SCOTTISH NATURAL HERITAGE

No 105

Development of a conceptual and methodological framework for monitoring site condition in geomorphological systems

A Werritty, R W Duck and M P Kirkbride

1998

SCOTTISH NATURAL HERITAGE

Research, Survey and Monitoring

REPORT

No 105

Development of a conceptual and methodological framework for monitoring site condition in geomorphological systems

A Werritty, R W Duck and M P Kirkbride

1998

Department of Geography, University of Dundee, Dundee DD1 4HN

Nominated Officer: John E Gordon, Advisory Services
Report date: 1997
Report to: Scottish Natural Heritage
Contract No: RASD/013/07/ESB

This report should be cited as follows:

Werritty, A., Duck, R.W. & Kirkbride, M.P. 1998. Development of a conceptual and methodological framework for monitoring site condition in geomorphological systems. Scottish Natural Heritage Research, Survey and Monitoring Report No 105.

Scottish Natural Heritage
Publications Section
Battleby, Redgorton, Perth PH1 3EW
UNITED KINGDOM

Scottish Natural Heritage
Advisory Services
2 Anderson Place, Edinburgh EH6 5NP
UNITED KINGDOM

ISSN 1350-3111

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance they received from the following SNH staff in compiling this report: John Gordon, Kath Leys, Phil Shaw and George Lees. In seeking to develop a methodology for monitoring sites which is scientifically robust but also realistic in terms of resourcing, extended discussions with above staff proved invaluable.

EXECUTIVE SUMMARY

1. The purpose of this report is (i) to produce a conceptual and methodological framework for the development and application of site condition monitoring for features found in geomorphological systems, and (ii) to provide generic guidelines on defining 'favourable condition' and 'limits to acceptable change' for the geomorphological components of the natural heritage.

2. The report should be read within the wider context of the SNH Inventory and Monitoring Programme. A key component of this is the development by the conservation agencies (SNH, English Nature, the Countryside Council for Wales and the Joint Nature Conservation Committee) of broadly comparable procedures for monitoring features of interest in SSSIs, Special Areas of Conservation (SACs) and Special Protection Areas (SPAs).

3. The fundamental properties of geomorphological systems of concern in this report are 'favourable condition' and 'limits of acceptable change'. These are properties which have already been defined as appropriate for monitoring features of conservation interest in terrestrial and aquatic ecosystems. In this report we extend this methodology to the earth sciences and specifically to active and relict geomorphological landforms.

4. The geomorphological components of the natural heritage can variously be viewed as *systems* (a complex assemblage of geomorphological features located within a specific site), *a landform assemblage* (a group of geomorphological features which have functional identity) or *geomorphological features* (individual components within a site or landform assemblage).

5. Prior to developing an appropriate methodology for defining 'favourable condition' and 'limits of acceptable change' a conceptual framework for monitoring active and relict landforms is developed. Crucial to this framework is the concept of geomorphic thresholds. Two main types of threshold are generally identified: *intrinsic* (one in which change occurs without a change in an external variable) and *extrinsic* (one that is exceeded by the application of a force or process external to the system). Dynamic landforms are formed and reformed by processes currently operating and are deemed to be active landforms. The role of thresholds, and the propensity of the landform to absorb or withstand change (in terms of being robust, responsive or sensitive) are all fundamental in understanding the process-form relationships of such landforms. By contrast in the case of relict landforms, the controlling processes no longer operate and the process-form relationships have to be inferred rather than directly observed. For these landforms the concepts of thresholds, robust, responsive or sensitive behaviour are largely irrelevant.

6. *Robust landforms* retain a stable identity as they form and reform under a given process regime, despite being changed in terms of morphology as intrinsic thresholds are crossed. *Responsive landforms* are those which, in response to externally imposed change, cross extrinsic thresholds to produce a new assemblage of landforms. *Sensitive landforms* respond to minor external disturbances by crossing an extrinsic threshold.

7. In terms of active fluvial environments, the two most important controls determining whether or not a channel is stable are sediment supply and flow regime. If either of these undergoes progressive or sudden change, the channel may cross an extrinsic threshold and undergo change. Except for the impact of major floods, most changes in sediment supply relate to changes in land-use within the catchment (typically afforestation, urbanisation and mineral extraction). Changes in flow regime are less easily summarised, but can result from climate change/increased climatic variability or from land-use changes (afforestation or urbanisation). The potential impacts on channels arising from changes in sediment supply and flow regime are best summarised in a qualitative sense by Schumm's model of river metamorphosis, although this approach is now being superseded by more robust model-based methods.

8. In terms of active coastal environments, a crucial determinant of stable or unstable behaviour is the location of the protected site within a hierarchy of coastal systems. To this end the concept of coastal cells has been developed by Hydraulics Research, initially for England and Wales, but now being extended (with some modifications) to Scotland. The boundaries between cells are either a littoral drift divide or a sediment sink. At a *littoral drift divide* beach material moves away from that point on both sides. A *sediment sink*, by contrast, is where beach material tends to build up because two sediment transport paths meet. Each of the major coastal cells can be sub-divided into sub-cells which may be considered as scaled-down versions of the major units. The definition of major coastal cells is aimed at the formulation of management plans, but sub-cells, or possibly groups of cells, are more likely to provide a practical basis for planning sustainable strategic coastal defence.

9. Fundamental to understanding whether or not an active river or coastal site is likely to undergo rapid change is the concept of the magnitude and frequency of the controlling geomorphic processes. The key question here is the relative roles of (i) small magnitude, high frequency events and (ii) large magnitude, rare events in transporting sediment and creating new landforms. Where entrainment thresholds are low (sand-bedded rivers and sandy beaches) the frequently occurring, small sized events are dominant. But where entrainment thresholds are high (boulder-bed mountain torrents), it is only the large flood once or twice a century that is an effective agent of geomorphic change. Also significant in assessing the geomorphic role of these contrasting high frequency and low frequency events is the time for recovery (relaxation time) between formative episodes.

10. The definition of favourable condition for active fluvial environments closely follows that developed by Ecoscope Applied Ecologists. Favourable condition is defined in terms of (i) physical attributes and morphology, (ii) processes and dynamics, (iii) composition, (iv) structure, (v) function, (vi) visibility and (vii) accessibility. For the purpose of the potential scientific and conservation value of the site, attributes (i) to (v) take precedence.

11. The condition of an active fluvial system is assessed as favourable/unfavourable by reference to each of the following attributes:

physical attributes and morphology: favourable condition if it is intact in terms of (i) the bedrock into which the feature is incised, (ii) the sedimentary/organic deposits within which the river is embedded, and (iii) the morphological form of the resultant erosional or depositional landforms created.

processes and dynamics: favourable condition if the processes can operate across the whole site unconstrained in terms of natural variability enabling the landforms present to be formed and reformed.

composition: favourable condition if the range of components of the system and their clarity of expression have not deteriorated. Composition includes both the range of individual fluvial features in a site assemblage and the clarity of expression of the individual landforms.

structure: favourable condition if the integrity, context and relationships of the system's main components have not diminished through physical damage or fragmentation. It is of crucial importance in defining favourable condition as, typically, the significance of the whole is greater than the sum of the parts.

function: favourable condition if the system has not deteriorated as a result of change within its wider setting. It is often appropriate to identify the function of an individual site as either a sediment source, sediment sink or sediment transfer zone, or a combination of all of these.

visibility: favourable condition if the visibility of the landforms is unimpaired (or there has been no deterioration since the site was notified).

accessibility: favourable condition if access is maintained for purposes of education and research as appropriate.

12. Defining limits of acceptable change for each attribute in the Site Attributes Table crucially depends on the definition of favourable condition for each attribute. Monitoring whether or not favourable condition is being maintained within those limits is then based upon a range of techniques which, for fluvial environments, comprise (i) terrestrial photographs, (ii) historical maps, (iii) field survey, (iv) aerial photographs, and (v) image processing and GIS.

13. Site Attributes Tables (comprising each of the seven attributes itemised above) are developed for the following fluvial systems: (i) wandering gravel bed river, (ii) active meandering river, (iii) mountain torrent, (iv) active alluvial fan, (v) fluvially-modified debris cone, (vi) integrated fluvial system, (vii) progressive fluvial system, and (viii) bedrock channels. Each of these fluvial systems is cross-referenced to appropriate sites listed in the GCR for fluvial sites in Scotland.

14. In developing a conceptual framework for active coastal environments, it is noted that robust behaviour can only be determined through regular and frequent monitoring. The frequency of site visits will depend on the coastal system in question and the degree to which the controlling processes are actively changing the geomorphological features present. It is also important to note that for coastal systems, favourable condition is often defined in terms of a 'band' and not a line. Thus one should seek to identify the optimum state of the site and manage it towards that goal. Numerous

processes (both natural and man-made) may interrupt the littoral transport regime in an area causing the site to cross an extrinsic threshold. The crucial question then becomes: what are the acceptable limits of change to the littoral sediment transport regime such that robust behaviour of the landforms/landforms assemblages is maintained?

15. The condition of an active coastal system is assessed as favourable/unfavourable by reference to each of the following attributes:

physical attributes and morphology: favourable condition if these remain intact in terms of the material components (e.g. sand, gravel, peat and bedrock) and water bodies such as coastal lagoons or those occupying dune slacks. The morphology of the feature is then the form of the resultant erosional or depositional landform created.

processes and dynamics: favourable condition if the processes can operate across the whole site unconstrained in terms of natural variability. The dynamics of a coastal site must maintain its function within its local setting of a coastal management unit, a coastal sub-cell or a coastal cell.

composition: favourable condition if the range of components of a feature and their clarity of expression have not deteriorated. Composition includes both the range of individual coastal landforms in a site assemblage and the clarity of expression of the individual landforms.

structure: favourable condition if the integrity, context and relationships of the system's main components have not diminished through physical damage or fragmentation. It is of crucial importance in defining favourable condition as, typically, the significance of the whole is greater than the sum of the parts.

function: favourable condition if the system has not deteriorated as a result of change within its wider setting. The function of a coastal site concerns its status within the wider setting of a coastal management unit, a coastal sub-cell or a coastal cell. It is necessary to identify the function of an individual site as a sediment source, a sediment sink or a sediment transfer zone.

visibility: favourable condition if the visibility of the landforms is unimpaired (or there has been no deterioration since the site was notified).

accessibility: favourable condition if access is maintained for purposes of education and research as appropriate.

16. Defining limits of acceptable change for each attribute in the Site Attributes Table crucially depends on the definition of favourable condition for each attribute. Monitoring whether or not favourable condition is being maintained within those limits is then based upon a range of techniques which, for coastal environments, comprise (i) historical maps, (ii) aerial photographs, (iii) terrestrial photographs, (iv) field surveying methods, and (v) GIS.

17. Site Attributes Tables (comprising each of the seven attributes itemised above) are developed for the following coastal systems: (i) beach-machair landform assemblage of Highlands and Islands; (ii) beach-dune-machair landform assemblage of Highlands and Islands; (iii) beach-bar landform assemblage of Highlands and Islands; (iv) prograding coastal foreland landform assemblage; (v) beach-dune landform assemblage of the Lowlands; (vi) shingle structures landform assemblage; (vii) rock cliff coast landform assemblage; (viii) rock shore platform landform assemblage; (ix) rock archipelago landform assemblage; and (x) saltmarsh-barrier beach, estuary and loch head landform assemblages.

18. In developing a conceptual framework for relict landforms it is important to note that their scientific value arises from the information they store about past environments (climatic, geomorphological and biological). Generally the information is retained in the surface expression of past processes and internal structure (stratigraphy). Occasionally relict landforms maintain their value in isolation from their surroundings. But more typically their spatial context adds meaning to the value of a site. Assemblages of relict landforms are especially valued because they demonstrate the former functioning of the geomorphological system and thereby elucidate the environmental controls which once existed.

19. The condition of a relict landform system is assessed as favourable/unfavourable by reference to each of the following five attributes:

physical attributes and morphology: favourable condition requires either (a) intact physical attributes and morphology, or (b) no deterioration in physical attributes and morphology since the time of designation. Physical attributes refer to the material constituents of the landform. Included in this are bedrock, clastic sediment, organic sediment and water. Morphology refers to the form of the resultant erosional or depositional landform created from the physical attributes.

composition: favourable condition requires that both the features and the clarity of expression of a geomorphological assemblage have not deteriorated since the time of designation. Composition includes not just the range of individual landform types present within the assemblage and their clarity of expression, but also the presence and location of stratigraphic sections relative to the surface landform.

structure: favourable condition is maintained if the integrity, context, and interrelationships of a site's main geomorphological features have not diminished through physical damage or fragmentation. Structure is an important element within the definition of favourable condition, because the totality of a site outweighs the scientific value of the individual geomorphological features (i.e. the total structure exceeds the sum of the parts).

visibility: favourable condition is maintained if either (a) the visibility of the feature is unimpaired, or (b) if there has been no significant deterioration since the site was notified, or (c) stratigraphic sections remain accessible through excavation or natural erosion.

accessibility: favourable condition requires that access is maintained for the purposes of education and research as appropriate.

Note that process/dynamics and function are not included as attributes for relict landforms systems because they would relate to controlling factors that are no longer operative. A relict landforms system is thus especially vulnerable to damage (either natural or of human origin) because it will not be reformed in the foreseeable future.

20. The threats to relict landform systems largely arise from Potentially Damaging Operations (a list of PDOs has been compiled by SNH see Table 3). The threats posed by individual PDOs can be grouped into three main categories (i) PDOs which may initiate landform destruction, (ii) PDOs which may accelerate landform destruction, and (iii) PDOs which obscure landforms.

21. Although relict landform systems are no longer actively functioning, they are subject to change. In seeking to manage that change SNH staff should take into account (i) the condition of the site at the time of designation, (ii) natural changes due to erosion and vegetation colonisation and growth, and (iii) the extent to which such natural change is deemed acceptable without devaluing the site.

22. Site Attributes Tables (comprising each of the five attributes itemised above) are developed for the following relict landform systems (i) stratigraphic sections, (ii) ice-margin landform assemblage, (iii) relict ice-margin lakes, (iv) glacial erosional landscapes, (v) subglacial depositional landforms (vi) fluvial and glaciofluvial terraces, and (vii) relict alluvial fans.

1. BACKGROUND

Reporting on the state of the natural heritage is a key duty in Scottish Natural Heritage's role as a nature conservation body. However, as the recent publication *The Natural Heritage of Scotland: an overview* (SNH, 1995) strikingly demonstrates, this duty is immensely complex and varied, embracing on the one hand relatively robust geological and geomorphological features and, on the other hand, fragile and ever changing terrestrial and aquatic ecosystems. This remit is currently being implemented via the development of the SNH Inventory and Monitoring Programme, within which there is to be a significant geomorphological component.

Reporting on the state of the geomorphic environment has, hitherto, largely been focused on the condition of features in protected areas (SSSIs). But increasingly SNH sees a need to broaden its concern to assess a wider representation of landforms in Scotland whose condition may give concern in terms of their current management. It is towards this increasingly holistic, landscape approach to natural heritage conservation that this report is addressed: an approach which is very much in keeping with the ethos of 'integrated catchment management' another key concept within SNH's overall strategy (Werritty, 1995). At present no systematic monitoring of the geomorphological environment is undertaken by SNH. This report seeks to provide the necessary conceptual framework, rationale and tools for this to be done. Whilst the focus will primarily be on SSSIs, it is hoped that the approach developed will have applicability to the wider landscape (e.g. Natural Heritage Zones).

1.1 Scotland's geomorphological heritage

The physical landscape of Scotland comprises a mosaic of landforms formed by diverse processes operating on timescales ranging from yesterday to millions of years. This landform mosaic provides an essential component of the natural heritage both in its own right and as the physical setting within which Scotland's flora and fauna has subsequently evolved.

Although, on a human timescale, the Scottish landscape is often thought of as being dominated by "the everlasting hills", the actual land surface is by no means unchanging. There are many active geomorphic processes at work today notably along the coast (>50% of beaches are eroding or aggrading, SNH 1995), within active gravel-bed rivers (erosion arising from major floods, see Brazier and Werritty, 1994; Werritty *et al.*, 1994; Hoey *et al.*, 1995) and on slopes in the uplands (Ballantyne, 1991). Some of these processes operate at a large scale, necessitating an immediate management response (e.g. the Tay floods in the early 1990s, see Gilvear and Winterbottom, 1992); others are small scale, continuous processes which, nevertheless, can cumulatively generate steady change (e.g. weathering, aeolian activity and frost action). Thus there is a continuum of processes at work testifying to the dynamic nature of Scotland's geomorphic heritage.

Another significant component of Scotland's geomorphic heritage are the cold-climate relict landforms dating from the last Scottish Icesheet more than 13,000 years ago. These individual landforms and their associated landform assemblages provide valuable climatic, geomorphological and biological information about past environments. Many of the most significant sites have been included in the Geological Conservation Review and are reported in *The Quaternary of Scotland* (Gordon and Sutherland, 1993). A fundamental distinction can be made between erosional and depositional cold-climate landforms. Whereas the former (corries, glacial breaches through watersheds, meltwater gorges) testify to the efficacy of glacial ice and meltwaters as erosive agents in the landscape, the latter (moraines, kame terraces, eskers, fossil rock glaciers, alluvial fans) provide the basis for reconstructing past environments and identifying the processes which formed them.

1.2 SNH Inventory and Monitoring Programme

The SNH Inventory and Monitoring Programme (concerned with geological/ geomorphological features and terrestrial ecosystems) provides the wider context within which this report should be read. As part of that programme, SNH has undertaken to monitor the condition of notified interests on statutory sites, based on an approach developed jointly with English Nature (EN), the Countryside Council for Wales (CCW) and the Joint Nature Conservation Committee (JNCC).

Although only concerned with geomorphological features of interest, this report will endeavour to take note of parallel studies being undertaken for terrestrial and aquatic ecosystems, (e.g. that on behalf of the JNCC by Ecoscope Applied Ecologists (1996)) in which 'favourable condition' is defined for each interest feature based on objectives which incorporate 'limits of acceptable change'. In this report we have endeavoured, to the best of our ability, to operate within a broadly similar conceptual framework, whilst acknowledging that this terminology cannot be transferred in its entirety to the earth science domain.

Prior to defining the term 'favourable condition', it is important to examine the potential scientific and conservation value of active and relict landforms and landform assemblages. This can be undertaken within a number of different frameworks, e.g.:

- scientific research into the origin and long-term development of a specific landform or landform assemblage;
- value of the specific landform or landform assemblage for educational purposes (e.g. use for field class instruction);
- quality of the specific landform or landform assemblage in terms of its ability to support terrestrial or aquatic habitats;
- quality of the specific landform or landform assemblage in terms of scenic resources.

In this report, the first of these has primacy, although the three other frameworks may, from time to time, be significant within the broader remit of SNH.

For the purposes of this report the attributes on which 'favourable condition' may be defined are presented for each geomorphological feature for which a site has been notified. In some cases the feature will comprise a single landform, in other cases an assemblage of landforms will be involved. For each geomorphological feature, one or more attributes will be identified, and against these attributes a target will be suggested, against which the feature's condition will be assessed. Not all of the targets for a specific geomorphological feature will need to be attained for that feature to be considered to be in a favourable condition. JNCC and the country agencies will develop simple aggregation rules by which the attributes of each feature can be assessed, and the overall condition determined.

The attributes for which targets will be set are consistent with the reasons for GCR site selection and take into account physical attributes and morphology, processes and dynamics, composition, structure, function, visibility and accessibility.

'Limits of acceptable change' define the boundaries within which a feature may be expected to fluctuate and within which its condition would be considered as favourable. Changes beyond these limits are regarded as undesirable and would result in action to investigate the likely cause of the decline and whether remedial action is feasible. For earth science features, limits of acceptable change should take account of:

- the condition of the feature at the time of its designation/selection;
- the natural variability of the system;
- the feature's capacity to recreate components that have been damaged or destroyed (e.g. a river's capacity to reform a series of gravel bars);
- the extent to which natural changes or trends (e.g. coastal erosion of a unique geological section) are accepted.

1.3 Aims, objectives and structure of the report

The aims of this report are:

(i) to produce a conceptual and methodological framework for the development and application of site condition monitoring for features found in geomorphological systems;

(ii) to provide generic guidelines on defining 'favourable condition' and 'limits of acceptable change' for the geomorphological components of the natural heritage.

The objectives of this report are:

(i) to review the concept of geomorphological sensitivity as a basis for the development of monitoring the condition of sites;

(ii) to identify and evaluate criteria for assessment of 'favourable condition' of active and relict geomorphological systems, including fluvial, coastal, glacial and periglacial features;

(iii) to evaluate and recommend how appropriate limits of acceptable change for a given geomorphological feature or system may be specified;

(iv) to provide an operational framework for site condition monitoring, to include the identification of the principal landform assemblages and their constituent components for fluvial, coastal and Quaternary geomorphological systems, and the specification for each of a set of attributes and targets for monitoring change arising from human activities and natural processes;

(v) to recommend appropriate methods for measurement of changes in the attributes of geomorphological features.

