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AN INTRODUCTION TO PHYSICAL GEOGRAPHY AND ENVIRONMENTAL SYSTEMS

by

Richard Whitlow
Associate Professor, Department of Geography,
University of Witwatersrand, South Africa

INTRODUCTION

The objectives of this paper are first, to outline the nature and development of physical geography; second, to introduce the systems concept and a scheme of classifying environmental systems; third to illustrate some of the complexities of such systems by way of examples, and fourth, to describe some key concepts related to the behaviour of environmental systems.

Physical geography is regarded sometimes as an **earth science**. If one accepts that the discipline is a science, then what precisely is it that scientists do? Assembly of facts about the world we live in is clearly an important facet of scientific work, but to do this scientists normally begin with posing questions. Indeed, science is more about **asking questions** than collecting data, since if we don't ask the right kinds of questions then we will not gather information that will be of great use to us in understanding the world around us and ultimately, in managing the world more effectively. Such questions may be presented as hypotheses, or statements about the nature and relationships of phenomena. For example, 'as slope angle increases so the depth of soil decreases', or 'the rate of soil loss on a slope is a function of slope angle and length'. These statements then serve as the **guidelines** to determine what data is required to evaluate the propositions concerned with soils, slopes and erosion, and how these data might be analysed (Harvey, 1969).

At a general level, the questions that scientists ask can be grouped into **five categories** as follows:

- WHAT questions? – concerned with the classifications and properties of phenomena;
- WHERE questions? – concerned with locations of phenomena;
- WHEN questions? – concerned with the temporal incidence of phenomena;
- WHY questions? – concerned with the cause-effect type of relationships of phenomena; and
- HOW questions? – concerned with the dynamics or processes of phenomena.

The first three questions are essentially DESCRIPTIVE and, generally, come in the early stages of an investigation. Although they are important, they don't give us much information about the actual behaviour of systems. It is the 'why' and 'how' questions that lead to EXPLANATION of the ways in which phenomena function and change. Ultimately, such questions should lead towards the PREDICTION of future states of phenomena. These, then, are the **roots** of what science is all about - asking questions and collecting appropriate data to answer those questions in a reasonably systematic and rigorous manner.

THE NATURE AND DEVELOPMENT OF PHYSICAL GEOGRAPHY

The main focus of physical geography is the study of the structure and functions of environmental systems and the interactions of man's activities with such systems (Gregory and Walling, 1986). Whilst geography is often divided into physical and human geography with their respective links with the earth sciences and social sciences, there is a great deal in common between the two disciplines that brings them together in a complementary manner, including the concern with man-environment relationships, the study of spatial patterns and analytical techniques, notably the extensive use of maps as data sources and a means of presentation of information.

However, as specialisation has occurred in the two disciplines so there has been a tendency for practitioners of physical and human geography to have less and less in common. Chorley (1971) has likened the position of the physical geographer to that of a 'tight-rope walker attempting to walk simultaneously on two ropes which are becoming more and more separated' (p.89). The two ropes that Chorley refers to are the **teaching inputs** into mainstream undergraduate programmes that are dominated by human geography subjects and the **research commitments** of physical geographers within the earth sciences. In some institutions the 'two ropes' have widened to such an extent that the two branches of geography are no longer linked and may even be housed in separate faculties.

Against this background, the following are examined here:

