Many rivers and river channels have been modified as a consequence of deliberate changes by human action so that streams have been channelized for flood control, for drainage, to prevent erosion and for improvement of navigation. In addition, land use change in the basin has often indirectly affected the river channels. Along the Itchen in Hampshire, the river channel was apparently made navigable as early as the 12th century (Hadfield, 1969). Other major changes have been much more difficult to detect, such as the way in which stream networks have been changed because seepage areas have been replaced by stream channels, ditches or field drains (Ovenden and Gregory, 1980). A particularly dramatic way in which fluvial systems of the past were changed was when deforestation between 2000 and 4000 years ago released quantities of fine sediment which were transferred into the river systems and which are very evident in the floodplain sediments of major rivers. In the upper Thames basin it has been shown how flooding and alluviation were largely restricted to the past 3000 years (Robinson and Lambrick, 1984). Palaeohydrology, mentioned above as an approach that allows a retrospective way of analysing environmental change, has been employed to enhance our understanding of past fluvial changes. An international project from 1977 to 1987 (Starkel *et al.*, 1990) included a study of the palaeohydrology of the Severn basin (Gregory *et al.*, 1987). The conclusion of the Severn study showed how four major phases of development could be identified in the past 15 000 years and each of these phases, associated with particular types of climate and land cover, could be identified in the impact on the fluvial system (Figure 1.4a).



Years BP	Phase	Precipitation	Temperature	Vegetation	Hydrology	Channel processes
Pre-15 000	Glacial	Snow	Low	None	Summer floods	Multithread channels and fluvioglacial systems
15 000–11 000	Earlier Late Glacial		Ameliorating cold winters	Grass sedge succeeded by birch woodland	High peak discharges, decreasing with forest spread	Multithread channels
11 000–10 000	Late-glacial Zone III		Extreme cold	Herb-rich grassland	Run-off reduced but sediment supply greatly increased	Fluvial deposits and instability in fluvial system
10 000 4 000	Flandrian/ Holocene	Drier, then oceanic	Rising	Mixed oak forest, some clearances	Run-off reduced, sometimes lower than present	Fluvial erosion and single-thread meandering channels
4000–present	Flandrian/ Holocene		Deterioration then fluctuating	Deforestation	Seasonality fluctuating, discharge regulated	Lowland cut-offs Floodplain accretion Sedimentation

Figure 1.4 (a) The sequence of environmental and palaeohydrological change in the Severn basin (after Gregory and Lewin, 1987). (b) The sequence of palaeohydrological changes in the Severn basin (after Gregory and Lewin 1987

FLUVIAL LANDSCAPES AND PRESSURES

The present fluvial system in Britain blends together the impact of present processes with the landforms produced by processes of the past, and the sites in this volume were selected for the GCR as the best examples to exemplify these two stages.

There is a general sequence of four major types of fluvial landscape in Britain (Figure 1.5), which can be thought of as proceeding from headwater areas, through gorges, to floodplains and finally to estuarine tidal areas. Each of these major types has particular characteristics, which are indicated in Figure 1.5, but there are also major contrasts between the upland and lowland zones and between the glaciated and non-glaciated areas. A major distinction within a river valley is between bedrock reaches, mainly in the upstream sections, and alluvial reaches, mainly downstream. The dividing line between the highland and lowland zones, approximately from the mouth of the River Exe to the mouth of the Tees, separates areas to the north and west, which tend to have the most active river systems and which can be expressed in terms of the stream power (a product of discharge, slope and water quality that is reflected in the amount of sediment carried by the water), whereas areas to the south-east of the line have much lower stream power values. Contrasts in river characteristics can be related to rock types and their interaction with relief and water quantity (Figure 1.5b). A further contrast is between areas that have been glaciated, especially in the most recent Quaternary glaciation, and those that have not. In the former there are ample deposits for rivers to excavate and to modify, whereas in the latter there has been ample opportunity for the impact of cold climatic conditions and different fluvial regimes (Lewin, 1981).