In terms of terminology, the following definitions will be used in this report:

(i) *Geomorphological system*: "a complex assemblage of geomorphological features located within a specific site". Typically a geomorphological system comprises the title for a Site Attributes Table and thus denotes all the landforms and landform assemblages to be found within that site.

(ii) *Landform assemblage*: "a group of geomorphological features which have a functional identity". Thus a wandering gravel-bed river comprises actively eroding banks, mobile lateral and mid-channel bars, a sinuous talweg, and pools and riffles: all of these features being functionally related one to another. Collectively these features comprise the components that comprise a wandering gravel-bed river.

(iii) *Geomorphological features*: "individual components within a site or a landform assemblage". Very often these are specific landforms which exceed a designated size and survive relatively unscathed for long periods of time, (e.g. kettle holes, eskers, boulder berms, dunes), but they can also be much smaller components which are effectively ephemeral or have a minimal topographic expression (e.g. striae, rills and ripple fields). The term 'landform' is appropriate for the former, but not the latter. The term geomorphological feature is inclusive of all the components found within a site irrespective of spatial and temporal scale.

The report comprises seven sections:

- executive summary;
- the earth science background and wider conservation context within which the report should be read;
- conceptual framework for monitoring active and relict landforms in Scotland;
- definition of favourable condition for active fluvial environments;
- definition of favourable condition for active coastal environments;
- definition of favourable condition for relict environments;
- discussion and conclusions.

2. CONCEPTUAL FRAMEWORK FOR MONITORING ACTIVE AND RELICT LANDFORMS IN SCOTLAND

A fundamental distinction will be made in subsequent sections between active and relict landforms in the Scottish landscape. Active landforms are being formed and reformed by processes currently operating. The role of thresholds, and the propensity of the landform to absorb or withstand change (in terms of it being robust, responsive or sensitive) are all fundamental in understanding the process-form relationships which characterise the behaviour of such landforms. By contrast in the case of relict landforms, the controlling processes no longer operate and the process-form relationships have to be inferred rather than directly observed. For these landforms the concepts of thresholds and robust, responsive or sensitive behaviour are largely irrelevant except in so far as the landforms are subject to reworking by processes currently operating (e.g. surface wash, mass movement and wind action). It is clear from the above use of the term "sensitive" as applied to landforms that this concept is only applicable to active and not relict landforms. It does not equate with the idea that relict landforms may be fragile and vulnerable to human activities.

In this section a conceptual framework for characterising the behaviour of active and relict landforms is developed. Initially, different types of threshold are examined together with the concept of geomorphic sensitivity. Having identified different types of threshold and distinguished between robust, responsive and sensitive landforms, the controls on active fluvial and coastal environments are then examined. Generally, these involve changes in either sediment supply or the flow regime for rivers, and wave climate or sea level for coasts. The relationship between form and processes operating with varying magnitudes and frequencies is then addressed together with the concepts of geomorphic effectiveness, relaxation and recovery times. Finally the roles of sediment stores and sediment fluxes is discussed in order to examine the behaviour of active landforms over longer-term timescales. The conceptual framework within which relict landforms can be monitored retains some of the above elements. However, the absence of currently operating processes means that many of these elements are redundant or irrelevant.

2.1 Geomorphic thresholds

The concept of geomorphic thresholds was first introduced by Schumm (1973) in a widely cited paper in which a fundamental distinction was made between *extrinsic* and *intrinsic* thresholds. Subsequently, these concepts have been revised and redefined by many other researchers. Definitions of these concepts and examples of different types of geomorphic thresholds are provided in Table 1.

In order to understand what is meant by the term extrinsic threshold, consider what happens as the flow of a river is increased over a bed of potentially mobile particles. As the discharge increases, individual particles on the bed are subject to an increase in applied boundary shear stress. At some point the submerged weight of each particle is no longer sufficient to resist the combined effects of the drag and lift forces exerted upon it. When this occurs the particle begins to move (i.e. it is entrained) and this constitutes the crossing of an extrinsic threshold: the threshold of motion. Other well-known examples of extrinsic thresholds are the Froude and Reynolds numbers in open channels which define the conditions at which flow becomes supercritical and turbulent respectively.

Table 1: Definitions and examples of different types of geomorphic thresholds

Definition	Example
Extrinsic threshold: "one that is exceeded by the application of a force or process external to the system" (Schumm, 1980)	climate change land use change base-level change Froude and Reynolds numbers
Intrinsic threshold: "one in which change occurs without a change in an external variable" (Schumm, 1980)	longterm progressive weathering leading to slope failure development of a meander cutoff

In these examples an abrupt change in process occurs in response to progressive change in the external variable. This means that a threshold exists, but will not be crossed and hence change will not occur without control being exerted by an external variable (hence extrinsic in describing this type of threshold). But intrinsic thresholds also exist. In this situation change occurs without control being exercised by an external variable (i.e. the capacity to change is intrinsic within the system). A well-known example of this is the process that leads to slope failure within deeply weathered bedrock. Long-term weathering of bedrock on a hillslope results in the formation of a deep regolith. If this occurs on a steep slope, eventually the downslope gravitational force operating within the regolith will exceed its inherent strength and a slope failure will occur. Whilst the actual failure (e.g. a debris flow) may be triggered by an external event such as large rainfall, the prime cause is the increasingly unstable deeply weathered regolith. In coastal environments the extraction of coastal aggregates or the construction of a coastal engineering structure (interrupting the littoral sediment transport regime) are examples of potential extrinsic thresholds leading to the development of a new assemblage of landforms.

New terms beyond those originally introduced by Schumm (1973) have also been added to the literature. For example Chappell's (1983) distinction between transitive and intransitive thresholds has extended our understanding of threshold phenomena. This distinction depends upon whether, in response to the change in external conditions, the new state is persistent (transitive) or short-lived (intransitive). Newson (1992), in his case study on the geomorphic impact of the Forest of Bowland floods in 1967 provides a well-argued case for Chappell's terminology. This case study also provides a good example of how the concept of geomorphic thresholds can help to identify the responsiveness of river systems.

The use of the threshold concept in geomorphology now extends back over two decades. During that time the original concept has been so loosely applied by some researchers that its original definition has lost its clarity (see the diversity of definitions used in the 1980 Binghampton Geomorphology Symposium edited by Coates and Vitek (1980)). Given this, the value of threshold concepts has been subject to re-appraisal (e.g. Newson, 1992). The question of whether thresholds involve abrupt or gradational change has also been the subject of a particularly vigorous debate. For example, it is now generally agreed that the distinction between braided and meandering channel patterns involves a transition rather than an abrupt threshold change (Carson and Griffiths, 1987; Ferguson, 1987).

Having explored the concept of geomorphic thresholds we now turn to the inter-related concepts of geomorphic robustness, responsiveness and sensitivity.

2.2 Geomorphic robustness, responsiveness and sensitivity

All landforms are subject from time to time to a disturbance in their immediate environment, but this does not necessarily result in the destruction or even a significant modification of the landform. Of crucial importance in predicting the outcome is the balance between the size of the disturbance and the ability of the landform to resist, or accommodate, the impact of the disturbance. The disturbance itself may arise naturally (e.g. in response to a variation in climate, sea-level or sediment supply) or by human action that may be either deliberate or inadvertent. Irrespective of the type of disturbance involved, the response ultimately depends on the nature of the geomorphic system and its limiting thresholds (Figure 1).

Some high energy systems (such as active, braided channels or beaches) are subject to frequent change by processes which occur many times within a few years and involve the repeated crossing of intrinsic thresholds. Such processes are an inherent part of the braided system and should be seen as the result of internally imposed change. Thus, the individual landforms (i.e. specific channels and bars, or sections of the beach) are frequently destroyed but the overall geomorphic system is robust since the new landforms which are created are recognisably similar to the old. In this situation the morphology is stable, but not static and the landform is said to be geomorphologically *robust*. If, however, the imposed disturbance causes the system to cross an extrinsic threshold into a new process regime in which a very different assemblage of landforms is likely to develop (e.g. the transition from braided channels to small meandering channels across the North European Plain during the Lateglacial and Holocene (Starkel, 1983)), then the initial landform assemblage is deemed to have been geomorphically responsive to the imposed change.

Thus, *responsive* landforms are those which are destroyed by externally imposed change. This contrasts with robust landforms which, despite being subject to change as intrinsic thresholds are exceeded, retain a stable identity as they form and reform under a given process regime. *Sensitive* landforms respond to minor external disturbances by crossing an extrinsic threshold. Being already located close to the threshold, they are sensitive because only a minor change in the external environment is needed to produce a major response (Schumm, 1991).

In coastal environments, a change from net accretion of a dune system to net erosion, would constitute an example of sensitive behaviour in that the geomorphological system is responding to externally imposed changes with the consequent development of a new set of landforms. This situation would constitute moving beyond the 'limits of acceptable change' (section 4) and, if the change were initiated by human agency rather than by natural processes, would often be the trigger for management intervention designed to restore the site to its former state. In the case of a coast this may involve one or more of several hard or soft engineering options.

These distinctions between geomorphically robust, sensitive and responsive landforms can also be understood in terms of the magnitude of the imposed change, and their contrasting responses as they cross different types of threshold. Crossing an intrinsic threshold within the normal spectrum of events (low magnitude and high frequency) involves negative feedback (i.e. the impact is self-regulating and stability is retained). An example of this would be the constant destruction and formation of the braid bars which collectively make up the surface of a proglacial outwash plain created by the meltwater and sediment discharged from an ice-sheet. By contrast, crossing an extrinsic threshold (e.g. the change from braiding to small-scale meandering) results in the river searching for a new equilibrium state in which negative feedback and stability can once more be achieved. The behaviour of a river is termed robust if it only crosses intrinsic thresholds as it adjusts to normal fluctuations in water and sediment supply. However, the same river is termed responsive if, in response to substantial changes in water and sediment supply, it becomes necessary to cross an extrinsic threshold in order to attain a new equilibrium state (Figure 1).

2.3 Controls on the development of active fluvial environments

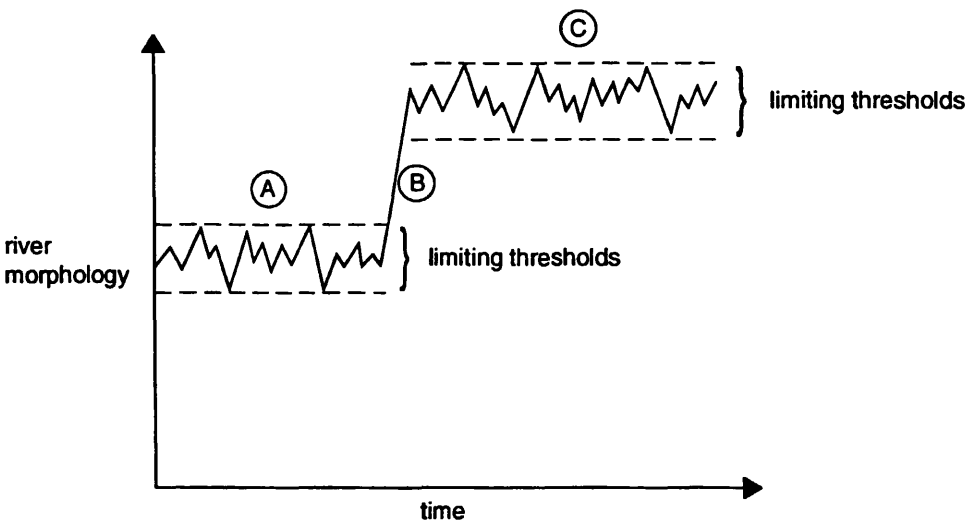
The two most important controls determining whether or not a channel is stable over a period of years or decades are sediment supply and flow regime. If either of these undergoes progressive or sudden change, the channel may cross an extrinsic threshold and undergo change. At its most extreme this process has attracted the term river metamorphosis since the morphology of the channel is completely changed. A good example of such behaviour is the localised shift from meandering to braided channels in small streams in the Howgill Fells of NW England (Harvey, 1986). This change occurs in response to sediment being released into the channel from hillslope gullies as they undergo erosion in response to major floods.

The supply of sediment to a channel can vary in response to changes in the source areas: hillslopes, small tributary channels, or the margins of the channel itself. Except for the impact of major floods (see below), most changes in sediment supply relate to changes in land-use within the catchment of which the three most important are afforestation, urbanisation and mineral extraction.

In humid, temperate environments, such as the British uplands, two parts of the forestry cycle are associated with major changes in sediment supply: planting (because of upslope/downslope ploughing as part of the land preparation) and felling (when heavy machinery is introduced to extract the timber). As Leeks (1992) demonstrated in his review of the impacts of forestry in the UK, both suspended and bedload transport are elevated (Figure 2), but their specific impact crucially depends on whether the sediment sources on the slopes (i.e. the eroding ditches) are directly linked by catchwater drains into the permanent stream system (see also Stott *et al.*, 1987).

Another major land-use change with significant implications for sediment supply to the channel is urbanisation and, specifically, the construction phase when local sediment yields can increase by two or three orders of magnitude (Wolman and Schick, 1967). In theory, the impact of urbanisation is two-fold (Wolman, 1967; Roberts, 1989). Initially, there is a reduction in channel capacity due to local aggradation caused by increased sediment supply to the channel during the construction phase. This is followed by erosion and an increase in channel capacity as the local sediment supply is reduced (in response to the newly concreted, asphalted and grassed surfaces) and the frequency of higher flows is increased (in response to overland flow directed into the river via stormwater sewers).

The third major land-use change that can have a profound impact on short-term channel stability is mineral extraction (Lewin and Macklin, 1987). Mining waste can very easily become incorporated into the downstream movement of sediment. Often, this can be tracked



Ⓐ, Ⓒ **robust behaviour** - river repeatedly crossing intrinsic thresholds, but overall response stable within limiting thresholds. Negative feedback regulates change. Landforms retain stable identity as they form and reform.

Ⓑ **responsive behaviour** - in response to externally imposed change river moves across extrinsic threshold to new process regime. Landforms in original regime Ⓐ destroyed and replaced by new landforms created in regime Ⓒ.

Figure 1 The distinctions between robust and responsive behaviour, the two types of geomorphic threshold and stable and unstable behaviour. (After Werritty and Brazier, 1994).

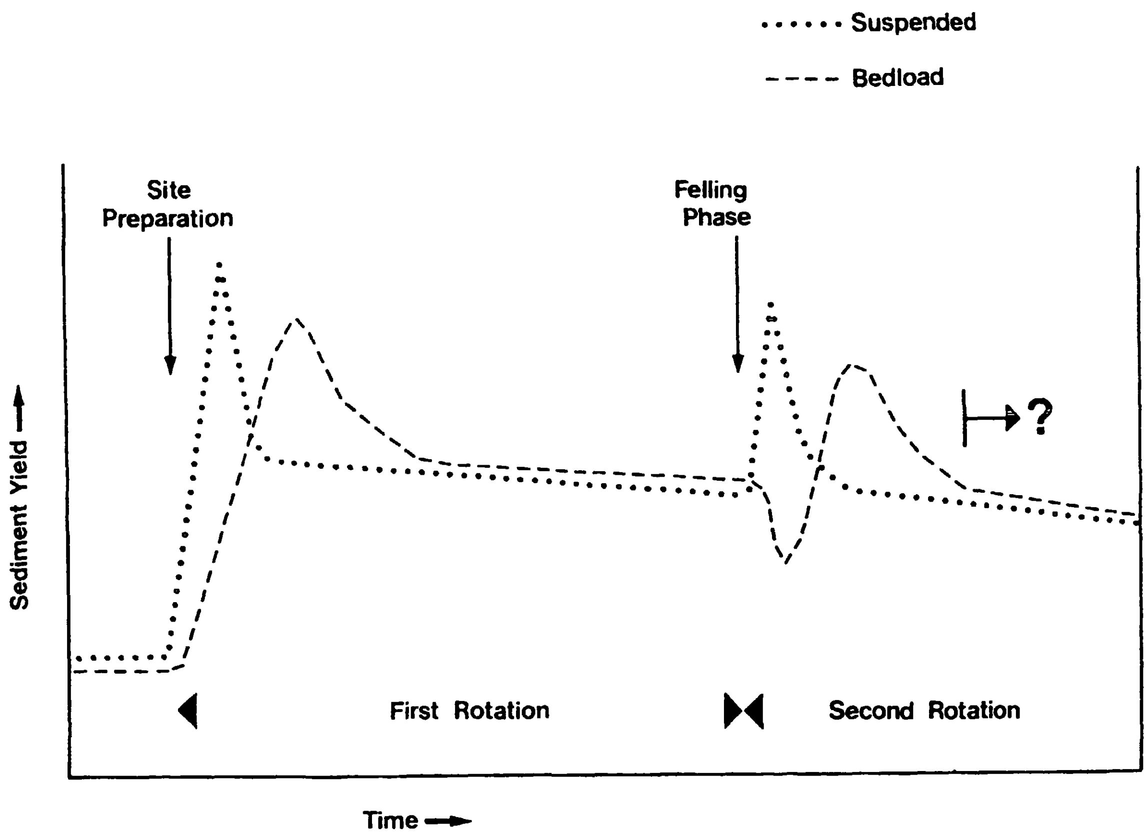


Figure 2 Summary diagram of upland stream sediment yields over the forest rotation. (Reprinted from G. J. L Leeks, 1992. Impact of plantation forestry on sediment transport processes. In: Billi, P., Hey, R. B., Thorne, C. E., and Tacconi, P. (Eds), *Dynamics of Gravel-bed Rivers.* Wiley, Chichester, 651-668. Copyright John Wiley & Sons Ltd. Reproduced with permission).

as a sediment slug moving as a wave through the fluvial system. At the scale of a drainage basin the complete passage of such a sediment slug typically involves several centuries, but for individual reaches the resulting instability may last decades (Macklin and Lewin, 1989).

Changes in flow regime are less easily summarised than changes in sediment supply as their potential origins are much more varied. Nevertheless, a useful distinction can be made between those which are inadvertent or are mainly natural in origin and those which are planned. The most significant inadvertent changes in river flow regime arise from climate change or, more accurately for a timescale of years and decades, increased climatic variability. The vexed question is how far the current increase in climatic variability is due to natural or human causes? Here, it is appropriate to note that changes in flow regime arising from increased climatic variability can register profound impacts on channel stability (for a useful case-study from Australia, see Warner, 1987).

Inadvertent changes in flow regime can also arise directly from land-use changes. Both urbanisation and, to a lesser extent, afforestation can locally register significant increases in high flows with potential impacts on channel stability. Since such land- use changes typically occur over areas covering hectares rather than square kilometres and across years rather than decades, their geomorphic impact can be both rapid and highly significant (e.g. Roberts, 1989). The impact of afforestation on flow regimes can be even more dramatic than that of urban sites (e.g. Robinson (1980) for the Coalburn site in NW England and Werritty *et al.*, (1993) for the Loch Dee basins in SW Scotland). In both studies the effects were substantially reduced within a decade of planting the forest (Figure 3), whereas the impact of urbanisation on the flow regime appears to be more permanent.

Having identified and documented the circumstances in which changes in sediment supply and flow regime can occur, what are their potential impacts on short-term channel stability? In his conceptual treatment of river metamorphosis Schumm (1977) identified eight possible combinations of changes in water and sediment discharge and their impacts on channel morphology (Table 2). In some cases the change is accommodated by the river as part of its inherent variability. In this case negative feedback will occur and the change will not result in sustained channel instability and irreversible channel change. In other cases, the change will exceed the natural inherent variability of the river, positive feedback will occur and the disturbance will result in the channel becoming unstable thus potentially crossing an extrinsic threshold. Under such conditions channel metamorphosis can occur. Examples of local channel metamorphosis within Britain which has occurred within a timespan of years or decades include upland streams in the Howgill Fells of NW England subject to localised convective storms (Harvey, 1986); headwater streams of the River Tyne which underwent trenching in response to a severe storm (Newson and Macklin, 1990); and the middle Rheidol Valley in Central Wales responding to a sediment wave made up of mining waste (Lewin and Macklin, 1987).