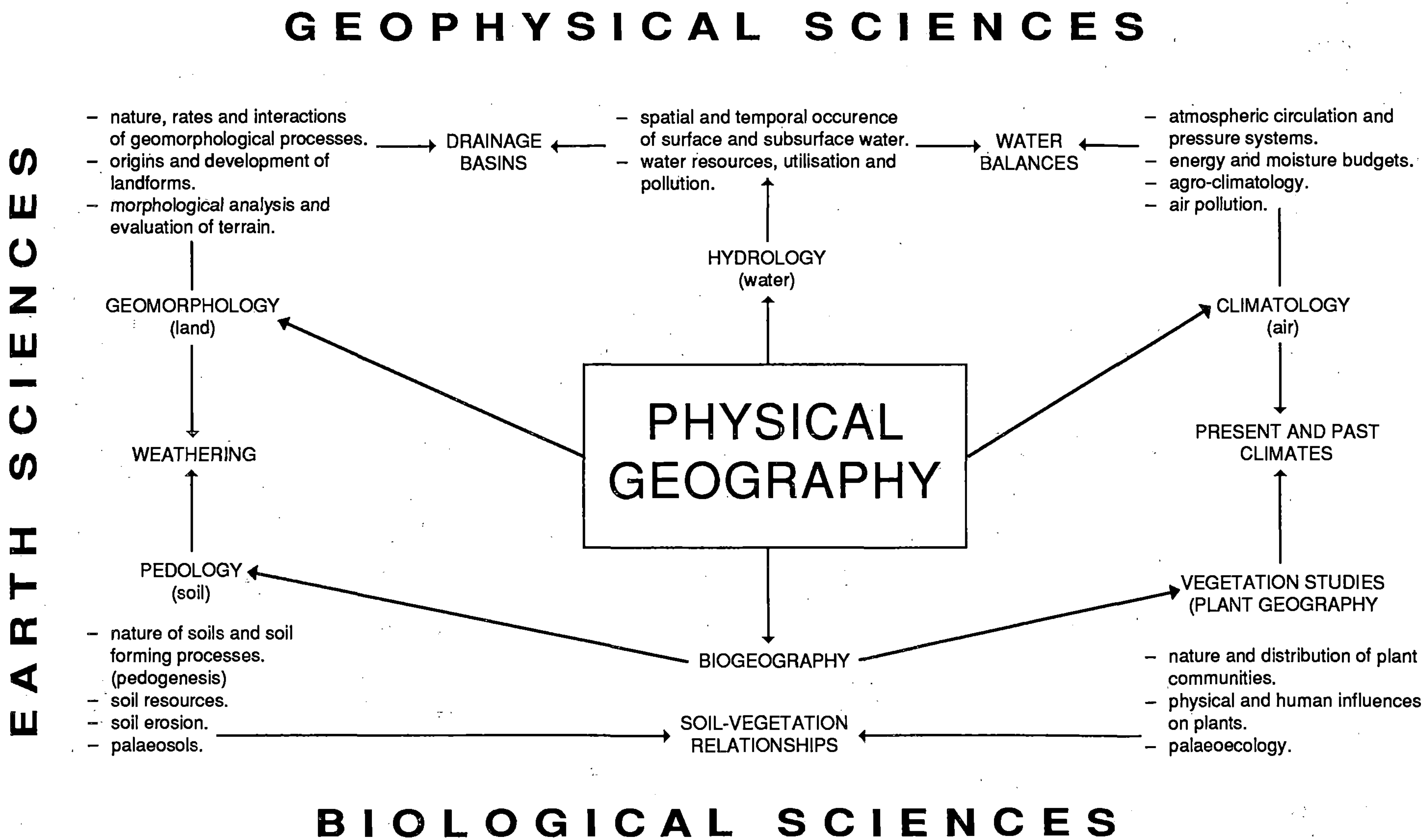
- the structure of physical geography; and
- the development of physical geography.

The Structure of Physical Geography

The main sub-disciplines within physical geography include geomorphology (the dominant field in terms of numbers of professional geographers and, in some cases, regarded as an independent discipline in its own right or linked with geology rather than geography), climatology, hydrology, soils geography and biogeography. Effectively these sub-disciplines cover the study of land, atmosphere, water, soils and the biosphere (plants and animals). The main areas of interest in each of these areas of study are summarised in Figure 1. Within each of the various sub-disciplines one could list specialist fields such as fluvial and arid geomorphology in geomorphology, aspects of which have been reviewed recently by Gregory (1985).

Two points can be illustrated in the context of Figure 1. Firstly, one must recognise the overlap of interests between the various sub-disciplines with, for example, the study of drainage basins having both geomorphological and hydrological inputs (Gregory and Walling, 1974). Secondly, one must be familiar with the external links of the specialist fields. These include EARTH sciences, for geomorphology and soils geography, BIOLOGICAL sciences for biogeography and soils geography, and GEOPHYSICAL sciences for climatology and hydrology. These external links are important insofar as the subject matter of physical geography overlaps with these associated sciences and geographers draw upon, as necessary, the concepts and methods of these sciences. This means, perforce, that physical geographers have to work with a wide-ranging scientific literature in their specialist fields that may have more in common, sometimes, with another science than with other sub-disciplines in physical geography.

Figure 1: The sub-disciplines and academic relations of physical geography



The Development of Physical Geography

It is useful to outline the general development of physical geography so that the current status and growth areas of the discipline can be placed in a historical context (Gregory, 1985). Broadly speaking, physical geography has passed through three major, but by no means discrete, phases since the early 1900s. These can be labelled the landscape evolution phase, the process studies phase and the environmental change phase.