A further contrast between the south and east of Britain and the north and west is the degree of human activity which has affected the present fluvial system and which continues to exert pressure upon it. Direct changes are very well exemplified by the distribution of channelization in England and Wales (Brookes *et al.*, 1983) which is illustrated in Figure 1.6. This shows that between 1930 and 1980 the extent of direct modification of river channels by engineering works or for channel maintenance was very substantial, and such channelization has a density 20 times greater than the density of channelization of rivers in the USA, where the concerns about channelization effects have been much greater. Similar direct influences of human activity on the river channel can be seen at the sites of dams and reservoirs, where water power has been generated, where gravel or river deposits have been extracted, or where river diversions have been engineered. In addition, there have been indirect changes arising as a consequence of these direct pressures. After direct modification of stretches of the river channel, for example for flood prevention or for water supply by river regulation through dam construction, it has been shown that considerable lengths of the river channel downstream have been modified as a consequence of the effect on the river flow. Thus downstream of channelization works, flows can be increased and so may induce erosion, whereas downstream of dams a decrease of flows can lead to accretion of sediments, such as along the Derbyshire Derwent, where Petts (1977) identified changes of the channel of the River Derwent following impoundment of reservoirs in the headwaters of the basin. In addition, changes of drainage areas, for example from forest to farmland or from farmland to urban areas, can significantly change the hydrology of the drainage basins, and the different flows that result can produce significant changes in the river channels downstream. Most dramatic are the changes downstream of urban areas, and it has been found that the increased floodflows from urban areas can produce stream channel dimensions downstream that are twice the dimensions expected (Gregory, 1976). A range of pressures on the drainage basin, including both spatial ones associated with land-use changes and point pressures (for example where bridges are constructed across rivers or where outfalls of storm water drains augment the flow and sediment of the river channel) can induce substantial amounts of river channel adjustment downstream. A series of associated questions relate to what causes the river channel change, how much will occur, when it will take place and where it will be located (Gregory, 1987). Some answers to these questions are known but others require more detailed investigation. Therefore, it is imperative that there are sites available for further research where natural landscape features from the present and past have not been obliterated so that the extent to which changes have occurred can be ascertained. The