2.4 Controls on the development of active coastal environments

It is important to recognise that the status of coastal geomorphological SSSIs must be considered within a hierarchy of coastal systems in the sense of sediment supply and human activities. For an example, an individual feature, such as a spit, forms part of a larger coastal system which may be much greater in size than that normally considered as appropriate for

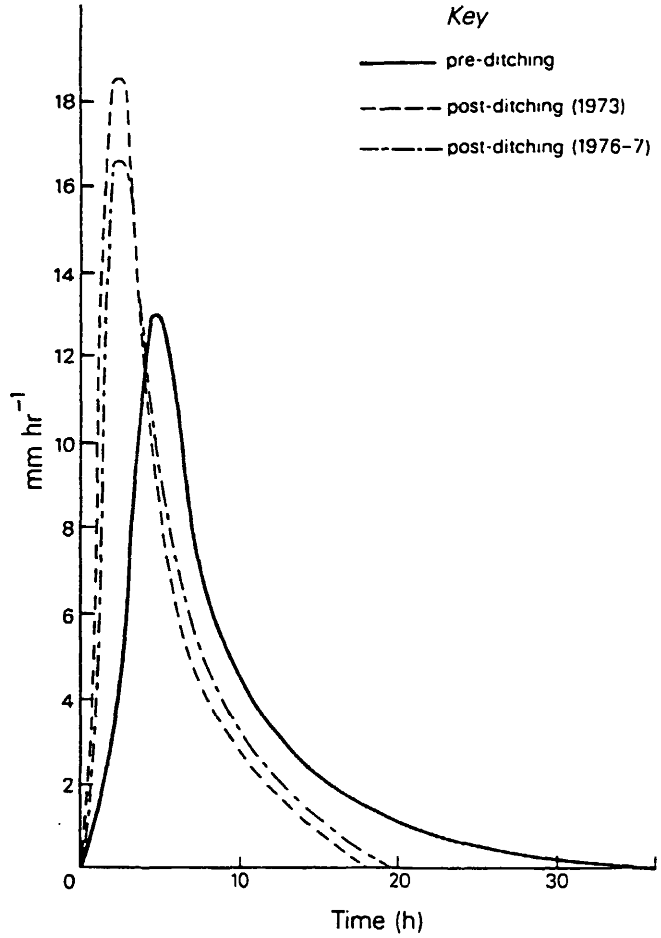


Figure 3 Pre- and post-ditching unit hydrographs for a forestry plantation at Coalburn, NW England. (Reprinted from M. Robinson, 1980. *The effect of pre-afforestation drainage on the stream flow and water quality of a small upland catchment.* Institute of Hydrology Report 73, Wallingford. Reproduced with permission of the Institute of Hydrology).

management purposes. However, rather than isolating an individual site for management attention, a holistic approach to the coastal environment should be adopted.

To this end, the concept of coastal cells was devised by Hydraulics Research (HR) Wallingford, initially for England and Wales, as a guide for effective management of the coastline. The value of coastal cells is as a management tool, principally to help manage coastal erosion. They have been defined primarily according to the movement of sand and gravel along beaches and the nearshore zone. It must be emphasised that they have no bearing on the development of, for example, mudflats, saltmarshes and cliff coasts. The fundamental basis for the definition of coastal cells (or sediment cells) is that of beach sediment movement. A *coastal cell* is thus defined as a length of coastline which is relatively self contained as far as the movement of sand or shingle along the beach or nearshore zone is concerned and where interruptions to such movement should not have significant effect on adjacent cells.

Table 2: Geomorphic impacts on channels of changes in water and sediment leading to river metamorphosis (after Schumm, 1977)

Change	River bed morphology	Change	River bed morphology
Qs+ Qw=	aggradation, channel instability, wider and shallower channel	Qs+ Qw-	aggradation
Qs- Qw=	incision, channel instability, narrower and deeper channel	Qs+ Qw+	processes increased in intensity
Qw+ Qs=	incision, channel instability, wider and deeper channel	Qs- Qw-	processes decreased in intensity
Qw- Qs=	aggradation, channel instability, narrower and shallower channel	Qs- Qw+	incision, channel instability, deeper, wider? channel

Key: Qs sediment discharge; Qw water discharge; + increase; - decrease; = remains constant; ? uncertain response

The movement of fine grained sediment (i.e. silt plus clay), which do not normally settle out of suspension onto a beach face, has not been used by HR Wallingford in their evaluation of coastal cell boundaries.

Cells are usually large; the smallest of the 11 defined for England and Wales extends for 20 km along the coast. The boundaries between cells, which generally coincide with prominent headlands or where a distinct change in littoral transport regime takes place, are either a littoral drift divide or a sediment sink. At a *littoral drift divide*, usually defined by a rocky headland, beach material moves away from that point on both sides. A *sediment sink* is where beach material tends to build up because two sediment transport paths meet, this naturally taking place in well sheltered areas such as deeply indented bays, tidal inlets and estuaries. Each of the major coastal cells has been sub-divided into sub-cells, either independent or weakly dependent on each other, which may be considered as scaled down versions of the major units, having similarly defined boundaries. The boundaries of sub-cells are not definitive but are based on the best available knowledge of large scale coastal sedimentary processes. Whilst the definition of major coastal cells is aimed at the formulation of Shoreline

Management Plans for the coasts of England and Wales (MAFF *et al.*, 1995), the sub-cells, or perhaps groups of cells, are more likely to provide a practical basis for the formulation of such plans, owing to their more manageable size.

HR Wallingford (1997) have now extended the coastal cells concept to Scotland. However, in Scotland, unlike England and Wales, sediment sinks (i.e. estuaries) were not used to define cell boundaries. This is because, following the English and Welsh studies, it was recognised that, for the management of estuaries, it makes little sense to have opposite shores managed under separate Shoreline Management Plans, even though there may be no sand and gravel movement across the estuary. It is proposed that the division of the coast, as established by HR Wallingford, will allow future management to be conducted according to natural geomorphological process regimes, rather than be constrained by unnatural, administrative/council boundaries defined for local government purposes. Thus, the Scottish coastal zone has been divided into seven major cells for the mainland (including the Inner Hebrides) and two (Numbers 8 and 9) for the Western Isles:

Cell number	Approximate extent along coast (km)
1. St Abb's Head to Fife Ness	60
2. Fife Ness to Cairnbulg Point	220
3. Cairnbulg Point to Duncansby Head (= the Moray Firth)	120
4. Duncansby Head to Cape Wrath	120
5. Cape Wrath to Mull of Kintyre	480
6. Mull of Kintyre to Mull of Galloway	120
7. Mull of Galloway to Solway Firth	100
8. Butt of Lewis to Barra Head (east side of Western Isles)	280
9. Butt of Lewis to Barra Head (west side of Western Isles)	280

For the purposes of this report, the 'approximate extent along the coast' has been measured in either a straight or curving line, according to the configuration of the cell. Thus the smallest coastal cell as defined for Scotland is three times greater in lateral extent than its counterpart south of the border. This is, in part, a reflection of the overall great length and complexity of Scotland's coastline. Though the cells defined in Scotland are especially large they can, in theory, be of any size, so long as the movement of sand and gravel is confined by the cell boundaries. Thus, any deeply indented pocket beach may, in reality, be a separate cell. On deeply indented coastlines, such as that of the west coast of mainland Scotland, each bay or sea loch constitutes a distinct cell in terms of sediment movement (i.e. sediment supply and transport along the shores of each embayment are unrelated to sediment movement in neighbouring bays or lochs). In common with England and Wales, the major Scottish coastal cells have been sub-divided into smaller units denoted as "sub-cells". Since the ultimate purpose of defining coastal cells and sub-cells is as a management tool, these are not all distinguished on the maps produced by HR Wallingford but are, in effect, grouped together into the so-called "cells" and "sub-cells" defined according to other, additional factors pertinent to shoreline management such as exposure and physical character. Although Shoreline Management Plans have yet to emerge for the Scottish coast, it is evident, given the size of the major cells as defined, that management strategies at the sub-cell level, or indeed smaller, would seem more relevant.

The combined publication of the Ministry of Agriculture Fisheries and Food, the Welsh Office, the Association of District Councils, English Nature and the National Rivers Authority, entitled *Shoreline Management Plans: A guide for coastal defence authorities*, emphasises the need for operating authorities to divide cells or sub-cells into *management units* in order to develop sustainable strategic coastal defence options. Within a sub-cell there may be more than, say, ten management units defined on a variety of bases. As examples, a management unit may represent that portion of a coastline bordering a town or an industrial estate or that in the hands of a private owner. Similarly, it is suggested that a coastal SSSI may be thought of in the terms of a management unit. However, it must be emphasised that the division of a sub-cell into management units is somewhat artificial, not necessarily being wholly or partially based on natural geomorphological criteria. It is therefore important that due consideration be given to the natural processes in operation within the relevant sub-cell, or even on a still wider scale embracing several sub-cells, according to the location of the specific SSSI under consideration as a management unit. So, whilst in simple management terms it may be logical for, say, an SNH Area Officer to consider a coastal SSSI as a management unit, this may be quite inappropriate on geomorphological grounds and the status of the site within the coastal process hierarchy at sub-cell or cell level must be understood.

An example of the significance of scale is provided by the coastal landform suite of Tentsmuir, Fife (Whittington, 1996). On the large 'whole site' scale this is a net accreting site, allegedly one of the most rapidly accreting parts of Scotland. On the smaller scale, however, the 'whole site' is made up of many sub-sites, some of which are undergoing net accretion and others net erosion, according to locality. Should one or several of the latter sub-sites be viewed in isolation, an impression of net erosion would be gained. Thus, if extrapolated to the wider picture of the 'whole site', an erroneous conclusion as to its condition would be drawn.

2.5 Magnitude and frequency of geomorphic processes

Anyone who has stood beside a large river in flood or on a section of coast during a major storm must have been struck by the awesome nature of such an event. The lay person's reaction to such an experience is to conclude that extreme floods and storms must be the major geomorphic agent responsible for transporting sediment and thus the major agent in creating suites of new landforms. The purpose of this section is to put that lay person's opinion to the test and evaluate the geomorphic role of floods and storms on a scientific basis.

Wolman and Miller (1960) first posed this question in geomorphology using the following homely metaphor. Imagine a forest inhabited by a single giant and by a dwarf. Each has the task of felling the forest. Every day the dwarf sets to with his small, and largely ineffective hand-axe. Bit by bit, but very slowly, the smaller and medium sized trees are felled, but the larger ones remain beyond his grasp. By contrast, the giant only wakes up very rarely and goes on a rampage pulling trees both large and small up by their roots. But which is the more effective in felling the forest: the person who attacks the task everyday on a piecemeal basis, or the one who makes a violent but very short-lived attack on the forest? The metaphor, in the context of the geomorphic role of floods and storms, is between small to medium-sized events which occur many times a year (dwarfs) and a large, catastrophic event (the giant) which is immensely powerful, but very rare.

In order to answer the question posed by Wolman and Miller (1960) the joint roles of the magnitude of a flood or storm and its frequency must be examined. This is most easily undertaken via a simple diagram (Figure 4) in which curves (a) and (b) are characterised separately, and then jointly (c). Two processes must be treated individually:

- the sediment transport rate once the threshold of motion has been exceeded (typically a power function): magnitude;
- the frequency of occurrence of events of varying magnitude: frequency.

If the threshold of motion is relatively low, the peak in the curve defining the product of magnitude and frequency (curve c) typically occurs in the middle range of events. This led Wolman and Miller (1960) to conclude that, contrary to the lay person's view, low magnitude, relatively high frequency events are more important than rare floods in terms of their cumulative sediment transport.

But Wolman and Miller (1960) also attached three important qualifications to their conclusion:

- the conclusion is only valid where the entrainment threshold is low;
- the more variable the events, the greater the percentage of the load which is transported by more infrequent events;
- in the case of rivers, the smaller the drainage basin, the greater the amount of sediment transported by less frequent flows. This is because rare high magnitude storms can "blanket" a small basin (e.g. Wells and Harvey, 1987).

It is important to note that the dominant role attributed by Wolman and Miller to low magnitude-high frequency events was based upon data generally derived in humid/sub-humid, temperate, well-vegetated drainage basins with fine-grained, alluvial channels. As Baker (1977) observed in central Texas, a change in climate, lithology, vegetation and the timing of floods significantly alters the magnitude-frequency distribution. Wolman and Gerson (1978), on re-examining this balance across a range of environments, came to broadly comparable conclusions to Baker (1977).

The timing of rare, catastrophic floods and storms is also highly significant in understanding the geomorphic role of such events. But this requires the context to be broadened beyond that of the sediment transport occurring during individual floods and storms to embrace concepts such as geomorphic effectiveness, and relaxation or recovery times.

2.6 Geomorphic effectiveness, relaxation and recovery times

Wolman and Gerson (1978, p.190) further added to our understanding of the magnitude and frequency of geomorphic processes by introducing the concept of geomorphic effectiveness which they defined as "the ability of an event or combination of events to affect the shape or form of the landscape". This is significant because it reminds us that floods and storms not only transport sediment, but in so doing also sculpt the earth's surface. Their true geomorphic impact may thus be in long-term erosion or deposition rather than in terms of sediment

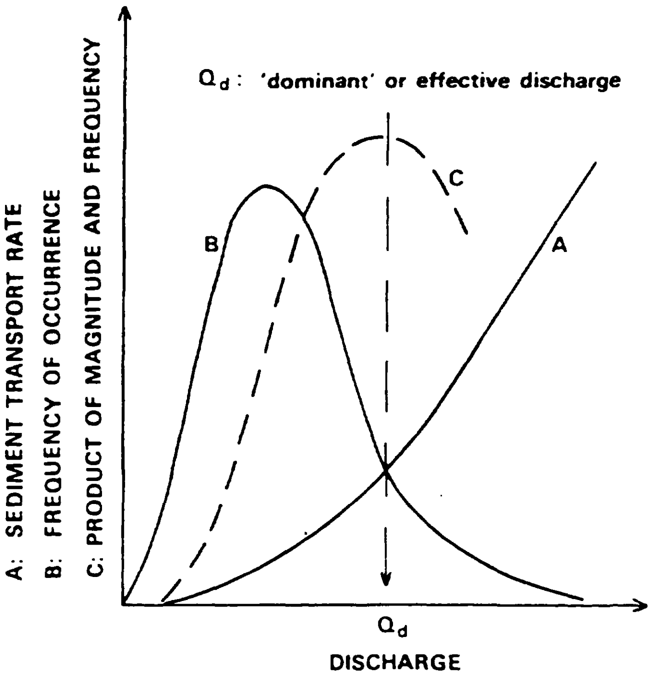


Figure 4 Hypothetical magnitude and frequency distributions showing the dominant role of middle range flows. (Reprinted from D. Knighton, 1994, *Fluvial Forms and Processes*, Edward Arnold, London, by permission of Edward Arnold/Hodder & Stoughton Educational).

transport. But the erosive or depositional impact of a flood or storm will only be registered in the long-term if its impact is not erased by the restorative effects of lesser events (e.g. the very short-term impact of Hurricane Agnes in 1972 on the eastern seaboard of the USA (Costa, 1974)). Thus, the effectiveness of a flood or storm as "a destructive event depends on the force exerted, the return period of the event, and upon the magnitude of the constructive or restorative processes which occur in the intervening period" (Wolman and Gerson, 1978, p.190).

The return period of an event provides a measure of its comparative rarity and is defined as the inverse of its probability of occurrence. Hence the likelihood of an event of a hundred year magnitude occurring in any particular year is one in a hundred. In Figure 5 such events are recorded as vertical "steps" on the "staircase". Following a highly disruptive event, a period of form adjustment is likely to occur. This healing of the landscape is generally referred to as the recovery time or relaxation time. Its duration will vary between environments and is typically brief in channels with fine-grained bed material in humid temperate climates (see Costa, 1974), but is much longer in semi-arid climates (Wolman and Gerson, 1978). In some environments (such as Central Texas (see Baker, 1977)), where the entrainment threshold is very high, minimal relaxation occurs and the landscape merely awaits the arrival of the next catastrophic flood. But this is atypical and in most environments relaxation eventually gives way to a temporary equilibrium period, during which the form of the landscape may be constant (static equilibrium) or may evolve under the action of low magnitude, high frequency events (dynamic equilibrium). This situation lasts until the next catastrophic event. Selby (1974) uses this model to contrast the overall rates of landscape change across contrasting climatic and land-use types. The steepness of the overall "staircase" (Figure 5) is at its greatest in the Himalayas (see Starkel (1976) for details) and at its lowest in Western Europe. Intermediate values are recorded for North Island, New Zealand, with areas under pasture undergoing more rapid transformation than areas under woodland.

This important idea of formative events punctuated by periods of evolution, recovery or even temporary periods of steady state can be illustrated by a case study from the Scottish Highlands (McEwen and Werritty, 1988). The Allt Mor draining the Northern slopes of the Cairngorm Mountains is a mountain torrent which, during the last half century, has been subject to formative events in 1956 and 1978. During both floods the peak discharges exceeded 60 m^3s^{-1}, well above the entrainment threshold, and much of the valley floor was reworked. In assessing the geomorphic effectiveness of the two catastrophic floods it is important to note the sequence of the floods (the larger being the first) and the relaxation time between the floods during which some sediment sources recovered and ceased to be accessible to fluvial reworking.

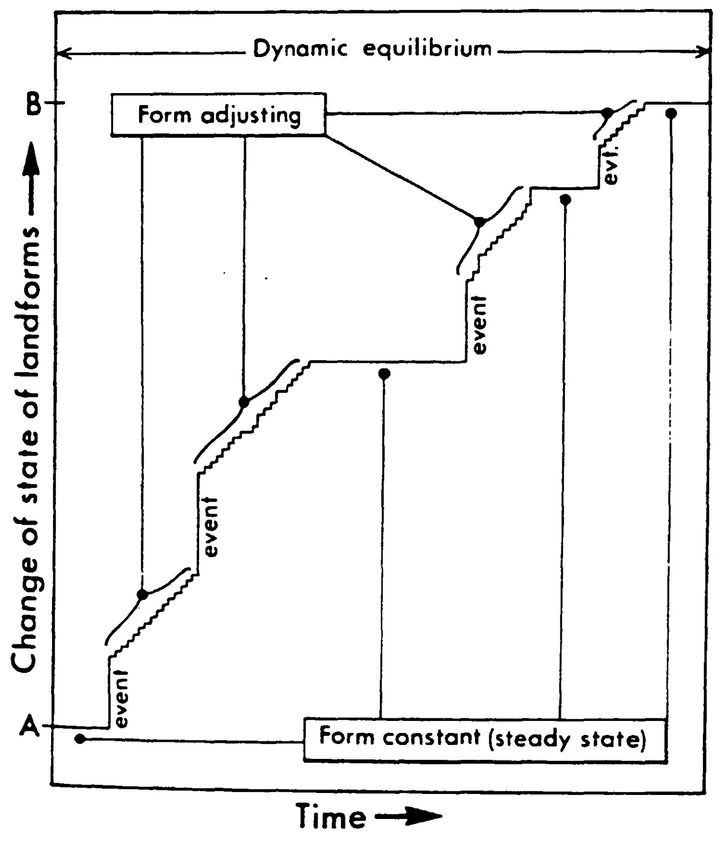


Figure 5 Within the term dynamic equilibrium are contained three states of (1) a landforming event; (2) the adjustment of form that follows that event; and (3) a period of steady state in which there is virtually no adjustment of form. The curve which represents the change of landforms with time may, therefore, rise very steeply, gradually, or slightly, depending upon the magnitude and frequency of the dominant process. (Reprinted from M.J. Selby, 1974. Dominant geomorphic events in landform evolution. *Bulletin of the International Association of Engineering Geology*, 9, 85-89).

3. DEFINITION OF FAVOURABLE CONDITION FOR ACTIVE FLUVIAL ENVIRONMENTS

In the next three sections the term favourable condition will be defined specifically within the context of active fluvial and coastal environments (sections 3 and 4 respectively) and relict environments (section 5). The methodology closely follows that adopted by SNH in its Inventory and Monitoring Programme and exemplified, in part, by studies being undertaken by Ecoscope Applied Ecologists (1996). In identifying the site attributes necessary to define favourable condition, this section also relies upon the quality-based classification of composition, structure and function developed by Noss (1990) for monitoring biodiversity. Having defined the term favourable condition, each of the next three sections concludes with a set of Site Attributes Tables for a variety of geomorphological environments.

3.1 Conceptual framework and rationale

Before defining favourable condition it is necessary to examine why active fluvial environments have a scientific, and therefore conservation, value. The recognition of scientific value based upon some statement of favourable condition must precede the development of a conservation strategy.

Active fluvial environments are scientifically important because they enable the processes controlling the formation of fluvial landforms to be directly observed (Werritty and Ferguson, 1981; Ferguson and Werritty, 1983) and in special cases directly measured (Bridge and Jarvis, 1977; Ferguson and Ashworth, 1990). The dynamic nature of the site is especially important since it potentially enables responses to a wide range of flow conditions to be observed and measured in a relatively short period of time (Ferguson *et al.*, 1996). More generally applicable conceptual and mathematical models of river development can then be developed from such field-based research. In recent years a series of projects on the dynamic Allt Dubhaig at the Pass of Drumochter (northern Perthshire) has provided many examples of conceptual and physics-based models of channel stability and downstream fining (Wathen, 1996; Hoey and Ferguson, 1994; Leys, 1997).