Landscape Evolution Phase: in the early 1900s physical geography was dominated by the Davisian concepts of landscape evolution framed in terms of cycles of erosion (expressed in terms of youth, maturity and old age) on geological time scales. The subject was essentially qualitative, descriptive and took little heed of man's activities impacting upon the physical landscape.

Process Studies Phase: from the early 1950s onwards there was a progressive shift away from general, sometimes rather hypothetical landscape studies towards a concern with the contemporary processes. This necessitated concentrating research on detailed investigation of more localised areas or specific landform features and involved a more quantitative approach in collection and analysis of data in the field and the laboratory. A concern with processes remains an important facet of physical geography today.

Environmental Change Phase: during the late 1960s and 1970s it was recognised that firstly, man's activities had modified physical landscapes and processes, sometimes quite extensively, and secondly, there had been major shifts in climatic conditions that had also affected physical landscapes throughout the world, so that certain features could only be accounted for in terms of past climatic conditions. Consequently, more attention has been given to the environmental impacts of man's activities and Quaternary environmental changes, with particular interest in the last few years in the dynamics and implications of global climatic changes.

Some of the factors that have promoted and assisted in changes in emphasis in physical geography include the following:

- **improvements in environmental data collection.** Extension of facilities to record climatic and hydrological data on a regular, systematic basis, sometimes using automatic recording devices and assisted by satellite imagery, has improved the data available for analysis at local, regional and national scales in some fields of physical geography. Greater, more frequent conventional aerial photographic coverage has also assisted in mapping and monitoring selected features, as illustrated in the national erosion survey of Zimbabwe (Whitlow, 1988); and

- **applications of statistical methods and computers.** As more data were obtained, so there was a need to develop and apply rigorous statistical analyses to evaluate the complex relationships of physical features and processes, a task made easier by the development of powerful computers to store and manipulate large data sets. These also enabled the development of various modelling techniques in physical geography, particularly in geomorphology (Anderson, 1988).

Consequently, today physical geography is a wide-ranging discipline focusing on a variety of research areas and employing a variety of techniques in the study of physical phenomena (Goudie, 1981). Much of the work done by physical geographers, however, has tended to be somewhat empirical or 'case study' oriented and greater attention needs to be devoted now to the development of a coherent theoretical basis and scientific method for the discipline as a whole (Haines-Young and Petch, 1986).

THE SYSTEMS CONCEPT AND CLASSIFYING ENVIRONMENTAL SYSTEMS

Some geographers have advocated that research and teaching should be built around the 'systems concept' and 'systems approach', notably Chorley and Kennedy (1971) and Huggett (1980), the latter citing five main reasons why geographers should do this as follows:

- traditional scientific methods are seemingly not capable of analysing complex systems, whereas 'systems methods' show good prospects in furthering understanding of these;
- the notion of hierarchies of systems enables overcoming the scale problems in geography;
- the framework of 'open systems' can be applied readily in the real world, allowing the identification and analysis of inputs, outputs and processes within systems at different levels of resolution;
- there are possibilities of developing macro-scale theory and law for more complex, higher level systems, not possible with present approaches; and
- the systems theory and terminology would bring geography closer to the natural, physical and engineering disciplines within which systems analysis is well established.

Chorley and Kennedy (1971) present a different case for the adoption of the systems approach, specifically in physical geography. Their case proceeds as follows:

- the 'real world' is **extremely complex**, so that for scientific study it is necessary to
  - (a) select and isolate discrete components of the 'real world'; and
  - (b) examine the characteristics and functions of these components;
- however, the 'real world' is **continuous** so that its components are inter-linked in various ways, thus necessitating a conceptual approach that
  - (a) enables the selection and simplification of key environmental variables; and
  - (b) enables scientist to assess how their 'abstraction of reality' relates to the other components in the 'real world'; that is, providing a framework for sampling and subsequent extrapolation of findings.

In common with Huggett (1980), they also see the 'real world' as comprising 'sets of interlinked systems at various scales and of varying complexity, which are nested into each other to form a systems hierarchy' (Chorley and Kennedy, 1971, p.1).

In practice, the systems approach has **not** been taken up very widely in physical geography, partly because of the difficulties in defining and modelling more complex systems (although one could argue that this is precisely where the systems approach might allow progress) and partly because of the mathematical formulations needed to examine such systems. Whilst the approach may not be accepted and practised widely, there are many useful ideas embodied in the systems approach that all physical geographers should be aware of in their environmental studies. Aspects of these are outlined here with respect to classification of environmental systems and, in the next section of this paper, by means of examples of selected systems.