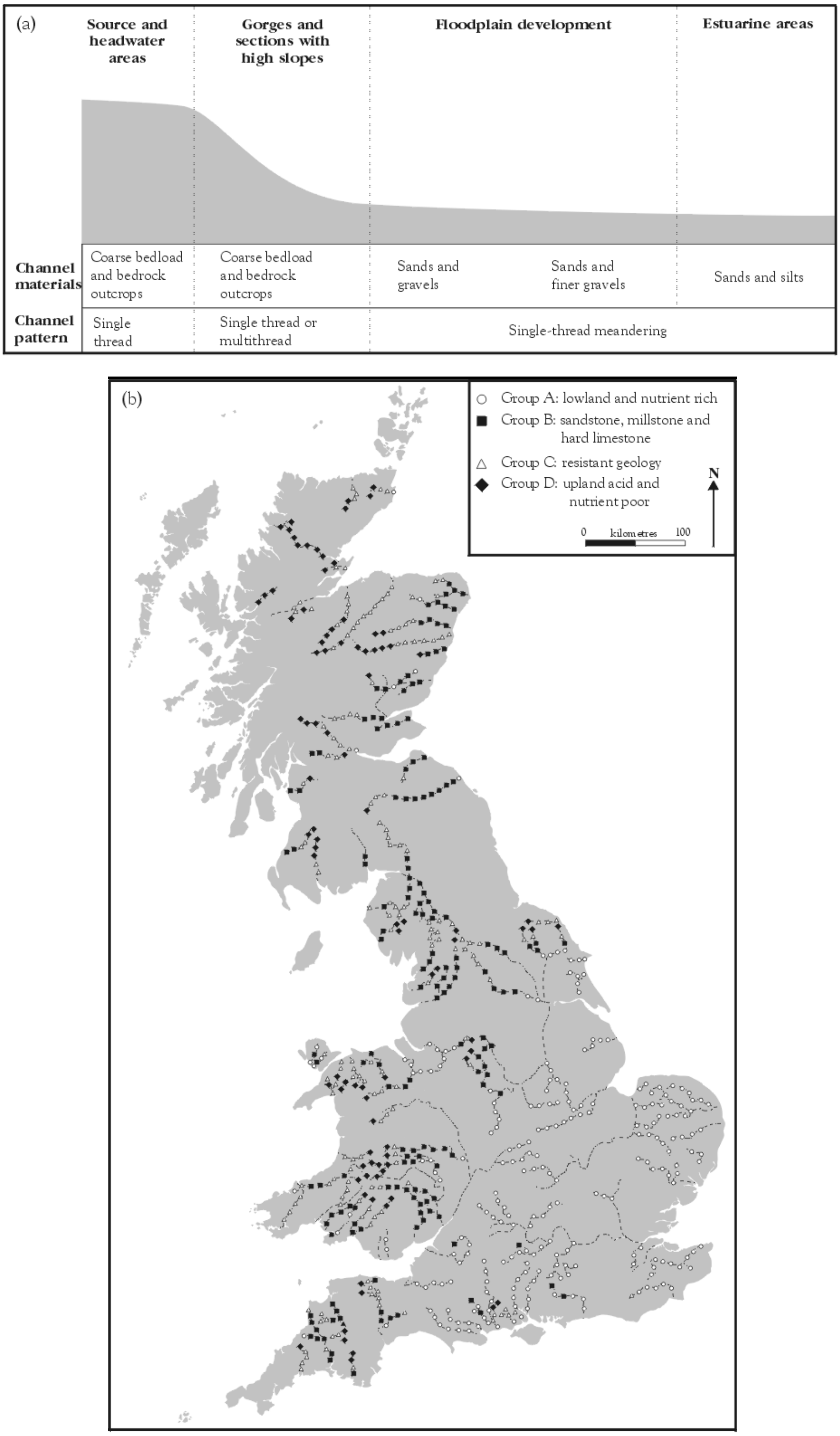


Figure 1.5 (a) An idealized section showing the relationship between river profile, channel materials and channel pattern (after Smith and Lyle, 1979). (b) Map showing 'surveyed' rivers in Great Britain (after Smith and Lyle, 1979).