Having developed an understanding as to how active gravel-bed rivers behave in terms of their cross sectional and planform stability and their rate of downstream fining, the assessment of their likely response to land-use and climatic change has a more secure scientific basis. Questions related to the development of a catchment for water supply or hydro-electric power, or the potential impact of afforestation or river engineering designed to improve a fishery can then also be addressed with greater assurance by environmental managers.

Fundamental to scientific research into the origin and long-term development of a specific landform or landform assemblage is the link between form and process (Schumm, 1991). In the case of actively forming features (e.g. bars, bends, channels) the nature of the link between form and process is often observed directly in the field by repeated mapping of a specific reach of a river (e.g. Ferguson and Werritty, 1983). In lower energy environments where the rate of change proceeds more at a more leisurely pace (e.g. the development of an ox-bow or part of a floodplain) or where a longer-term study is required, the link between form and process may be monitored by indirect methods (e.g. analysis of repeated maps or air photos of the reach (e.g. Brazier *et al.*, 1993; Leys, 1997), or sediment analysis of bed, bank and floodplain materials).

The link between form and process also underpins the statement that "the present is the key to the past": a fundamental axiom in geology. For example we cannot understand the ancient alluvial fan deposits of Devonian age in the Central Lowlands of Scotland unless we study how similar alluvial fans develop in present-day terrestrial environments. The investigation of the present-day sedimentary environments associated with rivers and their valley floors is thus a crucial component to advances in understanding the ancient sedimentary record.

It is rare that fluvial landforms exist in isolation from each other, and it is often more useful to examine active landforms as aggregates or landform assemblages. Thus an actively braided river (such as the lower Spey or the Feshie) is a landform assemblage composed of rapidly shifting channels, eroding banks, and bars of various kinds that constantly form and reform. Even the adjacent floodplain is not spared this flux: in some locations it is undergoing rapid erosion, whilst in others it is being rebuilt (Werritty and Ferguson, 1981). Although features within the assemblage can usefully be examined individually, it is very important to note the linkages in terms of local sediment fluxes. Thus erosion on the outer bank of a meander bend is the reason for local aggradation on the next mid-channel bar downstream. One of the advantages of using landform assemblages as the focus for detailed monitoring is that it becomes easier to recognise the crossing of intrinsic thresholds, and easier to determine whether or not the site is approaching a limit of acceptable change.

3.2 Definition and usage of terms

The following definitions are adopted for active fluvial environments in order to develop Site Attributes Tables for individual sites. For active fluvial and active coastal environments (Section 4) the Site Attributes Tables conform to similar templates since the underlying conceptual frameworks are directly comparable.

Favourable condition is defined in terms of the physical attributes and morphology, processes and dynamics, composition, structure, function, visibility and accessibility of the site. For active fluvial sites Potentially Damaging Operations (PDOs) Numbers 7, 12, 13b, 13c, 14, 15, 16, 19, 21, 23 and 27 (Table 3) are considered the most relevant in terms of defining favourable condition.

3.2.1 Physical attributes and morphology

The condition of an active fluvial system may be defined as favourable if its physical attributes and morphology are intact (or there has been no deterioration arising from human activities if the system was not intact at the time of designation). More specifically this includes the bedrock into which the landforms are incised (in the case of gorges, and waterfalls), the unconsolidated sedimentary or organic deposits within which a loch or river reach is embedded, and the morphological form of the resultant erosional or depositional landforms created. Since a continuous replenishment of water is needed to sustain the landforms, the maintenance of surface and/or sub-surface water flows are key physical attributes for active fluvial systems.

Table 3: List of Potentially Damaging Operations on SSSIs (Source: SNH)

Standard Ref No.	*Type of Operation*
1.	Cultivation, including ploughing, rotovating, harrowing and re-seeding.
2.	Grazing and changes in the grazing regime (including type of stock or intensity or seasonal pattern of grazing and cessation of grazing)
3.	The introduction of stock feeding and changes in stock feeding practice.
4.	Mowing or other methods of cutting the vegetation.
5.	Application of manure, fertilisers and lime.
6.	Application of pesticides, including herbicides (weedkillers).
7.	Dumping, spreading or discharge of any materials.
8.	Burning and changes in the pattern or frequency of burning.
9.	The release into the site of any wild, feral or domestic animal*, plant or seed.
10.	The killing or removal of any wild animal*, including pest control.
11.	The destruction, displacement, removal or cutting of any plant or plant remains, including tree, shrub, herb, moss, lichen, fungus or turf.
12.	The introduction of tree and/or woodland management, including afforestation and planting.
13a.	Drainage (including moor-gripping and the use of mole, tile, tunnel or other artificial drains).
13b.	Modification of the structure of water courses (e.g. rivers, streams, springs, ditches, drains) including their banks and beds, as by re-alignment, regrading and dredging.
13c.	Management of aquatic and bank vegetation for drainage purposes.
14.	The changing of water levels and tables and water utilisation (including storage and abstraction from existing water bodies).
15.	Infilling of ditches, drains, pools or marshes.
16.	The introduction of or changes in freshwater fishery production and management including sporting fishing and angling.
17.	Reclamation of land from sea.
19.	Erection of sea defences or coast protection works, including cliff or landslip drainage or stabilisation measures.
20.	Extraction of minerals including peat, single, sand, gravel, topsoil and sub-soil.
21.	Construction, removal or destruction of roads, tracks, walls, fences, hardstands, banks, ditches or other earthworks, or the laying, maintenance or removal of pipelines and cables, above or below ground.
22.	Storage of materials on any part of the beach complex.
23.	Erection of permanent or temporary structures, or the undertaking of engineering works, including drilling.
24.	Battering or grading the sand dunes.
25.	Removal of geological specimens, including rock samples, minerals and fossils.
26.	Use of vehicles or craft likely to damage or disturb features of interest.
27.	Recreational or other activities likely to damage landforms, features of interest.
28.	Changes in game and waterfowl management and hunting practice.

*animal includes any mammal, reptile, amphibian, bird, fish or invertebrate.

The recording of physical attributes and morphology in a Site Attributes Table is straightforward. In the case of bedrock and unconsolidated sediments it is sufficient to record the type of material present and whether the resultant landforms are subject to erosion or degradation thereby changing their morphology. In terms of water bodies present it is important that the flow regime necessary to sustain the continued formation of the landforms/landform assemblage is maintained. Thus if a very flashy river were to be regulated with the result that none of the flows were competent to transport bedload, an active braided reach would quickly atrophy.

3.2.2 Processes and dynamics

The condition of an active fluvial system may be defined as favourable if the processes can operate across the whole site unconstrained in terms of natural variability (or there has been no deterioration if these processes were constrained by human activity at the time of designation). Crucial to the maintenance of favourable condition is the retention of as full a range of processes as possible such that the landforms present on the site can be formed and reformed over time (i.e. displaying robust behaviour).

The dynamics of a fluvial site must maintain its function (see below) within the local reach and more generally within the drainage basin. In this respect the dynamics of a fluvial site is best characterised in terms of its inputs (high or low energy) and thresholds (high or low). The condition of an active fluvial system may be defined as favourable if the system has the capacity to recreate the components for which it was notified, where these have been lost or damaged or deteriorated naturally (i.e. the system displays robust behaviour). PDOs Numbers 7, 13b, 13c, 14, 15, 20, 21, and 23 and 27 are considered the most relevant in this context (Table 3). In terms of monitoring in a Sites Attributes Table, an initial inventory of processes operating at the site needs to be established. Thereafter, this should be checked on a regular basis to ascertain whether or not there has been a significant change.

Maintaining favourable condition in terms of the site's dynamics is complicated by variations in the magnitude and frequency of the controlling processes and the size of the threshold before significant change occurs. Thus the precise specification of a target condition in a Site Attributes Table will vary greatly depending on whether one is dealing with a high energy or low energy environment and a high threshold or low threshold site (Werritty and McEwen, 1997):

(i) *High energy: high threshold environments*

These fluvial environments are characterised by episodic bursts of intense activity interspersed with periods of relative quiescence and are represented by coarse-grained alluvial fans and mountain torrents. Such sites are only reworked by extreme floods produced by low frequency, high intensity rainfall (e.g. Ferguson, 1981; McEwen and Werritty, 1988; Acreman, 1991). The landforms produced during such rare events tend to persist in the landscape since, under normal flow conditions, the river is not competent to undertake further major geomorphic work.

(ii) *High energy; low threshold environments*

This combination results in the highest rates of channel adjustment as, under these circumstances, floodplains and fine-grained alluvial fans can rapidly be re-worked resulting in frequent channel migration (Ferguson and Werritty, 1983; Werritty and Brazier, 1991).

(iii) *Low energy: high threshold environments*

Such environments result in stable channels which display little change over decades or even centuries. Very often this arises because bed material inherited from deglaciation is very coarse and the present-day river is not competent to transport this material except under exceptionally rare floods. Such channels characterise the middle reaches of many Scottish rivers (McEwen, 1986).

(iv) *Low energy: low threshold environments*

This final category is characterised by sites which record slow progressive change in response to the crossing of intrinsic thresholds. An example would be a lowland meandering stream where progressive migration eventually leads to the breaching of meander necks. The adjacent floodplain typically displays oxbow lakes and ridges and swales as evidence of former channel alignments (Brazier *et. al.*, 1993). These palaeoforms are often well-preserved on account of the low rates of channel migration.

3.2.3 Composition

The condition of an active fluvial system may be defined as favourable if the range of components of the system and their clarity of expression have not deteriorated. Composition includes both the range of individual fluvial features in a site assemblage and the clarity of the individual landform expression.

Monitoring composition in a Site Attributes Table requires an initial inventory to be established of specified geomorphological features. Thereafter, any degradation in the composition of the site can be determined by reference to this inventory.

3.2.4 Structure

The condition of an active fluvial system may be defined as favourable in terms of structure if the integrity, context and relationships of the system's main components have not diminished through physical damage or fragmentation. In common with coastal environments, structure refers to the clarity of inter-relationships between individual component landforms and thus relates primarily to landform assemblages. It is of crucial importance in defining favourable condition as, typically, the significance of the whole is greater than the sum of the parts. Structure, in turn, enables the dynamics and function of the site to be determined.

Monitoring structure in a Site Attributes Table involves an assessment over time of the continued clarity of the interrelationships between the component landforms. If this clarity is steadily reduced, degradation of the site will ensue and the whole landform assemblage could then approach a limit of acceptable change.

3.2.5 Function

The condition of an active fluvial system may be defined as favourable if the system has not deteriorated as a result of change within its wider setting. The function of a fluvial site concerns its status within the wider setting of its drainage basin. It is often appropriate to identify the function of an individual site as either a sediment source, sediment sink or sediment transfer zone, or a combination of all of these.

Monitoring function in a Site Attributes Table involves noting whether the overall behaviour of the landform assemblage (or individual landforms) is changing as a result of some external change (e.g. change in runoff regime as a result of flow regulation, or increase/decrease in sediment supplied from upstream because of a land-use change).

3.2.6 Visibility

The condition of an active fluvial system may be defined as favourable if the visibility of the landforms is unimpaired (or there has been no deterioration since the site was notified). Monitoring change in visibility in a Site Attributes Table is relatively straightforward and involves specifically checking for activity under PDOs 12, 21 and 23 (Table 3).

3.2.7 Accessibility

The condition of an active fluvial system may be defined as favourable if access is maintained for purposes of education and research as appropriate. PDOs Numbers 7, 13b, 20, 21, 22 and 23 are considered the most relevant in this context (Table 3).

3.3 Methods for determining entries in the Site Attributes Tables

The determination of robust or sensitive behaviour by active rivers can be determined either by modelling the physical system (Hoey and Ferguson, 1994) or by historical analysis of the site (Werritty and Ferguson, 1981). Occasionally the two methods can be combined (Leys 1997), but typically one or other is followed. For the purposes of this project only the historical method will evaluated. Methods which have proved to be most valuable in monitoring the long-term behaviour of rivers comprise:

- terrestrial photographs
- historical maps
- field survey
- aerial photographs
- image processing and GIS

Not all of these methods are readily applicable to individual sites and many require a high level of technical competence. The above list has been compiled in terms of the level of sophistication and the technical demands (low to high) made on SNH staff.

3.3.1 Terrestrial photographs

This involves repeated ground photography of the site from one or more fixed positions. It has been used to very good effect by A. M. Harvey over a period of more than 20 years to monitor the development of active gullies and their associated debris cones/alluvial fans in the Howgill Fells in NW England. When combined with available historical photographs of the same site, this simple method can prove invaluable in determining whether or not key attributes have undergone change over time.

3.3.2 Historical maps

In Scotland there are three editions of large scale topographic maps which have proved invaluable in monitoring long-term channel change (Lewin and Weir, 1977; Werritty and Ferguson, 1981; Werritty, 1984; McEwen, 1986; Gilvear and Winterbottom, 1992; Leys, 1997). These are the First and Second Editions of the Six Inch County Series (scale 1:10,560) typically dated around 1860 and 1900 respectively, and the Metric Edition at a scale of 1:10,000 published in the 1960s and 70s. For rural areas no larger scale topographic maps have been published by the Ordnance Survey. Historical maps extending further back in time are available on a very limited scale and usually take the form of estate plans extending into the mid 18th century. Their availability is very erratic and best determined by checking the inventory of maps and plans held in the Scottish Record Office. The earliest available historical map of Scotland (at an approximate scale of 1:33,000) from which qualitative information on the planform of Scottish rivers prior to large scale river engineering can be determined is the Military Survey of General Roy (1745-50). Used with care, these maps can provide crucial information on the long-term behaviour of active Scottish rivers.

3.3.3 Field survey

Topographic survey using a level to generate cross sections of a channel, floodplain or valley or an EDM to map the planform of a reach has been extensively used to determine short-term channel change (Werritty and Ferguson, 1981; Werritty, 1984; Wathen, 1996; Leys, 1997). Ideally a system of fixed points (local bench marks) should be established from which repeated surveys (at an appropriate time interval) can be made. Repeated levelling of appropriately-spaced cross sections along a reach is a very cost effective way of determining whether favourable condition is being maintained. From such surveys the dynamics and functioning of the reach can readily be determined. Much simpler methods can also yield valuable data, e.g. using a tape and a compass to determine the location of the banks of a channel with respect to fixed points on the valley floor (fence post and large trees).

3.3.4 Aerial photographs

The whole of Scotland has been covered by repeated aerial photography since 1946. The number of surveys for a given site is variable, but usually one can be confident that at least four sets of photographs will exist. The quality varies from poor quality, but large scale photography in the 1940 and 50s, to high quality, but smaller scale photography in the 1970s and 90s, and includes both vertical prints (available from the Royal Commission on Ancient and Historical Monuments for Scotland) and oblique prints (available from the University of Cambridge Aerial Photograph Collection). Often the photos are not true verticals and they will always display radial distortion from the centre point necessitating the use of analogue or digital systems of image rectification (see below). Nonetheless, they contain a wealth of information on river behaviour over the last 50 years often at a temporal resolution (in terms of the numbers of repeated photographs) which makes them potentially a highly valuable source. They have been extensively used by a number of researchers assessing the behaviour of active Scottish gravel-bed rivers (Werritty and Ferguson, 1980; Werritty, 1984; McEwen, 1986; Gilvear and Winterbottom, 1992; Leys, 1997).

3.3.5 Image processing and GIS

This is the most recent technology to be developed to assess the short-term and long-term behaviour of active rivers (Leys, 1997). Using recently developed image-processing software (e.g. ER-Mapper), historical maps and vertical aerial photographs can now be processed in a single system. The aerial photographs are rectified by reference to fixed point on the large scale maps and the series of maps and rectified prints assembled into a series of temporally sequential layers (cf. a GIS). The quality and potential accuracy of the data that be extracted by this new technology is an order of magnitude better than that which existed before by analogue methods (e.g. McEwen, 1986). The disadvantages are the very high costs which arise in obtaining the imagery, mounting software and training the staff to operate the system. It is unlikely that this could ever be a routine method at the Area Office level, although it could be developed as a strategic resource with Advisory Services if this were thought appropriate.

3.4 Compilation of Site Attributes Tables for active fluvial systems

Using the conceptual and methodological framework developed above, Site Attributes Tables are now developed for active fluvial systems. Using the GCR sites for fluvial landforms in Scotland (Gregory, 1997), together with Tables 2.1 and 2.2 from the introduction to the Scottish sites in the GCR volume *Fluvial Geomorphology of Great Britain* (Werritty and McEwen, 1997), Site Attributes Tables have been compiled for the following types of active fluvial systems:

(i)	Wandering gravel bed river	Table 4
(ii)	Active meandering river	Table 5
(iii)	Mountain torrent	Table 6
(iv)	Active confluence alluvial fan	Table 7
(v)	Fluvially-modified debris cone	Table 8
(vi)	Integrated fluvial system	Table 9
(vii)	Progressive fluvial system	Table 10
(viii)	Bedrock channels (gorges and waterfalls)	Table 11

Some of the sites in the GCR comprise relict rather than active fluvial systems. Accordingly, Site Attributes Tables for these sites:

(i) Fluvial and glaciofluvial terraces
(ii) Relict alluvial fan

are included with other relict landform systems in section 5.

Since the above typology has been directly derived from published research on the GCR fluvial sites in Scotland, cross-referencing to individual sites is very straightforward (see Table 12).

Table 4: Site Attributes Table (wandering gravel bed river)

Type of site: **WANDERING GRAVEL BED RIVER**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Flow regime maintained so that channel actively forming and reforming bars within and at margins of channel.	High flows capable of mobilising bed material at least once per year maintained.	Check for mobilisation of bed material by visual inspection once per year.
	Volume of sediment stored within reach broadly maintained and subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment permanently from the reach.	Visual inspection and ground photography of any engineering works or introduction of artificial structures. Site visit once a year.
2. Processes /dynamics	Processes necessary to maintain range of individual components specified by high energy inputs and low thresholds.	Frequency of bankfull discharge and <5% flow on flow duration curve maintained.	Check flow record from gauging station: frequency of bankfull discharge and <5% flows on flow duration curve, if available. Check every six years.
		No addition of significant volumes of bed material coarser than D_{84}.	Check no significant coarsening of the bed by measuring D_{84} at a number of sites. Measurement to be made every six years.
3. Composition	Maintenance of range of individual components (mobile mid-channel and lateral bars, mobile pools and riffles, low, sinuosity talweg, actively eroding banks).	All the individual components continue to be present and active on the site, but not necessarily in the same locations.	Check inventory of individual components from air photo surveys once every six years.
		Designated reach continues to demonstrate rates of channel migration similar to those of the recent past.	Repeated cross-sectional surveys of channel and immediate floodplain every three years.

Type of site: **WANDERING GRAVEL BED RIVER**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between components retained (eroding channel margins and actively migrating channel).	Linkage between supply of sediment from eroding banks to channel not significantly impeded by structures.	Visual check on introduction of bank protection structures every year.
5. Function	Reach maintained as a transport reach within the river system.	Upstream sediment inputs broadly matched by downstream sediment outputs.	Area of active channel (bare gravel) determined every six years from air photo surveys.
6. Visibility	Whole site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual components by man-made structures or features. Natural vegetation regeneration acceptable except where key individual components are specified.	Visual inspection of site every year.
7. Accessibility	Access permitting all individual components to be observed and measured.	Access by arrangement with landowners/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every year.

Table 5: Site Attributes Table (active meandering river)

Type of site: **ACTIVE MEANDERING RIVER**

Site attributes	**Favourable condition**	**Limits of acceptable change**	**Monitoring prescription**
1. Physical attributes and morphology	Flow regime maintained so that actively eroding banks, point bars, pools and riffles continue to develop.	High flows capable of mobilising bed material within the channel and on the lower parts of point bars several times during the year.	Check for mobilisation of bed material by visual inspection once per year.
	Volume of sediment stored within the reach maintained and subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment permanently from the reach.	Visual inspection and ground photography of any engineering works or introduction of artificial structures. Site visit once a year.
2. Process/dynamics	Processes necessary for continued development of actively eroding banks, point bars, pools and riffles.	Frequency of bankfull discharge and <5% flow on flow duration curve maintained.	Check flow record from gauging station: frequency of bankfull discharge and <5% flows on flow duration curve, if available. Check every six years
		No addition of significant volumes of bed material coarser than D_{84}.	Check no significant coarsening of the bed by measuring D_{84} at a number of sites. Measurement to be made every six years.
3. Composition	Maintenance of range of individual components (mobile pools and riffles, high sinuosity talweg, actively eroding banks, developing point bars).	All the individual components continue to be present and active on the site, but not necessarily in the same locations.	Check inventory of individual components from air photo surveys once every six years.
		Designated reach continues to demonstrate rates of channel migration similar to those of the recent past.	Repeated cross-sectional surveys of channel and immediate floodplain every three years.