Before presenting the systems classification proposed by Chorley and Kennedy (1971), it is pertinent to raise the question '**Why should scientists wish to classify?**'. A simple response to this is as follows:

- classification provides for the grouping together of similar features and/or systems;
- classification provides a framework for systematic description of the general properties and functions of features and/or systems; and
- classification provides a reference for the extrapolation of results gained from the study of specific cases to general cases and/or application of knowledge gained in one area to another similar area.

Classification is often the **starting point** of a scientific investigation.

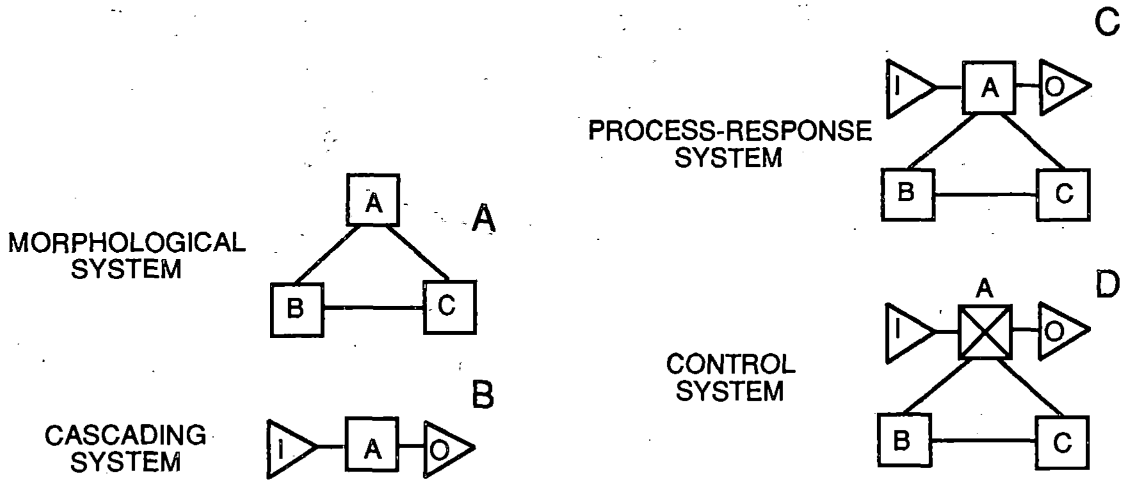
In theoretical terms a system can be defined as '**a set of interrelated parts**'. That is, a given system has specific components that are linked to each other in various ways. A system could be 'isolated', as might occur in a laboratory experiment, or 'closed', meaning that it neither receives inputs nor has outputs of energy and matter. More commonly, environmental scientists deal with what are termed 'open systems', given that no natural entity (e.g. ecosystem or hillslope) is independent of its surroundings. This means, also, that such systems can be modified both by external influences (e.g. climatic changes) and internal influences (e.g. changes in predator-prey population balances or steepening of a hillslope).

Chorley and Kennedy (1971) present a useful scheme for the classification of environmental systems, the main advantages of their scheme being that it is applicable to a variety of different types of environmental systems (i.e. in geomorphology, biogeography etc.) and is applicable at different scales from a micro (local) through to a macro (global) level. It begins with MORPHOLOGICAL SYSTEMS, identifying the main physical components of a given system; then moves on to CASCADING SYSTEMS, to define the inputs, throughputs and outputs of energy and matter in a given system; progresses on to PROCESS-RESPONSE SYSTEMS, to allow an analysis of the dynamics of a given system; and finally, lists CONTROL SYSTEMS, whereby man's activities can be accommodated, in intervening, positively or negatively, in a given system. The specific definitions given by Chorley and Kennedy (1971) for each of these different types of system are as follows:

- **Morphological systems** comprise 'a network of structural relationships between the constituent parts of a system' (p.3); that is, the study of *forms*;
- **Cascading systems** are 'defined by the path(s) followed by the throughputs of energy and mass' (p.3); that is, the study of *processes*;
- **Process-response systems** 'represent the linkage of at least one morphological and one cascading system, so that the process-response system demonstrates the manner in which *form* is related to *process*' (p.3);
- **Control systems** are 'process-response systems in which the key components are controlled by some intelligence' (p.4), specifically man's activities in attempting to manipulate environmental systems to his own advantage by modifying their *forms* and *processes*.