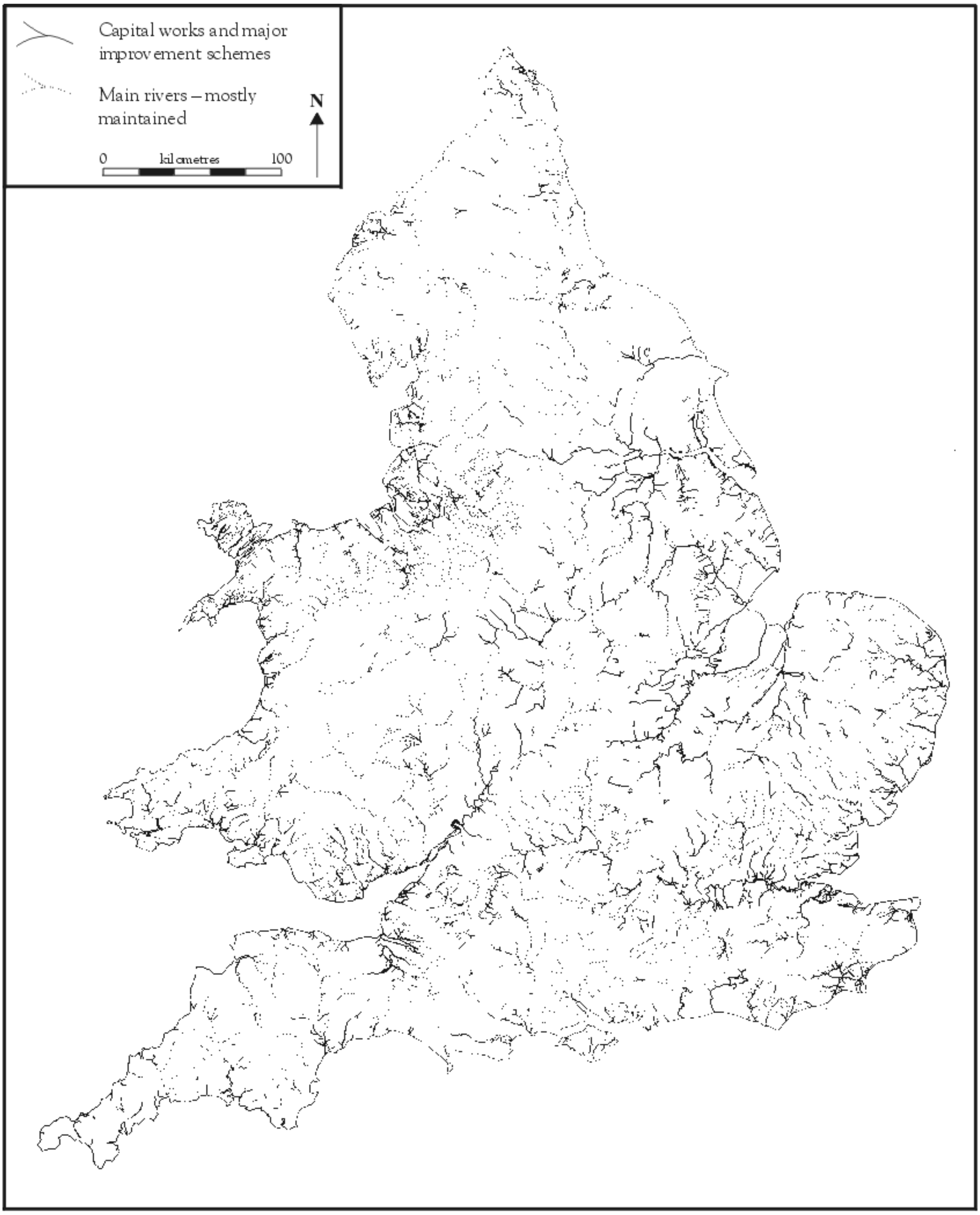


Figure 1.6 A map of England and Wales showing rivers channelized, 1930–1980 (after Brooks *et al*., 1983).

extent of detrimental modification partly accounts for the relatively sparse number of sites in central and south-east England.

Some sites are relatively static in their characteristics and need to be conserved as representatives of features inherited from past types of landscape-forming conditions. Other sites are still dynamic, undergoing active processes that continue to change the landforms. It is very important that the latter sites are allowed to remain dynamic so that processes can be studied and the evolution, rate and nature of change can be elucidated. Some of these changes will include responses to human activity and also to climatic change. So, for example, by understanding river adjustments scientists will be better placed to predict impacts of global warming as well as to understand the origin of the features within the sites themselves.

Investigation of the sensitivity of sites to a range of natural and human-induced pressures is required, but sensitivity has been interpreted in several ways (Downs and Gregory, 1992). Sensitivity is relevant to the management of river channels because it can help to indicate which channels are adjusting and which may be susceptible to adjustment in the future. Four types of interpretation of sensitivity have been used in different studies and these relate to ratios, thresholds, recovery times and sensitivity analysis (Downs and Gregory, 1995). In most investigations it is feasible to relate proximity to thresholds to the imbalance of forces, when sensitivity may be defined in terms of the relationship of disturbing forces to a specific threshold condition.

Awareness of the value of an understanding of geomorphology and of river channel change has increasingly influenced management methods and restoration schemes. In the USA an approach of working with, rather than against, the river was advocated (Winkley, 1972), and a similarly sympathetic approach to river management has been developed in Britain, where Brookes (1992) showed how the recovery and restoration of British river channels could be effected using a knowledge of river channel behaviour. Techniques necessary for the holistic appraisal of river projects have been collected together in a manual (Gardiner, 1991).

CONCLUSION

Changes exercised by human activity on river channels do not necessarily lead to a deteriorating river environment. Indeed, the recent trend to work with the river rather than against it has meant that greater understanding of river behaviour is being sought so that it can be utilized in devising management strategies that are as consistent as possible with natural river activity. This contrasts with earlier strategies which tended to replace natural rivers and their channels by very different concrete structures. To ensure that we have the best possible input to geomorphological approaches which work with the river, it is essential to recognize that the rivers of today have emerged from environmental systems of the past, that rivers themselves have a "memory' (Newson, 1987) and are dynamic and will continue to change. Indeed, it has been suggested that the timescales used for the management of a river, which are usually employed by an engineer, are necessarily much shorter than those necessary to the understanding used by the geomorphologist. In order to work with nature, it is essential that we have a range of sites in which natural processes are operating and in which naturally derived features are present. As considerable progress is now being made towards the restoration and enhancement of engineered river channels utilizing geomorphological research and understanding (Brookes, 1990; Gardiner, 1991; Sear and Newson, 1991), it is vital that we perceive the present river system as part of an evolving sequence which has a past, a memory, a prospect and a future. It is to this time continuum that the fluvial GCR sites are especially valuable. However, it is not only the direct and immediate benefit to river management that justifies the selection of sites for conservation. It is important that the best examples of fluvial landforms and of operation of processes are conserved, that spectacular and unique fluvial features in our natural heritage are protected, and that a range of sites with present or potential value for research is available.