Type of site: **ACTIVE MEANDERING RIVER**

Site attributes	**Favourable condition**	**Limits of acceptable change**	**Monitoring prescription**
4. Structure	Functional linkage between components retained (eroding channel margins and actively migrating channel).	Linkage between supply of sediment from eroding banks to channel not significantly impeded by structures.	Visual check on introduction of bank protection structures every year.
5. Function	Reach maintained as a transport reach within the river system.	Upstream sediment inputs broadly matched by downstream sediment outputs.	Area of active channel (bare gravel) determined every six years from air photo surveys.
6. Visibility	Whole site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual components by man-made structures or features. Natural vegetation regeneration acceptable except where key individual components are specified.	Visual inspection of site every year.
7. Accessibility	Access permitting all individual components to be observed and measured.	Access by arrangement with landowners/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every year.

Table 6: Site Attributes Table (mountain torrent)

Type of site: **MOUNTAIN TORRENT**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Ability to generate flash flood following intense and highly localised rainfall. Ideally flood should be competent to mobilise most boulders present within channel.	Occasional flood flows capable of mobilising most of the boulders present within the bed. These may only occur several times in a century.	Check that no upstream diversions or engineering schemes could prevent intense rainfall from generating a flash flood. Visual inspection of upstream source area once every three years.
	Volume of sediment stored within the reach maintained and subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment permanently from the reach.	Visual inspection and ground photography of any engineering works or introduction of artificial structures. Site visit every three years.
2. Process/dynamics	Processes necessary for occasional mobilisation of bed.	High energy levels and high thresholds to be maintained.	Check for introduction of flow diversions upstream once every three years.
		No significant change in potential for channel to convey occasional flash flood. No significant change in size of coarsest bed material.	Check for no significant change in the size of the coarsest material present within the bed. Undertaken by repeated photography of specific sections of the river bed every six years.
3. Composition	Maintenance of range of individual landform components (mid-channel boulder bars, step-pool sequences within channel and boulder berms at margins of channel).	All the individual components continue to be present and active on the site, but not necessarily in the same locations after competent floods.	Check inventory of individual components from air photo surveys or field mapping once every six years.

Type of site: **MOUNTAIN TORRENT**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between components retained (eroding valley sides and episodically active channel).	Linkage between supply of sediment from eroding slopes to channel not significantly impeded by structures.	Visual check every three years on introduction of engineering structures to impede erosion from valley sides.
5. Function	Reach maintained as a transport reach in which sediment released from the valley sides (landslides during severe storms) reworked by flood along valley floor.	Valley side sediment inputs continue to be reworked along valley floor by occasional flash floods.	Location and areal extent of actively eroding valley sides (unvegetated slopes) determined every six years from air photo surveys or field mapping.
6. Visibility	Site visible by direct inspection on the ground or via aerial survey	No obscuring of individual landform components by man-made structures. Natural vegetation regeneration acceptable except where key individual components are specified.	Visual inspection of site every three years
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every three years

Table 7: Site Attributes Table (active confluence alluvial fan)

Type of site: **ACTIVE CONFLUENCE ALLUVIAL FAN**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Flow regime maintained resulting in aggradation along distributary channels with potential for avulsion during major floods.	High flows capable of mobilising bed material at least once per year.	Check for mobilisation of bed material by visual inspection once per year.
	Volume of sediment stored within the reach subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment permanently from the reach.	Visual inspection and ground photography of any engineering works or introduction of artificial structures. Site visit once per year.
3. Composition	Maintenance of range of individual landform components (aggrading distributary channels, mobile mid-channel and lateral bars, mobile pools and riffles).	All the individual components continue to be present and active on the site, but not necessarily in the same locations after competent floods.	Check inventory of individual components from air photo surveys or field mapping once every six years.
		Designated reach continues to demonstrate rates of aggradation and avulsion similar to those of the recent past.	Repeated cross-sectional surveys of distributary channels and immediate floodplain every three years.
2. Process/dynamics	Processes necessary to maintain range of individual components specified by high energy inputs and relatively low thresholds.	Frequency of bankfull discharge and <5% flow on flow duration curve maintained.	Check flow record from gauging station: frequency of bankfull discharge and <5% flows on flow duration curve, if available. Check every six years.
		No addition of significant volumes of bed material coarser than D_{84}.	Check no significant coarsening of the bed by measuring D_{84} at a number of sites. Measurement to be made every six years.

Type of site: **ACTIVE CONFLUENCE**
ALLUVIAL FAN

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between components retained (aggrading distributaries supplied by bed material from upstream).	Linkage between supply of sediment from upstream and aggrading distributaries not impeded by structures or gravel extraction.	Visual check every three years on introduction of upstream structures or gravel extraction.
5. Function	Reach maintained as an aggrading reach within the river system in which distributary channels undergo episodic avulsion.	Sediment inputs from upstream maintained at current level. No attempt to stabilise distributary channels by engineering structures.	Visual inspection and ground photography of site every three years.
6. Visibility	Whole site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual landform components by man-made structures. Natural vegetation regeneration acceptable except where key individual components are specified.	Visual inspection of site every year.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every year.

Table 8: Site Attributes Table (fluvially-modified debris cone)

Type of site: **FLUVIALLY-MODIFIED DEBRIS CONE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Runoff and sediment supply from source areas maintained so that surface of debris cone periodically reworked and supplied with additional sediment.	Occasional flows must be capable of mobilising sediment stored on surface of cone.	Photographic record (preferably from air rather than ground-based) of changes in source area which could result in reduction of runoff and sediment to the cone. Photographs to be taken every six years.
	Supply and reworking of sediment on surface of cone subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment permanently from cone.	Changes in distribution of sediment on surface checked by repeated ground photography of cone every three years.
2. Process/dynamics	Processes necessary for periodic reworking of sediments on surface of cone.	High energy levels and relatively low thresholds to be maintained. No significant change in ability of the source areas to supply runoff and sediment to the cone resulting in reworking and locally aggrading the surface.	Photographic record (preferably from air rather than ground-based) of changes in source area which could result in reduction of runoff and sediment to the cone. Photographs to be taken every six years.
3. Composition	Maintenance of range of individual landform components (aggrading lobes, boulder berms and periodically active distributaries) on cone surface.	All the individual components continue to be present, on the cone surface but not necessarily in the same locations after competent flows.	Check inventory of individual components from photographic survey (ground-based of selected locations or by aerial photography) for the whole cone surface once every three years.

Type of site: **FLUVIALLY-MODIFIED DEBRIS CONE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between components retained (eroding source area and periodically active distributaries and lobes/boulder berms on aggrading cone).	Linkage between supply of water and sediment from source area not impeded by structures or gravel extraction.	Visual check every six years on introduction of structures or sediment removal from source areas.
5. Function	Cone retained as an aggradational unit but subject to fluvial reworking on its surface.	Water and sediment from source area continue to aggrade and rework the cone surface. No attempt to stabilise distributaries and lobes and berms on the surface by engineering structures.	Visual check every three years on introduction of engineering structures on cone surface.
6. Visibility	Cone visible by direct inspection on the ground or via aerial survey.	No obscuring of individual landform components by man-made structures. Natural regeneration acceptable except where key individual components are specified.	Visual inspection of site every three years.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every three every years.

Table 9: Site Attributes Table (integrated fluvial system)

Type of site: **INTEGRATED FLUVIAL SYSTEM**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Periodic runoff and sediment supply from source areas so that transport reach and sediment sink (alluvial fan) continue to function as part of integrated system.	Occasional flood flows must be capable of eroding sediment from source area and eventually transporting it to the sediment sink (alluvial fan).	Ground-based photographic record of changes in source area which could result in reduction of runoff and sediment being delivered downstream. Photographs to be taken every three years.
	Supply, transport and reworking of sediment throughout system subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment within the whole integrated system.	Visual inspection (by site visit every year) to check that the supply, transport and delivery of sediment from the sources to the sink not modified by engineering structures or abstraction or addition of sediment
2. Process/dynamics	Processes necessary for periodic erosion of sediment from source area, and transport and deposition in downstream sediment sink.	High energy levels and relatively low thresholds to be maintained. No significant change in ability of the source areas to supply runoff and sediment for delivery to sediment sink.	Ground-based photographic record of changes in source area which could result in reduction of runoff and sediment being delivered downstream. Photographs to be taken every three years.
3. Composition	Maintenance of range of individual landform components (rills, gullies, debris flow lobes, levees, boulder berms, active distributaries) within source area, transport reach and sediment sink.	All the individual components continue to be present, but not necessarily in the same locations after competent flows.	Check inventory of individual components from photographic survey (ground-based of selected locations or by aerial photography) for the whole integrated system once every three years.

Type of site: **INTEGRATED FLUVIAL SYSTEM**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between components retained (erosion of upstream sources supplying downstream sediment sink).	Linkage between supply of water and sediment from source area not impeded by structures or gravel extraction.	Visual check by site visit every year.
5. Function	Integrated system maintained as a functional unit with episodic transfers of sediment through system.	Water and sediment from source area continue to be transported to the sediment sink. No attempt to stabilise slopes in source area, or confine channel in transport reach or stabilise distributaries, debris flow lobes and levees on the surface of the sediment sink.	Visual inspection of site every three years.
6. Visibility	Site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual landform components by man-made structures. Natural regeneration acceptable except where key individual components are specified.	Visual inspection of site every year.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every year.

Table 10: Site Attributes Table (progressive fluvial system)

Type of site: **PROGRESSIVE FLUVIAL SYSTEM**

Site attributes	**Favourable condition**	**Limits of acceptable change**	**Monitoring prescription**
1. Physical attributes and morphology	Periodic runoff and sediment supply from sources enabling selective transport and deposition to function throughout progressive system.	Occasional flood flows must be capable of eroding sediment from sources and transporting and depositing sediment downstream.	Ground-based photographic record of changes in sources which could result in reduction of runoff and sediment being delivered downstream. Photographs to be taken every three years.
	Supply, transport and reworking of sediment throughout system subject to natural fluxes only.	No significant artificial addition, removal or large scale redistribution of sediment within the whole progressive system.	Visual inspection (by site visit every year) to check that the delivery of sediment from the sources not modified by engineering structures or abstraction or addition of sediment
2. Process/dynamics	Processes necessary for periodic erosion of sediment from sources and selective transport and deposition downstream.	High energy levels and relatively low thresholds to be maintained. No significant change in ability of the sources to supply runoff and sediment for delivery downstream.	Ground-based photographic record of changes in sources which could result in reduction of runoff and sediment being delivered downstream. Photographs to be taken every three years.
3. Composition	Maintenance of range of upstream landforms (mobile mid-channel and lateral bars, mobile pools and riffles, actively eroding banks) which progressively give way to downstream landforms (low-sinousity, stable channels, levees, floodbasins).	All the individual components continue to be present, but not necessarily in the same locations after competent flows.	Check inventory of individual components from photographic survey (ground-based of selected locations or by aerial photography) for the whole progressive system once every three years.

Type of site: **PROGRESSIVE FLUVIAL SYSTEM**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Structure	Functional linkage between upstream and downstream components retained (upstream supply of sediment and water maintain downstream fining of bed material).	Linkage between supply of water and sediment from sources not impeded by structures or gravel extraction.	Visual check by site visit every year.
5. Function	Progressive downstream fining of bed material maintained via episodic transfers of sediment through system.	Water and sediment from sources continue to be transported throughout site. No attempt to stabilise slopes in upstream source area, or confine channel within the reach in which downstream fining develops..	Visual inspection of site every three years.
6. Visibility	Site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual landform components by man-made structures. Natural regeneration acceptable except where key individual components are specified.	Visual inspection of site every year.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every year.

Table 11: Site Attributes Table (bedrock channels)

Type of site: **BEDROCK CHANNELS (GORGES AND WATERFALLS)**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Natural, unregulated runoff regime from upstream maintained. Bedrock features (cascades, pools, steps, ribs, potholes) not obscured by accumulation of sediment or growth of mosses, grasses and shrubs.	Ideally natural runoff regime should be maintained. If not possible, high flows needed to flush out sediment which would otherwise obscure the bedrock features and potentially allow mosses, grasses or shrubs to mask features.	Ground-based photographic record (every three years) of selected bedrock features to check that important components not obscured or masked. Check flow record from gauging station: monitoring >95% flows on flow duration curve, if available, every three years.
2. Process/dynamics	Processes necessary for maintaining the clarity of the bedrock features and, in the case of potholes and plunge pools, continued evolution.	Bedrock features to be maintained in as pristine a condition as possible. Potholes and plunge pools to remain operational and subject to further development.	Ground-based photographic record (every three years) of representative key bedrock features (especially plunge pools and potholes) to check that they are still operational.
3. Composition	Maintenance of individual landforms (cascades, pools, steps, ribs, potholes).	Individual landforms continue to be present and, where appropriate, subject to continued development.	Check inventory of specified landforms from ground-based photographic survey every three years.
4. Structure	Functional linkage between landforms retained (eg cascades and plunge pools, bedrock steps and pools).	No changes in flow regime such that the functional linkage between cascades and plunge pools and bedrock steps and pools severely damaged.	Visual check from site visit every three years that functional linkage between specified landforms being maintained.

Type of site: **BEDROCK CHANNELS (GORGES AND WATERFALLS)**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
5. Function	Total bedrock channel system continues to operate as a highly stable reach evacuating runoff and retaining minimal amounts of bed material.	Exposure of bedrock within site should remain broadly unaltered within minimal and only temporary accumulations of bed material in transit.	Ground-based photographic record of selected bedrock features (every three years) to be maintained to check that important components not obscured or masked.
6. Visibility	Whole site visible by direct inspection on the ground or via aerial survey.	No obscuring of individual landform components by man-made structures. Natural vegetation regeneration acceptable except where key individual components are specified.	Visual inspection and ground photography of site every three years.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site every three every years.

Table 12: Site Attributes Tables and sites included in the GCR Fluvial Geomorphology volume

Site Attributes Table	Sites
Active sites	
Wandering gravel bed river	Glen Feshie, Dorback Burn, Luibeg Burn, Lower River Spey, Glen Coe
Active meandering river	Strathglass meanders, Abhainn an t-srath Chuileannaich, Derry Burn, Endrick Water River Clyde meanders,
Mountain torrent	Allt Mor (Glenmore)
Active confluence alluvial fan	Glen Feshie, Quoich Water
Fluvially modified debris cone	Eas Na Broige debris cone, Glen Coe
Integrated fluvial system	Allt a' Choire, Allt Coire Chailein
Progressive fluvial system	Allt Dubhaig, Allt Coire Gabhail
Bedrock channels (gorges and waterfalls)	Corrieshalloch Gorge, Falls of Clyde, River Findhorn at Randolph's Leap, Falls of Dochart
Relict sites	
Fluvial and glaciofluvial terraces	Glen Feshie, Findhorn terraces, North Esk and West Water palaeochannels, Glen Roy
Relict alluvial fan	Glen Feshie, Allt a'Choire, Allt Coire Chailein, Glen Roy

For most sites only the dominant category of Site Attributes Table is cross referenced to the site. But for complex and composite sites (Glen Feshie, Allt a' Choire, Allt Coire Chailein and Glen Coe) more than one Site Attributes Table is cross referenced.

4. DEFINITION OF FAVOURABLE CONDITION FOR ACTIVE COASTAL ENVIRONMENTS

4.1 Conceptual framework and rationale

Favourable conditions imply that the site in question is one which is in the regime of robust behaviour. Werritty and Brazier (1994) use the term 'robust' to describe a fluvial geomorphic system where the landforms are frequently destroyed but where the new landforms created are recognisably similar to the old landforms. It is suggested that this terminology is equally applicable in coastal geomorphology. One may consider, for example, a suite of coastal dunes. Such a landform assemblage will, in general terms, accrete during spring, summer and autumn months. However, it is likely to be severely eroded by winter storms but then recreated as a new set of dunes of similar morphology the following year, and so on (e.g. this is the general pattern of change at the West Sands, St Andrews, Fife). Whilst intrinsic thresholds are repeatedly being crossed through time, the overall response is stable within limiting thresholds. The suite of landforms within the site retain a stable identity as they form and reform. It should be emphasised that sensitive systems can be in favourable condition if the force of change is natural. It may be appropriate to allow such a system to evolve naturally.

In an active exposed coastal site, during a prolonged period of winter storm activity, it would be appropriate for scientific interest, although perhaps unrealistic in practical terms, to institute weekly or even daily site inspections during that period, within an overall normal programme of, say, monthly, sub-seasonal or seasonal monitoring. The latter will be determined as appropriate to the dynamics of the site in question.

If monitoring over the years has shown that the usual pattern, over a period of many years, has been for, as in the above example, dune assemblages to reform to their pre-winter state (i.e. in extent, altitude etc.) following storm activity, the system may be considered to display robust behaviour. It is only when the winter 'damage' to the system becomes consistently irreparable by natural processes during the following spring to autumn period, and the cycle of natural landform change is destroyed, that it may be considered that an extrinsic threshold has been crossed.

In terms of coastal sites, favourable condition is a 'band' and not a line. One should aim to identify the optimal state of a coastal site and manage towards that optimal state. It should also be noted that it is not always possible for a coastal site to achieve a favourable condition but it may nevertheless be the best example of a particular geomorphological feature which is available. Favourable condition must be defined for each feature for which a site has been notified. One feature may consist of a single exposure, or an assemblage of components as specified in the GCR. For each feature, one or more attributes must be identified, and against each of these a target will be set. Not all of the targets for a geomorphological feature need to be attained in order for that feature to be considered in favourable condition. The Joint Nature Conservation Committee and the country agencies propose to develop simple aggregation rules by which each feature's attributes will be assessed and its overall condition determined. The attributes for which targets are set should be consistent with the reasons for GCR site selection, and hence should take account of physical attributes and morphology, process dynamics, composition, structure, function, visibility and accessibility as appropriate. It should be recognised that the PDOs may be different for different types of coasts.

When considering coastal sites the links between sediment supply and landform assemblages are of crucial importance. The importance of the interruption of longshore sediment transport is emphasised, with particular reference to the USA, by Galvin (1990) who stated that, "...all examples of shore erosion on non-subsiding sandy coasts are traceable to manmade or natural interruptions of longshore sediment transport". This may be a rather bold assertion and not appropriate in all circumstances. However, it clearly emphasizes the significance of sediment transport along beaches and in the nearshore zone and is fundamental to the basis of the coastal cells concept.

Numerous processes in the coastal zone, and nearby, may interrupt the littoral transport regime in an area. The disturbances may be natural (e.g. up-drift coastal landslipping) or induced by man's activities. Such activities/external factors, both natural and anthropogenic, which may modify the normal littoral sediment transport regime in an area and which consequently may cause an extrinsic threshold to be crossed are, *inter alia*:

- The construction of groynes
- The construction of offshore breakwaters (detached breakwaters and sills)
- The construction of sea wall structures
- The construction of revetments
- The installation of strongpoints
- Cliff strengthening techniques
- Harbour/port and associated engineering projects
- The initiation of offshore dredging operations
- Changes in the frequency and amounts of extraction of offshore aggregates
- Extraction of beach sand and gravel
- Any factor causing changes in nearshore sediment supply
- Coastal tipping/dumping
- Coastal landsliding (either induced by man's activities or naturally occurring)
- Land use changes
- Changes in tourism/recreational patterns
- River engineering causing changes in the supply of sediment to coasts
- Changes in the wind-wave climate (frequency and direction) of an area
- Sea level rise
- Sea level fall

Most of the above are, *inter alia*, incorporated principally within PDOs Standard Reference Numbers: 7 (Dumping, spreading and discharge of any materials), 13b (Modification of the structure of water courses including their banks and beds, as by re-alignment, regrading and dredging), 15 (Infilling of ditches, pools, marshes or pits), 17 (Reclamation of land from the sea), 19 (Erection of sea defences or coast protection works, including cliff or landslip drainage or stabilisation measures), 20 (Extraction of minerals including peat, shingle, sand, gravel, topsoil and sub-soil), 21 (Construction, removal or destruction of roads, tracks, walls, fences, hardstands, banks, ditches or other earthworks, or the laying, maintenance or removal of pipelines and cables, above or below ground), 22 (Storage of materials on any part of the beach complex, 23 (Erection of permanent or temporary structures, or the undertaking of engineering works including drilling), 24 (Battering or grading the sand dunes), 26 (Use of vehicles or craft likely to damage or disturb features of interest and 27 (Recreational or other activities likely to damage landforms, features of interest).