A diagrammatic representation of these four types of system is given in Figure 2.

Figure 2: The four main types of environmental systems defined by Chorley and Kennedy (1971)



After Chorley and Kennedy (1971), p.4.

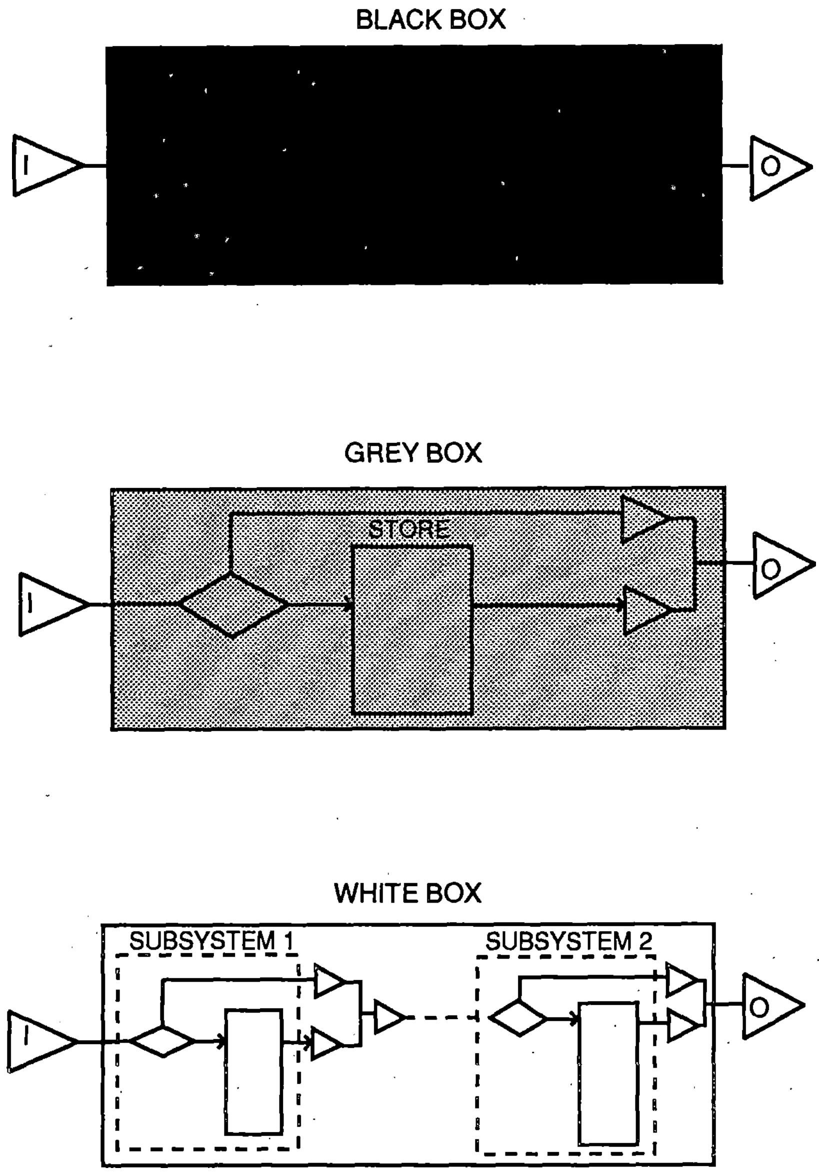
Typically, a geographical investigation of a given environmental system will begin by looking at the morphology of features (e.g. slope form and inclination), including spatial patterns, followed by identification of the rates and magnitudes of movements of materials (e.g. soil transported down a slope). This may be followed by the study of how processes modify forms (e.g. greater runoff with removal of plant cover, resulting in accelerated soil loss and changes in slope forms). In turn, this may proceed into ways in which man can intervene to reduce erosion by, for example, construction of contour banks to slow down runoff. Thus, there is a **progressive accumulation of knowledge** about the nature and functions of environmental systems as one proceeds from the morphological through to the control systems.

Another way of viewing the progressive improvement in our understanding of the nature and dynamics of environmental systems is in terms of **black box, grey box and white box systems** (Figure 3), a scheme defined in terms of cascading systems but applicable also to the other types of systems (Chorley and Kennedy, 1971). A black box system is one in which the major inputs and associated outputs are the focus of attention, with no attempt to determine what actually happens within the system to regulate the magnitude and timing of the outputs. A grey box system is one in which at least some of the key features and processes within the system are examined to obtain a better understanding of the internal operations of the system and so be able to determine more precisely the outputs. A white box system is one in which an attempt is made to identify, quantify and analyse as many of the components of the system as possible, so improving further on our levels of understanding of given systems.