In selecting the sites described in this volume, the three GCR components of international importance, presence of exceptional features and representativeness have been kept in mind. The full rationale of the GCR and the detailed criteria and guidelines used in site selection are given elsewhere (Crowther and Wimbledon, 1988; Allen *et al*., 1989; Gordon and Campbell, 1992; Gordon and Sutherland, 1993; Gordon, 1994; Wimbledon *et al*., 1995; Ellis *et al*., 1996). However, the selection of fluvial geomorphology sites for the GCR necessarily reflects the sites that have been investigated in earlier research; and there is also some imbalance in distribution of the sites not only reflecting the research that has been undertaken but also related to the extent of the influence of human activity. Nonetheless, it has been possible to group the sites described in this volume (Figure 1.7 and Table 1.1) into five major categories. The fluvial landforms category (A) consists of those which

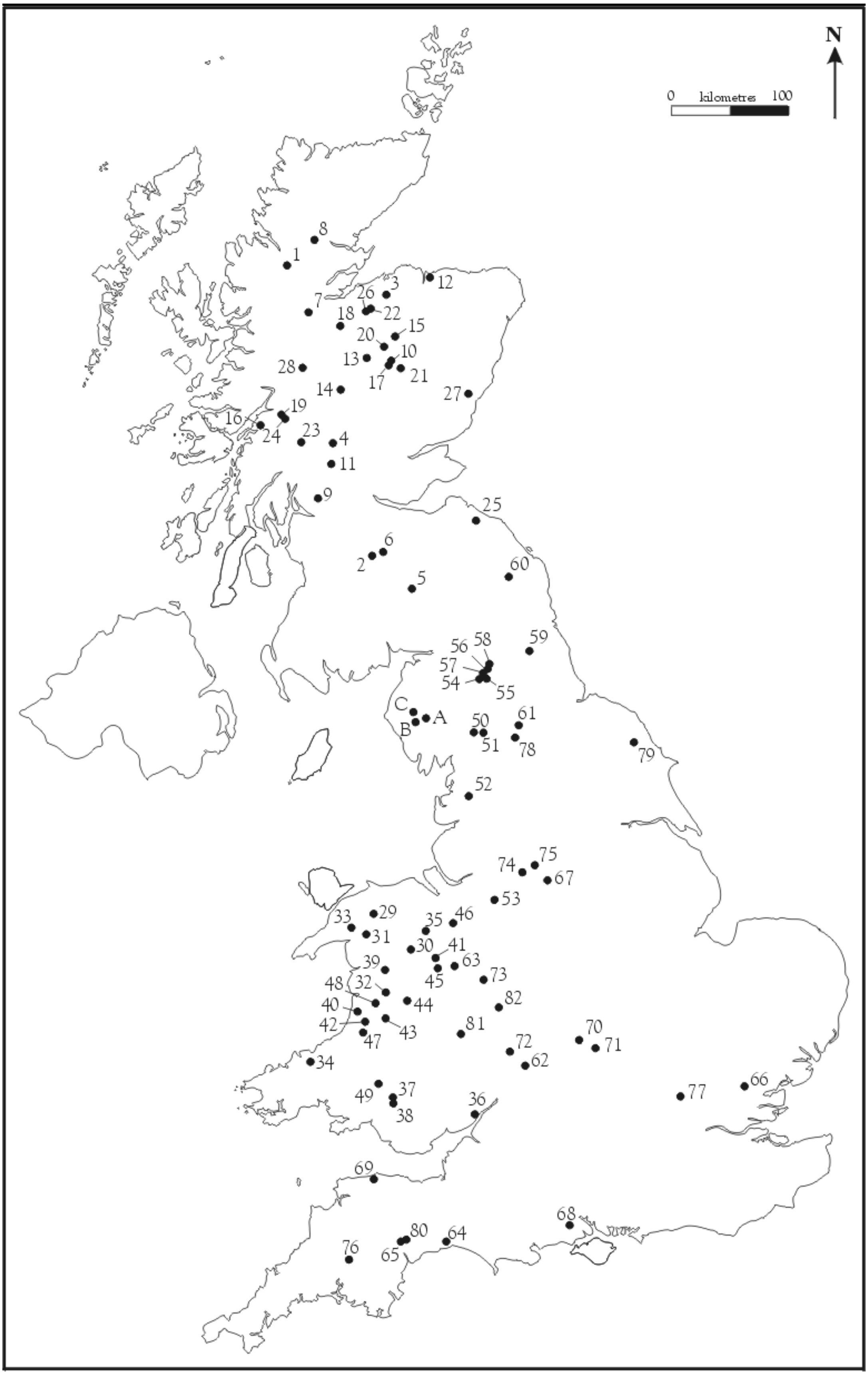


Figure 1.7 A map of Great Britain showing the classification of GCR fluvial geomorphology sites. See also Table 1.1

Table 1.1 Key to the sites shown on Figure 1.7, including classifications used in Table 1.2.

Site name	A	B	C	D	E
1 Corrieshalloch Gorge	4				
2 Falls of Clyde	4,5				
3 River Findhorn at Randolph's Leap	4	1			
4 Falls of Dochart	5				
5 The Grey Mare's Tail	5				
6 River Clyde meanders			1	2	
7 Strathglass meanders		1	1	1	
8 Abhainn an t-Srath Chuileannnaich		1	1,2	2	
9 Endrick Water			1	2	
10 Derry Burn	1	1,2,4	1		
11 River Balvag delta		5	1		
12 The Lower River Spey		1	4	1	
13 Glen Feshie	1	1,3	2,4,5		