Each of the above may serve to either decrease or increase the amount of sediment in transit in the littoral zone. For example, beach feeding and control structures such as timber or rock groynes are built in order to impede sediment transport. By such means a down-drift site may become starved of its normal supply of sediment, whilst up-drift sites near to the groynes become locally nourished with entrapped sediment. Cliff strengthening techniques may be deemed desirable to prevent erosion in one area but their use may similarly prevent sediment being supplied to down drift-sites. Coastal landsliding, triggered by whatever means, and dumping of debris at the coastline may, conversely, increase the availability of sediment for longshore transport and thereby change the geomorphological character of down drift landforms. River engineering works, close to the mouth, may cause either increased or decreased sediment supply to the nearshore zone, depending on the nature of the operations. Changes in the wind-wave climate in a region through time may have important consequences to the stability of coastal landforms. For example, in eastern Scotland, an increase in the frequency of easterly winds in winter months has taken place in recent years. As a consequence, 9 m of recession of the raised shoreline, on which two golf courses are situated, and associated dunes, at Montrose, Angus has occurred in 1995-96.

Thus the various processes and activities listed above may cause either an increase or a decrease in the amount of littoral sediment transport. It does not follow that all perturbations to the natural rate of supply will cause an extrinsic threshold to be crossed. The important question is, what are the acceptable limits of change to the littoral sediment transport regime in an area such that robust behaviour of the coastal landforms of a given SSSI is maintained? It is suggested that an answer is that the sediment supply must be maintained within whatever limits (either increase or decrease from the norm) which permit the landform assemblage to retain robust behaviour. These limits can, in practice, be defined only as a consequence of the extensive monitoring (including contemporary and archive information) of a site (see Site Attributes Tables below).

4.2 Definition and usage of terms

The following definitions are adopted for active coastal environments to develop Site Attributes Tables for individual sites. As with the Tables for active fluvial environments (see section 3), the Tables here conform to similar templates since the underlying conceptual frameworks are directly comparable.

In the 'Generic Guidelines for HSD and Birds Directive' (Ecoscope Applied Ecologists, 1996), attributes that may define favourable condition of a [biological] habitat were presented. Using a similar set of sub-divisions it is suggested that this material can sensibly be recast in a way which enables the definition of 'favourable condition' for coastal geomorphological SSSIs. It should be noted, however, that whilst one can 'freeze' a habitat one cannot adopt the same approach for dynamic geomorphological features. Using this approach, favourable condition is defined in terms of physical attributes and morphology, processes and dynamics, composition, structure, function, visibility and accessibility.

4.2 1 Physical attributes and morphology

The condition of an active coastal system may be defined as favourable if its physical attributes and morphology are intact (or there has been no deterioration if the system was not intact at the time of designation). For coastal sites the physical attributes comprise the material components (e.g. sand, gravel, peat, bedrock, i.e. the solid and drift geological components) and water bodies such as coastal lagoons or those occupying dune slacks. The morphology of the system is then the form of the resultant erosional or depositional landform created. PDOs Numbers 7, 13b, 15, 17, 19, 20, 21, 22, 23, 24, 26 and 27 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.2 Processes and dynamics

The condition of an active coastal system may be defined as favourable if the processes can operate across the whole site unconstrained in terms of natural variability (or there has been no deterioration arising from human activities, if the processes were constrained by human activity at the time of designation). The dynamics of a coastal site must maintain its function within its local setting of a coastal management unit, a coastal sub-cell or a coastal cell. In this respect the dynamics of a coastal site is best characterised in terms of its inputs (high or low energy) and thresholds (high or low). The condition of an active coastal system may then be defined as favourable if the system has the capacity to recreate the components for which it was notified where these have been lost, damaged or deteriorated naturally (i.e. the system displays robust behaviour). PDOs Numbers 7, 13b, 15, 17, 19, 20, 21, 22, 23, 24 and 27 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.3 Composition

The condition of an active coastal system may be defined as favourable if the range of components of a system and their clarity of expression have not deteriorated. Composition includes both the range of individual coastal landforms in a site assemblage and the clarity of the individual landform expression. PDOs Numbers 7, 13b, 15, 17, 19, 20, 21, 22, 23, 24, 26 and 27 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.4 Structure

The condition of an active coastal system may be defined as favourable if the integrity, context and relationships of the system's main components have not diminished through physical damage or fragmentation. In common with fluvial environments, structure refers to the clarity of inter-relationships between individual component landforms and thus relates primarily to landform assemblages. It is of crucial importance in defining favourable condition as, typically, the significance of the whole is greater than the sum of the parts. Structure, in turn, enables the dynamics and function of the site to be determined. PDOs Numbers 7, 13b, 15, 17, 19, 20, 21, 22, 23, 24, 26 and 27 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.5 Function

The condition of an active coastal system may be defined as favourable if the system has not deteriorated as a result of change within its wider setting. The function of a coastal site concerns its status within the wider setting of a coastal management unit, a coastal sub-cell or a coastal cell. It is necessary to identify the function of an individual site as a sediment source, a sediment sink or a sediment transfer zone. PDOs Numbers 7, 13b, 15, 17, 19, 20, 21, 22, 23, 24, 26 and 27 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.6 Visibility

The condition of an active coastal system may be defined as favourable if the visibility of the system is unimpaired (or there has been no deterioration since the site was notified). PDOs Numbers 7, 17, 19, 20, 21, 22 and 23 (Table 3) are considered the most relevant to the coastal zone in this context.

4.2.7 Accessibility

The condition of an active coastal system may be defined as favourable if access is maintained for purposes of education and research as appropriate. PDOs Numbers 7, 13b, 19, 20, 21, 22 and 23 (Table 3) are considered the most relevant to the coastal zone in this context.

4.3 Methods for determining entries in the Site Attributes Tables

One can only ascertain the existence of robust or sensitive behaviour in retrospect. Landform behaviour determination is achieved through the time series analysis of archive data and by continued site monitoring. Several techniques which may be used to monitor changes in the morphology of coastal landforms involve the use of expensive equipment or extensive mathematical modelling. These are not considered within the remit of this report which concentrates specifically on methods which are easy to use, relatively inexpensive and readily available to SNH Area Officers. Techniques considered most appropriate for coastal monitoring are:

- Historical maps
- Aerial photographs
- Terrestrial photographs
- Field surveying methods
- GIS

4.3.1 Historical maps

It is generally accepted that there are few reliable maps available prior to the publication of the Ordnance Survey's "six inch" (1:10,560) maps in the 1880s. Comparison of these with present day OS maps will give an indication of the extent of coastal erosion or accretion over the past 100 years in a form that can be quantified. Although general deductions may be made from older maps and charts, they are unlikely to be reliable. Even the earlier OS maps are open to doubt since they were not always surveyed very accurately, especially near to the coast. Thus, although parts of a map are verified as accurate, it cannot be assumed that the shoreline is equally reliable and errors of plus or minus 5-6 m are common. However, lines marking the tops of cliffs are usually more accurate than those along sandy shores. By comparing the various editions of OS maps at scales of 1:10,560 (now 1:10,000) or 1:2,500, it is possible to estimate, in general terms, the rates of erosion or accretion which have occurred. In some localities, other maps or surveys may be available. For information prior to the 1880s, maps may be extant and available from local archives or in the form of estate plans in the Scottish Records Office. Such sources are unlikely to yield wholly reliable data but can offer an insight into the general patterns of change through time. For more recent data, individual pieces of research carried out within centres of higher education, or by statutory or other bodies may provide additional sources.

4.3.2 Aerial photographs

Information on coastline changes can be obtained where photographs taken from the air are available. This technique is particularly powerful where the coastline is difficult to reach because of high cliffs with no beaches at their base. Usually the height of the aircraft is known and from this exact ground measurements can be obtained. Aerial photographs of Scotland have been flown for a number of purposes over the past 40-50 years and a temporal sequence for a specific site is likely to be available though it may not always be easy to access the requisite frames. An extensive collection is held by the Royal Commission on Ancient and

Historic Monuments (RCAHMS), Edinburgh. Ideally, aerial photographs should be used in conjunction with reliable maps so that geomorphological features can be identified with accuracy. It is also important to know the date and time of day that the photograph was flown so that the state of the tide can be determined.

4.3.3 Terrestrial photographs

Coastal landforms may be photographed from the ground in order to produce a record of change. Such a record may start from the present or make use of an old photograph of a particular geomorphological feature or site. If a new record is begun, the location from which the photograph is taken should be meticulously chosen and noted so that return visits to the spot are simplified and can be undertaken by another person if necessary (sometimes referred to as fixed-point photography). Where an old picture is used, it is easiest if a copy is taken to the site so that the same view may be obtained. In order that any changes can be quantified, an object of known dimension should be incorporated into the photograph. The advantage of this technique is that old photographs of most parts of the Scottish coast are likely to be available although they were probably taken for an entirely different purpose with the coast as an incidental feature.

4.3.4 Field surveying methods

Any analysis of coastal change should include ground measurements of the contemporary shoreline. The degree of sophistication of such measurements will depend on the equipment available. This could range from a simple tape measure to an electronic survey instrument (e.g. theodolite with EDM). While it is desirable to obtain the greatest possible accuracy and reliability, any measurement is better than none at all and can be used to support and supplement other evidence. Whichever method is employed, it is important to establish control points that can be used for repeat surveys in the future. A variety of types of stake have been used to measure erosion along a coast. On cliffs, the exposure of steel pegs driven into the face can be measured directly over time to establish the rate of cliff recession. Alternatively, stakes may be driven into a till overburden to assess the existence, or extent, of movement. Fence posts may be used to collect data on the build-up of sand in a dune or beach area. Notches cut into wooden groynes can also be used to monitor changes in beach levels through time. Evidence of coastal erosion and accretion can sometimes be deduced by reference to relicts in the landscape which can be dated. For example, World War II defences, such as lines of tank traps, can provide an important time marker relative to which erosion or accretion can be quantified. Such defences are present at Tentsmuir Point, where they were emplaced at high water mark in 1941, and at the western part of Spey Bay.

4.3.5 GIS

It is important that monitoring data are collated in a quantified and easily comparable format. Ideally, to this end, all of the various forms of monitoring information, derived from maps, aerial and terrestrial photographs and field surveying, should be in some way combined. Geographical Information Systems (GIS) provide an important means of managing information. They have assisted many realms of natural resource and environmental management but have enjoyed limited success to date in coastal applications for technical and organisational reasons. Benefits of GIS include the ability to model potential scenarios, to handle large amounts of data and the ability to integrate data from diverse sources that are of relevance but hitherto have been unable to be integrated manually. The ability of GIS to assimilate data sets at differing scales and resolutions is likely provide the coastal planner with a more holistic view of the coastal zone (McCall and Devoy, 1995). Limitations to the use of

GIS are generally twofold: technical and organisational. Technical limitations to the effective use of GIS for coastal zone management include difficulties in devising appropriate data models and the coupling of GIS with various types of models (e.g. hydrological models). Although GIS can be used to overlay spatial information from different time periods, the inability to represent temporal information is a further limitation for coastal applications.

4.3.6 Monitoring and temporal change

The fact that the coastal zone is continually changing gives rise to the problem of when and how frequently measurements should be taken. There can be no hard and fast rules that may be applied, since timing and frequency will depend on a number of factors including the nature of the site, the frequency of storm events, the purpose of the measurements etc. In general, an annual survey will usually suffice and this being so, the best time to undertake it will be in early spring, after the high energy wave events of the winter storms. It is suggested that such 'early spring' conditions (i.e. on the assumption that these are likely to record the 'worst case' in terms of the effects of natural processes on a site) should be used for baseline comparative purposes to integrate changes over time. In the case of cliffs of resistant rock, annual measurement without sophisticated equipment may not reveal any change over several years. However, a landslide or localised erosional feature should ideally be monitored at a frequency and over a timescale that is outside the scope and resources of SNH. Beach profiles can also show measurable change in the duration of a day. During storms, when wave energy is high, a beach profile tends to flatten out as sediment is drawn down the beach slope. Under calmer conditions, sediment is pushed landward and the beach profile steepens. Thus data collected midway between winter and summer will often provide an adequate mean. As a general rule, the average slope of a beach taken over a ten year period will reflect its true equilibrium characteristics. The coast as a recreational resource poses its own problems. Man may be actively participating in the destruction of the environment which is the basis for his leisure activities, as for example, by trampling the vegetation cover of sand dunes. In such a case, monitoring should include an assessment of visitor movements as well as the degree of erosion caused if the monitoring is to be useful in the production of a management strategy.

4.4 Compilation of Site Attributes Tables for active coastal systems

Using the conceptual and methodological framework developed above, Site Attributes Tables are now developed for active coastal systems found in Scotland. The latter may be classified as follows:

(i)	Beach-machair landform assemblage of Highlands and Islands	Table 13
(ii)	Beach-dune-machair landform assemblage of Highlands and Islands	Table 14
(iii)	Beach-bar landform assemblage of Highlands and Islands	Table 15
(iv)	Prograding coastal foreland landform assemblage	Table 16
(v)	Beach-dune landform assemblage of the Lowlands	Table 17
(vi)	Shingle structures landform assemblage	Table 18
(vii)	Rock cliff coast landform assemblage	Table 19
(viii)	Rock shore platform landform assemblage	Table 20
(ix)	Rock archipelago landform assemblage	Table 21
(x)	Saltmarsh-barrier beach, estuary and loch head landform assemblages	Table 22

Cross-referencing to individual sites in the GCR Coastal Geomorphology volume (in prep.) is made in Table 23.

Table 13: Site Attributes Table (beach-machair landform assemblage of Highlands and Islands)

Type of site: **BEACH-MACHAIR LANDFORM ASSEMBLAGE OF HIGHLANDS AND ISLANDS**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: beach, machair plain, machair escarpment, deflation plain.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 14: Site Attributes Table (beach-dune-machair landform assemblage of Highlands and Islands)

Type of site: **BEACH-DUNE-MACHAIR LANDFORM ASSEMBLAGE OF HIGHLANDS AND ISLANDS**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: beach, dune ridge, blow outs, machair plain, hill machair escarpment, spits, tombolos, conical sandhills, climbing dunes, aeolianite.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 15: Site Attributes Table (beach-bar landform assemblage of Highlands and Islands)

Type of site: **BEACH-BAR LANDFORM ASSEMBLAGE OF HIGHLANDS AND ISLANDS**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: beach, bar/tombolo.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 16: Site Attributes Table (prograding coastal foreland landform assemblage)

Type of site: **PROGRADING COASTAL FORELAND LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: offshore bar (barrier island), sandflat, saltmarsh, dune ridge, dune slack, beach ridges (sand/shingle), raised beach, Holocene/Late-glacial cliffline; possible parabolic dunes, blowouts, deflation surfaces.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.

Type of site: **PROGRADING COASTAL FORELAND LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 17: Site Attributes Table (beach-dune landform assemblage of the Lowlands)

Type of site: **BEACH-DUNE LANDFORM ASSEMBLAGE OF THE LOWLANDS**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing landform assemblage: sand beach, foredunes, dune ridge, blow-outs, links, dune slacks, grey dunes, Holocene/Late-glacial cliffline, possible spits, beach berms, parabolic dunes, winter lochs, raised beaches.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 18: Site Attributes Table (shingle structures landform assemblage)

Type of site: **SHINGLE STRUCTURES LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: active shingle bar/spit, shingle beach, beach cusps, raised shingle bars, Holocene/Late-glacial cliffline.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 19: Site Attributes Tables (rock cliff coast landform assemblage)

Type of site: **ROCK CLIFF COAST LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: cliffs, stacks, arches, blowholes, caves, geos, cliff-top storm beaches and stripped vegetation, pocket beaches.	No loss of any individual landform component other than by natural processes.	Three-yearly visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity.	Three yearly visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components c. every three years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 20: Site Attributes Table (rock shore platform landform assemblage)

Type of site: **ROCK SHORE PLATFORM LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: intertidal platform, raised platform, till cover, ice moulding, raised beaches, fossil cliffline, raised stacks and arches.	No loss of any individual landform component other than by natural processes.	Three-yearly visits; comparative ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual active landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity.	Three-yearly, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components c. every three years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 21: Site Attributes Table (rock archipelago landform assemblage)

Type of site: **ROCK ARCHIPELAGO LANDFORM ASSEMBLAGE**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: islands, fjord inlets, reefs, skerries, pseudo-cliffs, pocket beaches.	No loss of any individual landform component other than by natural processes.	Three-yearly visits; comparative ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large scale sediment extraction.	Three-yearly visits, comparative ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components c. every three years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 22: Site Attributes Table (saltmarsh-barrier beach, estuary and loch head landform assemblages)

Type of site: **SALTMARSH-BARRIER BEACH, ESTUARY AND LOCH HEAD LANDFORM ASSEMBLAGES**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landform components: barrier beach or mud/sandflats or beach; saltmarsh, creeks, pans.	No loss of any individual landform component other than by natural processes.	Annual visits; comparative annual ground photography; obtain all past and new aerial photographs.
2. Process/dynamics	Processes necessary to maintain range of individual landform components are not constrained by human activity.	No loss of any individual landform component as a result of human activity. No large-scale sediment extraction.	Annual visits, comparative annual ground photography.
3. Composition	Maintenance of existing assemblage of landform components and their individual clarity of expression.	As for 1. No permanent damage to any individual landform component as a result of human activities.	Check inventory of individual landform components every one to two years.
4. Structure	Maintenance of the structural linkage between the individual landform components.	No loss of linkages between landform components other than by natural processes.	As for 2.
5. Function	Maintenance of the landform assemblage at its current status (sediment source, sink or transfer zone) within a coastal cell, sub-cell or management unit.	No change of function of landform assemblage other than by natural processes.	As for 3.
6. Visibility	Site composition and structure should be maintained from near and distant viewpoint and/or from the air.	No obscuring of individual landform components by man-made structures or human activities. Natural vegetation regeneration acceptable except where key individual components are specified.	As for 1.
7. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 23: Site Attributes Tables and sites included in the GCR Coastal Geomorphology volume (in prep.)

Site Attributes Table	Sites
Beach-machair landform assemblage of the Highlands and Islands	Balta Island, Mangersta
Beach-dune-machair landform assemblage of the Highlands and Islands	Central Sandy, Traigh na Berie, Pabbay, Luskentyre and Corran Seilebost, Hornish and Lingay Strand/Machair Robach and Newton, Ardivachar and Stoneybridge, Eoligarry, West Coast of Jura, Machir Bay, Dunnet Bay, Torrisdale Bay, Sandwood Bay
Beach-bar landform assemblage of the Highlands and Islands	St Ninian's Tombolo, Ayres of Swinster
Prograding coastal foreland landform assemblage	Culbin, Morrich More, Barry Links, Tentsmuir
Beach-dune landform assemblage of the Lowlands	Strathbeg, Forvie, Luce Bay
Shingle structures landform assemblage	Spey Bay, Whiteness Head
Rock cliff coast landform assemblage	Papa Stour, Villians of Hamnavoe, Foula, West Coast of Orkney, St Kilda, Duncansby Head, Bullers of Buchan, St Abb's Head
Rock shore platform landform assemblage	Dunbar, Northern Islay, Tarbat Ness
Rock archipelago landform assemblage	Loch Maddy - Sound of Harris
Saltmarsh: barrier beach, estuary and loch head landform assemblages	Morrich More, Culbin, Cree, Solway Firth, Loch Gruinart

5. DEFINITION OF FAVOURABLE CONDITION FOR RELICT ENVIRONMENTS

5.1 Conceptual framework and rationale

Before defining 'favourable condition', it is desirable to consider the reasons why relict geomorphological features have scientific, and therefore conservation, value. Any definition of favourable condition must recognise the scientific value and strategy for how best to conserve relict landform sites, and is consequent upon consideration of scientific value.

Relict geomorphological features are those landforms which were formed by processes no longer in operation under present-day climates. If these features are damaged or destroyed, there is no possibility that they will reform and they are usually irreparably lost. In Scotland they are almost exclusively cold-climate landforms formed when the landscape was subject to glacial or periglacial processes more than 10,000 years ago, but a few landforms created during postglacial time are also important for conservation.

Relict landforms have conservation value by reason of the information they store about past environments: climatic, geomorphological, biological (subfossil flora and fauna within sediments). Relict depositional landforms generally possess both a surface expression of past processes and an internal structure (stratigraphy) reflecting the disposition of sediment within the landform. At some sites no internal structure is exposed in eroded slopes or gullies and the landform is entirely vegetated. At others, the scientific interest derives from stratigraphy alone, particularly at those sites where detailed pollen profiles from cores record changing vegetation communities due to climate and/or landuse change in the catchment. On occasions, both the morphological and stratigraphic approach can be combined to give fuller environmental reconstructions supported by radiometric dating of organic material.

Some landforms maintain their scientific value in isolation from the landforms around them. For example, a stratigraphic section with vertical variation in texture, lithology, and subfossil composition records temporal environmental change without reference to the spatial context (though this too is desirable for interpreting the stratigraphic section, but often unavailable). Sediments in erosional outliers may survive with no stratigraphic equivalents in the landscape, and their value then lies in being the only evidence of the environment at the time of deposition. More usually, spatial context adds to the scientific value of a site. This is striking in site descriptions in the GCR volume *Quaternary of Scotland* (Gordon and Sutherland, 1993), in which landform assemblages are emphasised. Such assemblages have high conservation value where they demonstrate interfaces between process domains.

'Landform assemblages' are interrelated groups of individual landforms which together demonstrate the former functioning of the geomorphological system and thereby elucidate the environmental controls which once existed. Assemblages are important because they usually reveal much more information to scientists than the individual landforms alone. The concept is recognised in standard texts in, for example, glacial geomorphology (the 'landsystem approach' of Eyles, 1983). For the conservation manager, it is recommended here that the assemblage has conservation priority, rather than selecting one type of landform for conservation as being more "interesting" than other types. For example, a terminal moraine has less value in isolation than if it is preserved in association with lateral and/or subglacial moraines upvalley and linked to palaeosandur terraces downvalley. Through these associations, the assemblage can be used to reconstruct former ice extents and palaeoclimate (e.g. Ballantyne, 1989) or palaeohydrology (e.g. Maizels, 1983). Similarly, cores from peat bogs or lake infills record former vegetation communities, and must be interpreted in their geographical context (catchment characteristics, relations with former ice limits etc). Again, the lake or bog can be viewed as part of the wider landform assemblage.

Favourable condition must take into account the site attributes on which the scientific value is based. Following Ecoscope (1996, Table 3.1), attributes relevant to relict landforms are listed in a series of Site Attributes Tables (see section 5.3) In these listings, attributes fall within the quality-based classification of composition, structure and function identified by Noss (1990). Both vulnerable and non-vulnerable relict landforms will be assessed in terms of favourable condition as part of the natural heritage. Broadly similar criteria will be used for making this assessment as for dynamic geomorphological features.

5.2 Definition and usage of terms

In the context of relict landforms, the following definitions are adopted. These guidelines are intended to aid the conservation manager in constructing Site Attributes Tables for individual relict landform sites.

Favourable condition is maintained if the variety, dimensions and relationships between relict landforms at a site are maintained at or close to their current preserved level, so that the evidence for the operation of past geomorphological systems is not being lost to a significant extent, and if the site is visible and accessible for study. Specific attributes which together comprise favourable condition are listed below.

5.2.1 Physical attributes and morphology

Favourable condition requires either (a) intact physical attributes and morphology, or (b) no deterioration in physical attributes and morphology arising from human activities since the time of designation. 'Physical attributes' refer to the material constituents of the landform. Included in this are bedrock (i.e. *in situ* rock which has not been physically disaggregated but which may have been chemically decomposed); clastic sediment (bedrock physically transported from its source and redeposited as mud, silt, sand, gravel or boulders); organic sediment (peat, organic mud, macrofossil or subfossil floral and faunal remains; microscopic floral and faunal remains); and water (groundwater, soil moisture or surface water which may form an integral part of preserved deposits). 'Morphology' refers to the form of the resultant erosional or depositional landform created from the physical attributes.

Recording of physical attributes and morphology will normally be a straightforward procedure, noting the constituent materials within landforms. For example, fluvio-glacial terraces usually comprise clastic sediment throughout, while sediments within low-energy lakes are commonly characterised by clastic sediments during cold climates (such as the Younger Dryas/Loch Lomond Stadial) and by organic deposition during warm climates (such as the Lateglacial Interstadial and the Flandrian/Holocene period). Erosional landforms are always composed of local bedrock lithologies.

5.2.2 Composition

Favourable condition requires that both the features and the clarity of expression of a geomorphological assemblage have not deteriorated since the time of designation. 'Composition' includes not just the range of individual landform types present within assemblage and their clarity of expression, but also the presence and location of stratigraphic sections relative to the surface landform expression. Such exposures may be important for correct interpretation of surface morphology.

Terms used to define clarity may include subjective descriptors ("well-defined", "distinct", "sharp-crested", "subdued", "partially eroded", "complete", "fragmentary". The term "fresh", which has commonly been applied to hummocky moraine in the Highlands, should be avoided, as this implies an age rather than merely describing form.). Specific individual landforms at all scales should be named: e.g. a fluvioglacial terrace may be described as "terrace fragments distributed along both valley sides and marked by sharp breaks-of-slope at the base of risers, but subtle changes-of-slope where treads meet the hillslope above. Subdued palaeochannels infilled with peat are preserved on terrace treads, and distinct kettle holes are preserved at the upvalley extreme of the terrace".

5.2.3 Structure
'Structure' refers to the integrity, context, and interrelationships of a site's main geomorphological features. Favourable condition is maintained if these have not diminished through physical damage or fragmentation. Structure is an important element within the definition of favourable condition, because the totality of a site outweighs the scientific value of the individual geomorphological features (i.e. the total structure exceeds the sum of the parts). The scientific rationale for this is that it is assemblages of landforms that reveal the functioning of past environmental systems. Study of individual features alone does not provide enough information.

Examples of the clarity of landform interrelationships include the following: the matching of terminal moraines with their contemporary outwash surfaces or with eskers and meltwater channels; the correlation of the shorelines of former ice-dammed lakes with evidence for glacier limits and lake outflow points (e.g. Glen Roy and the Parallel Roads); the location of cored lake or bog sediments with respect to former ice limits and sediment sources (e.g. Loch Ettridge); the relationship between moraines, outwash surfaces and former marine limits and raised shorelines (e.g. Muir of Ord). The structure of all such sites requires careful interpretation by staff with a geomorphological training, as site structures can at times be initially obscure and open to different interpretations.

At some sites, the interrelationships between individual landforms are illuminated by the existence of exposures of the constituent sediments. These stratigraphic sections usually provide information solely on the texture and disposition of clastic sediment within the landform, and are useful for determining (for example) whether deposition was from ice, from water, or by mass movement processes, and the energy levels of flow based on particle sizes. On occasions, organic material contained between layers of clastic sediment allows dating of events, usually by the radiocarbon method. Such information is scarce and scientifically very important, because it is usually the only way in which a firm chronology of events can be constructed to allow correlation with other localities and other regions. Dated sections should be given a high conservation priority, particularly in Lateglacial deposits where such evidence is rare.

5.2.4 Visibility
Favourable condition is maintained if either

(a) the visibility of the feature is unimpaired, or

(b) if there has been no significant deterioration since the site was notified, or

(c) stratigraphic sections remain accessible through excavation or natural erosion.

In case (c), exposed sections need not correspond exactly with those originally exposed at the time of designation, but others which maintain or enhance the scientific interest should also be considered when assessing favourable condition.

5.2.5 Accessibility
Favourable condition requires that access is maintained for the purposes of education and research as appropriate. However, it should be borne in mind that landholding is transient and that if access restrictions are imposed by individual land owners/ land managers, in the long term the access situation may improve. It is important to maintain the conservation status of relict sites where access is currently restricted, for future education and research.

By their definition as relict, no new landforms can be created because their formative processes no longer operate, but preserved forms can be lost due to natural erosion or human excavation. Natural erosion as accepted as part of landscape evolution, in which relict depositional landforms represent temporary sediment stores when viewed over timescales of millennia. Thus, some designated sites may be lost in the future for entirely natural reasons. Exceptions to this would be small stratigraphic sections of key palaeoenvironmental importance. Maximum site area is notional, as it will always equate to the present area of preserved landforms.

5.3 Compilation of Site Attributes Tables for relict landform assemblages

As in previous sections of this report, Site Attributes Tables for relict landform assemblages require a definition of favourable condition along with the limits of acceptable change. Following these definitions, monitoring prescriptions can then be identified.

It is important to note that some sites will be in favourable condition based on a different set of attributes from other sites, depending on the specific scientific interest of each site. To illustrate, sites identified in the GCR volume *Quaternary of Scotland* (Gordon and Sutherland, 1993) include, at one extreme, small single-interest localities (e.g. palaeoecological records from small sedimentary infills) to large multi-interest regions at the other (e.g. the Cairngorm Mountains and the Cuillin Hills of Skye). The Site Attributes Tables provide a framework which is sufficiently versatile to accommodate the variety of site characteristics whose condition may need to be determined.

A further distinction exists between landforms of depositional and of erosional origins. In Scotland, designated sites are dominated by depositional landform assemblages (Gordon and Sutherland, 1993), reflecting the stratigraphic tradition of Quaternary science in the UK. Such landforms are of greatest multidisciplinary interest through their value in recording datable environmental changes upon which regional chronologies of events can be based. Erosional landforms invariably consist of sculpted, moulded or incised bedrock and are more of interest to process theoreticians, who collectively have not been a strong voice in UK Quaternary studies. Nevertheless, theoretical advances in glaciology make the conservation of erosional forms important as testing grounds for developing ideas (e.g. Sharp *et al.*, 1989; Sugden *et al.*, 1992; Glasser, 1995), and these must be accommodated within the same site attributes framework as depositional landforms.

Each Site Attributes Table includes the limits of acceptable change with regard to each attribute and to Potentially Damaging Operations discussed below. It is emphasised that local knowledge of sites is essential for effective monitoring and conservation, and strategies for managing different types of site are presented in the Site Attributes Tables. The threats to individual sites will depend not just on the nature and intensity of the PDO but also on inherent site attributes, even though landforms are relict. An acceptable level of change at one site may not be acceptable at another, due to the reasons why each is scientifically valuable. Limits of acceptable change must be set with regard to the minimum quantity and quality of landforms necessary to allow palaeogeomorphological reconstruction to be made, and to allow future work at the site to be possible should our interpretations and dating technology improve over time.

PDOs are any anthropogenic change which directly and detrimentally affects the quality and quantity of site attributes detailed in the Site Attributes Table for each relict landform site. A comprehensive list of 28 PDOs is included as Table 3. With specific reference to relict landforms, the impact of any PDO is determined by the likelihood that such an operation will initiate or accelerate the destruction of the landform/ landform assemblage, or will obscure from view the landform so that geomorphological reconstruction based on landform evidence will no longer be possible even if the landform still exists.

PDOs thus fall into one or more of the following categories.

(i) *PDOs which may initiate landform destruction*
These will act through damage to (including removal of) the stabilising vegetation cover on depositional landforms to the extent that the threshold of stability of the relict landform is lowered, so that wind, (especially) surface runoff, and subsurface sapping will be able to entrain the material constituents of the landform. Those PDOs most likely to initiate erosion are numbers 1, 4, 8, 11, 14, 20 and 24 (Table 3).

(ii) *PDOs which may accelerate landform destruction*
Where erosion of depositional landforms is already in progress due to either natural or anthropogenic processes, some PDOs have the potential to accelerate erosion. Generally, this will again act through degradation of the stabilising vegetation cover. Those PDOs most likely to initiate erosion are numbers 1, 4, 8, 11, 20, 24, 25, 26 and 27 (Table 3).

(iii) *PDOs which may obscure landforms*
The visibility of landforms and stratigraphic sections is essential to allow geomorphological maps showing their distribution and interrelationships. Visibility may be impaired by vegetation changes (natural succession or, more commonly in Scotland, afforestation) or by construction of paved surfaces, buildings, retaining walls etc. Visibility may also effectively be prevented by restrictive access policies on the part of landowners. Those PDOs most likely to reduce visibility are numbers 7, 12, 15, 19, 21, 22 and 23 (Table 3).

Limits of acceptable change define the boundaries between which we would expect a feature to fluctuate, and within which its condition is considered to be favourable. Changes beyond these limits would be regarded as undesirable and would trigger action to investigate the likely cause of the decline and whether remedial action is feasible.

Relict landform sites, though no longer actively-functioning systems, are nevertheless subject to fluctuations in those attributes which together define favourable condition. Thus, limits of acceptable change are conceptually little different from those relating to active process systems, except that deterioration results exclusively from external and not internal influences. Limits of acceptable change should take account of:

- the condition of the feature at the time of designation;
- natural changes due to erosion and vegetation colonisation and growth;
- the extent to which such natural change is deemed acceptable without devaluing the site attributes.

When coming to a decision on remedial action to offset site deterioration, it is first necessary to decide whether deterioration is due to natural processes or to human interference. If natural, deterioration is regarded as an integral part of the site's evolution and therefore no remedial action is taken. Conversely, human interference may be cause for remedial conservation action.

Using the conceptual and methodological framework developed above, Site Attributes Tables are now developed for relict landform assemblages found in Scotland.

(i)	Stratigraphic sections	Table 24
(ii)	Ice-margin landform assemblage	Table 25
(iii)	Relict ice-marginal lakes	Table 26
(iv)	Glacial erosional landscapes	Table 27
(v)	Subglacial depositional landforms	Table 28
(vi)	Fluvial and glaciofluvial terraces	Table 29
(vii)	Relict alluvial fans	Table 30

Table 24: Site Attributes Table (stratigraphic sections)

Type of Site: **STRATIGRAPHIC SECTIONS**

Site attribute	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing textural and compositional assemblages.	No loss of sediment other than by natural erosion processes. Protection against fluvial undercutting may be deemed necessary at sites of exceptional importance.	Annual visits and comparative annual photography.
2. Composition	Existing temporal representation to be maintained. Extension to temporal range by basal erosion/excavation would improve condition.	No loss of any stratigraphic horizon.	As for 1, with detailed observation of lowermost and uppermost exposure.
3. Structure	Maintenance of stratigraphic and structural relationships.	As for 2.	As for 1.
4. Visibility	Little excavation or clearance required to access individual strata or to demonstrate stratigraphic relationships.	No burial by landfill or any other extraneous material. Natural slope degradation acceptable as long as section can be reinstated manually (eg. trowel or spade, or in specific cases by mechanical digger). No growth of deep-rooted vegetation (shrubs or trees), but lower-order colonisers acceptable.	As for 1.
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 25: Site Attributes Table (ice-margin landform assemblage)

Type of Site: **ICE-MARGIN LANDFORM ASSEMBLAGE**

Site attribute	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of existing assemblage of landforms in ice-marginal zone, including representatives of subglacial and proximal proglacial landforms.	No loss of any individual landform component through excavation or quarrying, though loss through natural erosion accepted as part of postglacial landscape adjustment as long as erosion is not artificially accelerated.	Annual visits; obtain all past and new aerial photographs. Comparative annual ground photography. Impacts of consented PDOs must be specifically monitored.
2. Composition	Maintenance of existing range of landform types and clarity of expression.	As for 1. No regrading of slopes, ditching, or ploughing.	As for 1. Check inventory of individual landform components every one to two years.
3. Structure	As for 1 and 2, paying particular attention to location and clarity of exposed sections.	As for 1 and 2.	As for 1.
4. Visibility	Site composition and structure is well displayed from distant viewpoint and/or from the air.	Succession from existing vegetation cover should not be encouraged. No planting of trees. No building of structures on site which will obscure landforms. Light, temporary structures without deep foundations possibly acceptable.	As for 1. .
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 26: Site Attributes Table (relict ice-marginal lakes)

Type of site: **RELICT ICE-MARGINAL LAKES**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of all erosional and sedimentary evidence of former lake shorelines; inflow and outflow points (raised deltas, fans, rock-cut channels; alluvial channels)	No removal or quarrying of any bedrock or sediment directly related to former lacustrine and related fluvial processes. Natural erosion processes acceptable as part of postglacial landscape readjustment.	Annual visits. Comparative annual ground photography. Check aerial photographs as they become available.
2. Composition	Existing components maintained at present areal extent and range of landforms. These may include erosional and depositional shorelines, rock-cut and alluvial channels, river terraces, moraines and kame terraces associated with former ice dam, deltas and fans at former inflow points, and lake-floor sediments.	As for 1.	As for 1. Check inventory of individual landform components every one to two years. Impacts of consented PDOs must be specifically monitored.
3. Structure	Spatial relationships between former ice dam(s), lake shorelines, lake-floor sediments and inflow/outflow points clearly displayed. Temporal changes in lake level as reflected in some or all of these components also displayed.	As for 1. No regrading of slopes by ploughing or earth-moving	As for 1.

Type of site: **RELICT ICE-MARGINAL LAKES**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Visibility	Site structure clearly displayed from distant viewpoint. Individual components sufficiently visible for detailed study. Stratigraphic sections form and degrade by natural processes only.	No building of structures which would inhibit visibility according to 4. No planting of trees and deep-rooting shrubs. Temporary structures with shallow foundations may be acceptable in places. No burial of depositional or bedrock forms by landfill, waste disposal, or construction/ engineering work.	As for 1.
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 27: Site Attributes Table (glacial erosional landscapes)

Type of site: **GLACIAL EROSIONAL LANDSCAPES**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of undisturbed rock surfaces and sculpted landforms (or present extent, if less).	No removal of rock by quarrying, blasting, construction of cuttings, tunneling. Natural rock weathering by frost and chemical changes acceptable.	Annual visits to check for alteration. Robust forms, so no photography necessary for monitoring, but photography for baselines.
2. Composition	Maintenance of some or all of the following components: striated and plucked surfaces; chattermarks; p-forms, Nye channels and other meltwater-erosional forms; stoss-lee forms; large-scale forms such as cirques, troughs, rock basins, areally-scoured and selectively-eroded landscapes.	As for 1.	As for 1. Record damage by photography. Check inventory of individual landform components every three or five years.
3. Structure	Spatial distribution of small-scale forms is evident to trained geomorphologist, including zonation of forms at regional scale related to subglacial erosion processes and meltwater routeways.	As for 1.	As for 1 and 2.

Type of site: **GLACIAL EROSIONAL LANDSCAPES**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
4. Visibility	Structure of large-scale features visible from distant viewpoint and from aerial view. Small-scale forms visible by ground inspection.	As for 1. No obscuration by landfill, waste disposal, anthropogenically-induced deposition of sediment by wind or water. No vegetation growth and soil formation beyond present cover. No flooding of site by dam construction or engineered river channel change. No construction of buildings etc.	As for 1 and 2.
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 28: Site Attributes Table (subglacial depositional landforms)

Type of site: **SUBGLACIAL DEPOSITIONAL LANDFORMS**

Site attributes	**Favourable condition**	**Limits of Acceptable Change**	**Monitoring Prescription**
1. Physical attributes and morphology	Maintenance of sedimentary and landform evidence of former conditions of thermal regime, ice and water movement, sediment transport and deposition beneath glacier or icesheet.	No loss of any individual landform component through excavation or quarrying, though loss through natural erosion accepted as part of postglacial landscape adjustment as long as erosion is not artificially accelerated. (Consent for extraction may exceptionally be given).	Annual visits; check new aerial photographs as they become available. Comparative ground photography. Impacts of consented PDOs must be specifically monitored.
2. Composition	Maintenance of existing range of landform types and clarity of expression of some or all of the following components: longitudinal morainic forms (eg drumlinised and fluted till); sheets and patches of lodgement, deformation and melt-out till with no surface expression; transverse morainic forms (eg Rogen and De Geer moraines); eskers and associated meltwater landforms.	As for 1. No regrading of slopes, ditching or ploughing	As for 1. Check inventory every 5 years. Ground photography to record damage only.
3. Structure	As for 1 and 2 paying particular attention to location and clarity of exposed sections.	As for 1 and 2	As for 1 and 2
4. Visibility	Site composition and structure is well-displayed from distant viewpoint and/or from the air.	Succession from existing vegetation should not be encouraged. No planting of trees. No building of structures on site which will obscure landforms. Light, temporary structures without deep foundations possible acceptable.	As for 1

Type of site: **SUBGLACIAL DEPOSITIONAL LANDFORMS**

Site attributes	Favourable condition	Limits of Acceptable Change	Monitoring Prescription
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowners/tenants: some seasonal restrictions may be acceptable.	Check access status annually.

Table 29: Site Attributes Table (fluvial and glaciofluvial terraces)

Type of site: **FLUVIAL AND GLACIOFLUVIAL TERRACES**

Site attributes	Favourable condition	Limits of Acceptable Change	Monitoring Prescription
1. Physical attributes and morphology	Maintenance of all erosional and depositional evidence of construction of former river floodplain or outwash terrace (terrace treads and risers, palaeochannels, kettle holes).	No removal or quarrying of sediment directly related to construction of terrace treads, risers, palaeochannels, or kettle holes.	Site visit once per year. Inspection of site from aerial photographs as they become available. Comparative annual ground photography.
2. Composition	Existing components maintained in terms of areal extent and range of landforms. These may include terrace risers, terrace treads, palaeochannels and kettle holes.	No removal or quarrying of sediment directly related to construction of terrace treads, risers, palaeochannels, or kettle holes. No regrading of slopes, ditching or ploughing.	Site visit once per year. Inspection of site from aerial photographs as they become available. Check inventory of individual landform components every five years.
3. Structure	Maintenance of structural relationship between individual landform components enabling history of site to be reconstructed.	No removal or quarrying of sediment directly related to construction of terrace treads, risers, palaeochannels, or kettle holes. No regrading of slopes, ditching or ploughing.	Site visit once per year
4. Visibility	Site composition and structure well-displayed from distant viewpoint and/or from the air	Succession from existing vegetation cover should not be encouraged. No planting of trees. No building of structures on site which will obscure the individual landforms. Light temporary structures without foundations possibly acceptable.	Visual inspection of site once per year
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site once per year.