14 The Allt Dubhaig		4	4	4	
15 Dorback Burn		1	2,4		
16 Glen Coe: river and slope forms	4	1,3			
17 Luibeg Burn	4	1			
18 Allt Mor (River Nairn)	2,4	1	1,5		
19 Allt Coire Gabhail		3			
20 Allt Mor (River Druie)	4	1,4	5	4	
21 Quoich Water alluvial fan		1	5	2	
22 Allt a'Choire	4	4	5		
23 Allt Coire Chailein fan		4	5	1	
24 Eas na Broige debris cone		3	5		
25 Oldhamstocks Burn		1,2			
26 Findhorn Terraces	1				
27 North Esk and West Water palaeochannels			3	1	
28 Glen Roy, Glen Spean and Glen Gloy	1			5	
29 Afon Llugwy between Swallow Falls and Betws y Coed	3,4,5				
30 Afon Rhaeadr at Pistyll Rhaeadr	5				
31 Afon Cynfal at Rhaeadr y Cwm and Rhaeadr Cynfal	3,4,5				
32 Afon Teymyn at Ffrwd Fawr	3,4,5				
33 Afon Glaslyn at Aberglaslyn	4		1		
34 Afon Teifi at Cenarth	4			1	
35 River Dee at Llangollen	2,3				
36 River Wye at Lancaut	2,3				
37 Afon Hepste	6				
38 Afon Mellte downstream of Ystradfellte	6				
39 Afon Dyfi between Dinas Mawddwy and Mallwyd	1,3				
40 Afon Rheidol	1				
41 Afon Vyrnwy	1			1	
42 Afon Ystwyth			4		1
43 Upper Elan upstream of Graig Coch Reservoir at Bodtalog		9	1		
44 Upper Ruver Severn between Dolwen and Penstrowed		1,4	4		
45 River Severn between Welshpool and the confluence of the Vyrnwy and Severn			1		
46 River Dee, Holt to Worthenbury			1		
47 Afon Teifi at Cors Caron			1		
48 Maesnant, Pumlumon (Plynlinon)	7				
49 Black Mountain scarp		3			
50 Carlingill Valley, Howgill Fells	1,3	3	5	4,5	
51 Langdale and Bowderdale Valleys, Howgill Fells		1	5	4,5	
52 Langden Brook, Bowland Fells			4,5	4	
53 River Dane, near Swettenham	1		1	6	
A Langstrathdale*	4,5	3	4		
B Wasdale*	4	3	4,5		
C Fan Deltas at Buttermere and Crummock Mere			5		

Table 1.1 Continued

Site name	A	B	C	D	E
54 Black Burn	1		4	1	
55 Garrigill, River South Tyne				5	1
56 River Nent, Blagill		5	1	2	1
57 The Islands (Alston Shingles), River South Tyne		1		5	
58 Blackett Bridge, River West Allen		5			
59 River Tyne at Low Prudoe		1			1
60 Harthope Burn				2	
61 Shaw Beck Gill		1			
62 Beckford				4	
63 River Severn at Montford				3	
64 River Axe at Axminster and Whitford		8		2	
65 River Exe at Brampford Speke		5			
66 River Ter at Lyons Hall		6			
67 River Derwent at Hathersgate	1				2
68 Highland Water		7,8			
69 River Lyn	3	1			
70 River Itchen near Knightcote				3	
71 River Cherwell at Trafford House				3	
72 Ashmoor Common				1	
73 River Severn, Buildwas	1			6	
74 Alport Valley	4				
75 Bleaklow	3				
76 Lydford Gorge	4				
77 Mimmshall Brook at Water End	7				
78 Aysgarth	5				
79 Dovedale	1			6	
80 River Culm at Rewe		4,5		6	
81 River Lugg					3
82 Wilden	1			6	

*Potential GCR sites.

dominantly provide a landscape feature that is associated with a particular process or a particular stage in fluvial landform development. A second group of sites (B) is dominantly associated with a particular aspect of contemporary fluvial processes which vary across the breadth of Great Britain and contrast particularly between the north and the south. A particular aspect of the fluvial landscape concerns river channel pattern and floodplain features (C), which are classified as a separate category. As indicated above, in Britain we have considerable evidence of channel change which has arisen during the Quaternary, and a category of six types is included (D) to indicate these features. Finally, some sites are dominated by the impact of human activity on the fluvial landscape or upon the river system (E). Although it was convenient to recognize five major groups, it should be emphasized that many of the sites include more than one type and this is reflected in the key provided for each of the sites. The balance between the sites shows that 52% are associated with fluvial landforms, 42% with fluvial processes, 40% with river channel pattern and floodplain, and 34% with channel change while 6% are dominated by the impact of human activity. The selection therefore reflects a combination of valued landforms, of sites where processes and features can be seen at their best, and of sites where significant scientific work has been carried out. This reductionist approach to the sites, however, belies their potential contribution because they should be seen as a range that individually and collectively provides clues to the present and past fluvial system in Britain, and therefore gives us one basis for wise stewardship of the fluvial environment in the future. Once this selection has been made, then, to facilitate stewardship it is necessary to assess the sensitivity of sites according to liability to adjustment in relation to natural processes, and to their vulnerability to human activity by direct or indirect means. A preliminary analysis of the sites (Figure 1.7, Table 1.2) involved the development of a uniqueness index similar to that originally devised by Leopold (1969) and this was applied to the classification of 30 categories (Downs and Gregory, 1995). It is important to analyse not only the extent to which a site is unique but also to know its susceptibility to change. The sites described in this volume represent a selection made at a particular time, and it is important to remember that they are not all unique representatives and that some are more liable to change than others. Just as the management of river channels is now seen within the context of a dynamically changing river system, so these sites have to be visualized in a context of change over time.

Table 1.2 Numbers of GCR sites representing the categories shown on Figure 1.7.

Classification	Number of sites representing the category
A. Fluvial Landforms	
1 Terrace	14
2 Incised Meanders	3
3 River Capture/rejuvination	9
4 Mountain torrent/slot gorge	17
5 Waterfall	9
6 Karstic site	2
7 Soil pipe/swallow hole	2
B. Fluvial processes	
1 Process event-flood	19
2 Accelerated erosion	2
3 Debris flow/cones	8
4 Sediment movement	7
5 Floodplain sedimentation	5
6 Discharge control on capacity	1
7 Vegetation influence	1
8 Bank erosion	2
9 Response to confinement variation	1
C. River channel pattern and floodplain	
1 Meander	14
2 Wandering	3
3 Outwash sandur	1
4 Braided	10
5 Alluvial fans	12
D. Channel change	
1 Palaeochannel	18
2 Planform change	7
3 Underfit stream	3
4 Palaeofans/sediments	6
5 Palaeoterraces	5
6 Palaeoconditions	5
E. Human	
1 Mining	4
2 Reservoir	1
3 River management	1