Table30: Site Attributes Table (relict alluvial fan)

Type of site: **RELICT ALLUVIAL FAN**

Site attributes	Favourable condition	Limits of acceptable change	Monitoring prescription
1. Physical attributes and morphology	Maintenance of all erosional and depositional evidence of construction of former alluvial fan (alluvial surfaces, palaeochannels, risers and treads if fan trenched, kettleholes).	No removal or quarrying of sediment directly related to construction of fan (alluvial surfaces, palaeochannels, risers and treads or kettleholes).	Site visit once per year. Inspection of site from aerial photographs as they become available. Comparative annual ground photography.
2. Composition	Existing components maintained in terms of present areal extent and range of landforms. These may include fan surface, risers and treads, palaeochannels and kettleholes.	No removal or quarrying of sediment directly related to construction of fan (alluvial surfaces, palaeochannels, risers and treads or kettleholes). No regrading of slopes, ditching or ploughing.	Site visit once per year. Inspection of site from aerial photographs as they become available. Check inventory of individual landform components as they become available every five years.
3. Structure	Maintenance of structural relationship between individual landform components enabling history of site to be reconstructed.	No removal or quarrying of sediment directly related to construction of fan (alluvial surfaces, palaeochannels, risers and treads or kettleholes). No regrading of slopes, ditching or ploughing.	Visual inspection of site once per year
4. Visibility	Site composition and structure well-displayed from distant viewpoint and/or from the air	Succession from existing vegetation cover should not be encouraged. No planting of trees. No building of structures on site which will obscure the individual landforms. Light temporary structures without foundations possibly acceptable.	Visual inspection of site once per year
5. Accessibility	Access permitting all individual landform components to be observed and measured.	Access by arrangement with landowner/tenants; some seasonal restrictions may be acceptable.	Visual inspection of site once per year.

6. DISCUSSION AND CONCLUSIONS

This report offers SNH staff a conceptual and methodological framework for monitoring the condition of geomorphological features at specified sites. It also develops guidelines for defining 'favourable condition' and 'limits of acceptable change' for the geomorphological components of the natural heritage. The authors hope that this report will also make a useful contribution to SNH's Inventory and Monitoring Programme which encompasses robust geological and geomorphological features alongside the fragile and ever-changing components found in terrestrial and aquatic ecosystems. The authors have also sought to develop a methodological framework that is broadly consistent with, and sympathetic to, the quest for a common approach to monitoring the natural heritage as developed by the three national agencies and the Joint Nature Conservation Committee.

It has, however, become increasingly clear in compiling this report that the terminology developed for terrestrial and aquatic ecosystems cannot readily be transferred to the realm of the earth sciences. This is especially apparent in the following areas:

(i) Quantitative assessment of geomorphological features (e.g. drumlins, kettle holes, meanders or sand dunes) is exceedingly difficult and of dubious value. This is in marked contrast to assessing appropriate population levels for birds at a specified site, for example.

(ii) Sometimes a geomorphological site is designated as a SSSI although it may already be sub-optimal in terms of what might ideally be defined as 'favourable condition'. Thus many of Scotland's rivers have been subject to human interference and engineering over decades, if not centuries. Restoring them fully to a pristine, natural condition is both unrealistic and, in the short term, often unachievable. Nevertheless, a good case can often be made for retaining and steadily upgrading the quality of the natural features that are present on the site.

(iii) In a few special cases (e.g. stratigraphic sections) natural processes of erosion can, if left uncontrolled, result in damage and ultimately the destruction of a protected geomorphological feature. In such a situation, some intervention by SNH staff may be thought appropriate.

(iv) The concept of maximum site area (of great value for many terrestrial and aquatic ecosystems) is often rather notional for geomorphological sites, especially those which only include relict landforms. In this situation, where the formative processes are no longer operative, the site achieved its maximum area in the recent or distant past, and can now only suffer depletion by natural erosion or human interference.

(v) The entries in the Site Attributes Tables for active geomorphological sites (fluvial and coastal) have followed quite closely the quality-based typology of Noss (1990). Thus 'physical attributes and morphology', 'processes and dynamics', 'composition', 'structure', 'function', visibility' and 'accessibility' are readily applied to active fluvial and coastal environments. However, when one turns to relict landform assemblages, this list reduces to 'physical attributes and morphology', 'composition', 'structure', visibility' and 'accessibility', since neither 'process' nor 'function' have any relevance.

These reservations imply a need to be flexible in developing and applying monitoring systems to natural heritage features. No one scheme is likely to provide optimal criteria for all features found across all protected sites.

In compiling the Site Attributes Tables, the authors have been aware of the need to be both rigorous and realistic in terms of the resources likely to be available to SNH staff. Much of the monitoring can be undertaken via regular site visits and careful inspection and ground-based photography of the relevant geomorphological features. However, for some of the active sites, specially-commissioned aerial photography will be required and specialist analysis of sedimentological and hydrological date undertaken. Although we have not formally ranked the attributes in the Site Attributes Tables, it is clear to the authors that attributes 1-5 (active landforms) and 1-3 (relict landforms) should have priority in terms of the potential scientific and conservation value of sites.

It will be apparent to the specialist reader of this report that the authors have not been able to achieve complete consistency in approach across all the Site Attributes Tables for fluvial, coastal and relict landform systems. This has arisen because of contrasting starting points for different parts of this report. In the case of the fluvial systems, it was possible to draw upon the GCR volume *The Fluvial Geomorphology of Great Britain* (Gregory, 1997) which provided a wealth of information in compiling Site Attributes Tables. It even proved possible to develop contrasting monitoring strategies for different assemblages of active fluvial landforms. By contrast, accounts of the coastal systems of Scotland have yet to be published in a GCR volume. As a result the resulting Site Attributes Tables produced in this report for coasts typically define landform systems which contain a great diversity of individual landforms and landform assemblages. The approach to monitoring such complex systems is inevitably more broad brush than that which was possible to develop for fluvial systems. Relict landform systems (the majority of which relate to former cold-climate environments) are accorded a treatment somewhere between that for fluvial and coastal systems. This reflects the fact that a companion GCR volume does exist (*The Quaternary of Scotland*, Gordon and Sutherland, 1993), but many of the individual sites in that volume had to be aggregated into composite categories (e.g. stratigraphic sections, relict ice-marginal lakes) before they could be presented in Site Attribute Tables.

As with any research report, one ends asking as many questions as when one began. The authors of this report have indeed learnt a great deal about the difficulties of developing scientifically sound methods for monitoring the rich diversity of landforms to be found throughout Scotland. Nonetheless, it is hoped that this report provides a firm foundation upon which such monitoring can now be undertaken by SNH staff.

7. REFERENCES

Acreman, M. C. 1991. The flood of July 25th 1983 on the Hermitage Water, Roxburghshire. *Scottish Geographical Magazine*, **107**, 170-78.

Ballantyne, C. K. 1989. The Loch Lomond Readvance on the Isle of Skye, Scotland; glacier reconstruction and climatic implications. *Journal of Quaternary Science* **4**, 95-108.

Ballantyne, C. K. 1991. Holocene geomorphic activity in the Scottish Highlands. *Scottish Geographical Magazine*, **107**, 84-98.

Baker, V. R. 1977. Stream channel response to floods, with examples from Central Texas. *Bulletin of the Geological Society of America*, **88**, 1057-71.

Brazier, V., Kirkbride, M. P. and Werritty, A. 1993. Scottish landform examples: the R. Clyde-Medwin Water meanders. *Scottish Geographical Magazine*, **109**, 45-49.

Brazier, V. and Werritty A. 1994. Conservation management of dynamic rivers: the case of the River Feshie, Scotland. In: O'Halloran, D., Green, C., Harley, M., Stanley, M. and Knill, J. (Eds), *Geological and Landscape Conservation*. Geological Society of London, London, 147-52.

Bridge, J. S. and Jarvis, J. 1997. Velocity profiles and bed shear stress over various bed configurations in a river bend. *Earth Surface Processes*, **2**, 281-294.

Carson, M. A. and Griffiths, G. A. 1987. Bedload transport in gravel channels. *Journal of Hydrology (NZ)*, **26**, 1-151.

Chappell, J. 1983. Thresholds and lags in geomorphic changes. *Australian Geographer*, **15**, 357-66.

Coates, D. R. and Vitek, J. D. 1980. Perspectives on geomorphic thresholds. In: Coates, D. R. and Vitek, J. D. (Eds), *Thresholds in Geomorphology*. George Allen & Unwin, London, 3-23.

Costa, J. E. 1974. Response and recovery of a piedmont watershed from tropical storm Agnes. *Water Resources Research*, **10**, 106-112.

Ecoscope Applied Ecologists 1996. *Generic Guidelines for HSD & Birds Directive*. Unpublished Second Stage Report to Scottish Natural Heritage, Contract No. F71-12-408.

Eyles, N. 1983. *Glacial Geology: An Introduction for Engineers and Earth Scientists*. Pergamon Press, Oxford.

Ferguson, R. I. 1981. Channel forms and channel changes. In: Lewin, J. (Ed), *British Rivers*. George Allen and Unwin, London, 90-125.

Ferguson, R. I. 1987. Hydraulic and sedimentary controls of channel pattern. In: Richards, K. S. (Ed), *River channels: environment and process*. Blackwells, Oxford, 129-158.

Ferguson, R. I. and Werritty, A. 1983. Bar development and channel changes in the gravelly River Feshie, Scotland. In: Collinson, J. D. and Lewin, J. (Eds), *Modern and Ancient Fluvial Systems*. Special Publication 6 of the International Association of Sedimentologists, 181-193.

Ferguson, R. I. and Ashworth, P. 1990. Slope-induced changes in channel character along a gravel-bed stream: the Allt Dubhaig, Scotland. *Earth Surface Processes and Landforms*, **16**, 65-82.

Ferguson, R. I., Hoey, T. B., Wathen, S. and Werritty, A. 1996. Field evidence for rapid downstream fining of river gravels through selective transport. *Geology*, **24**, 179-182.

Galvin, C. J. 1990. Wave breaking in shallow water. In: Meyer, R. E. (Ed.), *Waves on Beaches and Resulting Sediment Transport*. Academic Press, London, 413-456.

Gilvear, D. J. and Winterbottom, S. J. 1992. Channel change and flood events since 1783 on the regulated River Tay, Scotland: implications for flood hazard management. *Regulated Rivers: Research and Management*, 7, 247-260.

Glasser, N. F. 1995. Modelling the effects of topography on ice sheet erosion, Scotland. *Geografiska Annaler* 77**A**, 67-82.

Gordon, J. E. and Sutherland, D.G. 1993. T*he Quaternary of Scotland*. Geological Conservation Review Series. Chapman and Hall, London.

Gregory, K. J. 1997. *Fluvial Geomorphology of Great Britain*. Geological Conservation Review Series. Chapman and Hall, London.

Harvey, A. M. 1986. Geomorphic effects of a 100-year storm in the Howgill Fells, Northwest England. *Zeitschrift für Geomorphologie*, **30**, 71-91.

Hoey, T. B. and Ferguson, R. I. 1994. Numerical simulation of downstream fining by selective transport in gravel-bed rivers: model development and illustration. *Water Resources Research*, **30**, 2251-2260.

Hoey, T. B., Smart, D. W. J., Pender, G. and Metcalfe, N. 1995. *Alternative Methods of River Management for Scottish Rivers*. Report to Scottish Natural Heritage.

HR Wallingford 1997. Coastal Cells in Scotland. *Scottish Natural Heritage Research Survey and Monitoring Report*, No. 56.

Knighton, D. 1984. *Fluvial forms and processes*. Arnold, London.

Leeks, G. J. L. 1992. Impact of plantation forestry on sediment transport processes. In: Billi, P., Hey, R. B., Thorne, C. E., and Tacconi, P. (Eds), *Dynamics of Gravel-bed Rivers.* Wiley, Chichester, 651-668.

Lewin, J. and Weir, M. J. C. 1977. Morphology and recent history on the lower Spey. *Scottish Geographical Magazine*, **93**, 45-51.

Lewin, J. and Macklin, M. G. 1987. Metal mining and floodplain sedimentation in Britain. In: Gardiner, V. (Ed.), *International Geomorphology.* (Part 1). Wiley, Chichester, 1009-1027.

Leys, K. F. 1997. *The geomorphic sensitivity of selected gravel-bed rivers in Scotland over the last 150 year*. Unpublished PhD thesis, University of Dundee.

Macklin, M. G. and Lewin, J. 1989. Sediment transfer and transformation of an alluvial valley floor, the River South Tyne, Northumbria, UK. *Earth Surface Processes and Landforms*, **14**, 233-246.

Maizels, J. K. 1983. Channel changes, palaeohydrology and deglaciation: evidence from some Lateglacial sandur deposits of north-east Scotland. *Quaternary Studies in Poland*, **4**, 171-187.

McCall, S. and Devoy, R. J. 1995. Application of Geographic Information Systems to Coastal Management: Approaches in Ireland. In: Healy, M. G. and Doody, J. P. (Eds), *Directions in European Coastal Management.* Samara Publishing Limited, Cardigan, 235-242.

McEwen, L. J. 1986. *River channel planform changes in upland Scotland with specific reference to climatic fluctuations and landuse changes over the last 250 years.* Unpublished PhD thesis, University of St Andrews.

McEwen, L. J. and Werritty, A. 1988. The hydrology and long-term geomorphic significance of a flash flood in the Cairngorm Mountains, Scotland. *Catena*, **15**, 361-377.

Ministry of Agriculture, Fisheries and Food, The Welsh Office, Association of District Councils, English Nature, National Rivers Authority 1995. *Shoreline Management Plans. A Guide for Coastal Defence Authorities.* 24 pp.

Newson, M. D. 1992. Geomorphic thresholds in gravel-bed rivers: refinement for an era of environmental change. In: Billi, P., Hey, R. B., Thorne, C. E. and Tacconi, P. (Eds), *Dynamics of Gravel-bed Rivers.* Wiley, Chichester, 3-15.

Newson, M. D. and Macklin, M. G. 1990. The geomorphologically-effective flood and vertical instability in river channels. In: White, W. R. (Ed), *Flood hydraulics.* Wiley, Chichester, 123-140.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, **4**, 355-364.

Roberts, C. R. 1989. Flood frequency and urban-induced channel change: some British examples. In: Beven, K. and Carling, P. A. (Eds), *Floods: Hydrological, Sedimentological and Geomorphological Implications*. Wiley, Chichester, 57-82.

Robinson, M. 1980. *The effect of pre-afforestation drainage on the stream flow and water quality of a small upland catchment.* Institute of Hydrology Report 73, Wallingford.

Schumm, S. A. 1973. Geomorphic thresholds and the complex response of drainage systems. In: Morisawa, M. (Ed.), *Fluvial geomorphology.* State University of New York, Binghampton, 299-310.

Schumm, S. A. 1977. *The Fluvial System*. Wiley, New York.

Schumm, S.A. 1980. Some application of the concept of geomorphic thresholds. In: Coates, D. R. and Vitek, J. D. (Eds), *Thresholds in Geomorphology.* George Allen & Unwin, London, 473-485.

Schumm, S. A. 1991. *To Interpret the Earth: Ten Ways to be Wrong.* Cambridge University Press, Cambridge.

Scottish Natural Heritage 1995. *The Natural Heritage of Scotland: an overview.* SNH Publications and Design, Edinburgh.

Selby, M. J. 1974. Dominant geomorphic events in landform evolution. *Bulletin of the International Association of Engineering Geology*, **9**, 85-89.

Sharp, M., Dowdeswell, J. A. and Gemmell, J. C. 1989. Reconstructing past glacier dynamics and erosion from glacial geomorphic evidence: Snowdon, North Wales. *Journal of Quaternary Science,* **4**, 115-130.

Starkel, L. 1976. The role of extreme (catastrophic) meteorological events in the contemporary evolution of slopes. In: Derbyshire, E. (Ed.), *Geomorphology and Climate.* Wiley, Chichester, 203-24,

Starkel, L. 1983. The reflection of hydrological changes in the fluvial environment of the temperate zone during the last 15,000 years. In: Gregory, K. J. (Ed.), *Background to Palaeohydrology.* Wiley, Chichester, 213-55.

Stott, T. A., Ferguson, R. I., Johnson, R. C. and Newson, M. D. 1987. Sediment budgets in forested and non-forested basins in upland Scotland. In: Hadley, R. F. (Ed), *Drainage Basin Sediment Delivery.* International Association of Scientific Hydrology, Publication 159, 57-68.

Sugden, D. E., Glasser, N. F. and Clapperton, C. M. 1992. Evolution of large roches moutonées. *Geografiska Annaler,* **74A**, 253-264.

Walling, D. E. 1979. The hydrological impact of building activity: a case study near Exeter. In: Hollis, G. E. (Ed.), *Man's Impact on the Hydrological Cycle in the UK*. Geo-books, Norwich, 135-51.

Warner, R. 1987. Spatial adjustments to temporal variations in flood regime in some Australian rivers. In: Richards, K. S. (Ed), *River Channels: Environment and Process*. Blackwells, Oxford, 14-40.

Wathen, S. J. 1996. *The effect of storage upon sediment transfer processes in a small Scottish gravel-bed river*. Unpublished PhD thesis, University of St Andrews.

Wells, S. G. and Harvey, A.M. 1987. Sedimentologic and geomorphic variations in storm-generated alluvial fans, Howgill Fells, northwest England. *Bulletin of the Geological Society of America*, **98**, 182-198.

Werritty, A. 1984. Stream response to flash floods in upland Scotland. In: Burt, T. P. and Walling, D. E. (Eds), *Catchment Experiments in Fluvial Geomorphology*. Geo-books, Norwich, 537-60.

Werritty, A. 1995. Integrated Catchment Management: a review and evaluation. *Scottish Natural Heritage Review*, No. 58, 70p.

Werritty, A. and Brazier, V. 1991. *The Geomorphology, Conservation and Management of the River Feshie SSSI.* Report to the Nature Conservancy Council, Peterborough.

Werritty, A. and Brazier, V. 1994. Geomorphic sensitivity and the conservation of fluvial geomorphology SSSIs. In: Stevens, C., Green, C. P., Gordon, J. E. and Macklin, M. G. (Eds), *Conserving Our Landscape: Evolving Landforms and Ice-age Heritage*. Peterborough, 100-109.

Werritty, A. and Ferguson, R. I. 1981. Pattern changes in a Scottish braided river over 1, 30 and 200 years. In: Cullingford, R. A., Davidson, D. A. and Lewin, J. (Eds.) *Timescales in geomorphology*. Wiley, Chichester, 53-68.

Werritty, A. and McEwen, L. J. 1997. Fluvial geomorphology of Scotland. In: Gregory, K. J. (Ed.), *Fluvial geomorphology of Great Britain*. Geological Conservation Review Series. Chapman and Hall, London, 21-32.

Werritty, A. Harper, F. and Burns, J. C. 1993. Rainfall and runoff response in the Loch Dee sub-catchments. In: Lees, F. M. (Ed.), *Acidification, Forestry and Fisheries Management in Upland Galloway*. Proceedings of the Loch Dee Symposium. Foundation for Water Research, Marlow, 13-21

Werritty, A., Brazier, V., Gordon, J. E. and McManus, J. 1994. Geomorphology. In: Maitland, P. S., Boon, P. J. and McLusky, D. S. (Eds), *The Fresh Waters of Scotland: A National Resource of International Significance*. Wiley, Chichester, 65-88.

Whittington, G. 1996. *Fragile Environments. The Use and Management of Tentsmuir NNR, Fife*. Scottish Cultural Press.

Williams, G. P. 1978. Bankfull discharge of rivers. *Water Resources Research*, **14**, 1141-58.

Wolman, M. G. 1967. A cycle of sedimentation and erosion in urban river channels. *Geografiska Annaler*, **49A**, 385-95.

Wolman, M. G. and Miller, J. P. 1960. Magnitude and frequency of geomorphic processes. *Journal of Geology*, **68**, 54-74.

Wolman, M. G. and Schick, A. P. 1967. Effects of construction on fluvial sediment, urban and suburban areas of Maryland. *Water Resources Research*, **3**, 117-25.

Wolman, M. G. and Gerson, R. 1978. Relative scales of time and effectiveness in watershed geomorphology. *Earth Surface Processes*, **3**, 189-208.

Scottish Natural Heritage

Scottish Natural Heritage is an independent body established by Parliament in 1992, responsible to the Secretary of State for Scotland.

Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, the habitats, the landscapes and the seascapes - which has evolved through the long partnership between people and nature.

We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people to enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.