EXAMPLES OF ENVIRONMENTAL SYSTEMS

When physical geographers study environmental systems they normally have to select the key elements and processes within those systems, a task that may be framed in terms of Chorley and Kennedy's (1971) scheme presented earlier but not necessarily so. The aim here is to outline some examples of environmental systems, illustrating their main features and functions as appropriate. The examples described include slope systems, erosion systems and hydrological systems.

Figure 3: Black box, grey box and white box systems



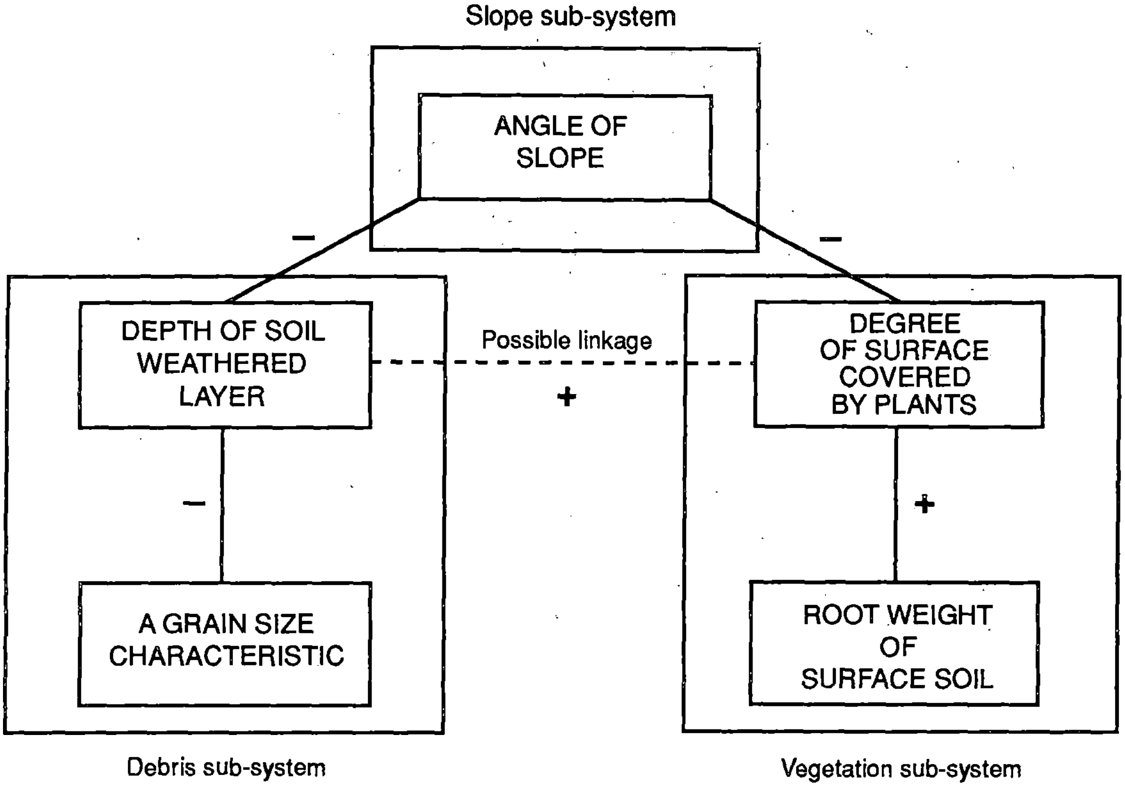
After Chorley and Kennedy (1971), p.8.

Slope systems

The basic units of all landscapes are slopes, hence these have attracted a great deal of attention from geomorphologists (e.g. Young, 1972; Selby, 1982). Clearly, the forms of, and the processes operating upon, hillslopes are extremely varied on different bedrock types and under different climatic conditions.

At a local level, one can investigate the morphology of slopes in terms of the systems approach outlined earlier. An important morphological property of a hillslope is its inclination or **slope angle**; something that is easy to measure along a transect in the field (Pitty, 1971, appendix on methods). The angle of slope will be influenced by both the nature of the materials on a slope and the plant cover. Thus we can conceptualise a 'slope sub-system', a 'debris sub-system' and a 'vegetation sub-system' whose properties are linked in positive (+) or negative (–) ways (Figure 4).

Figure 4: A simple morphological slope system



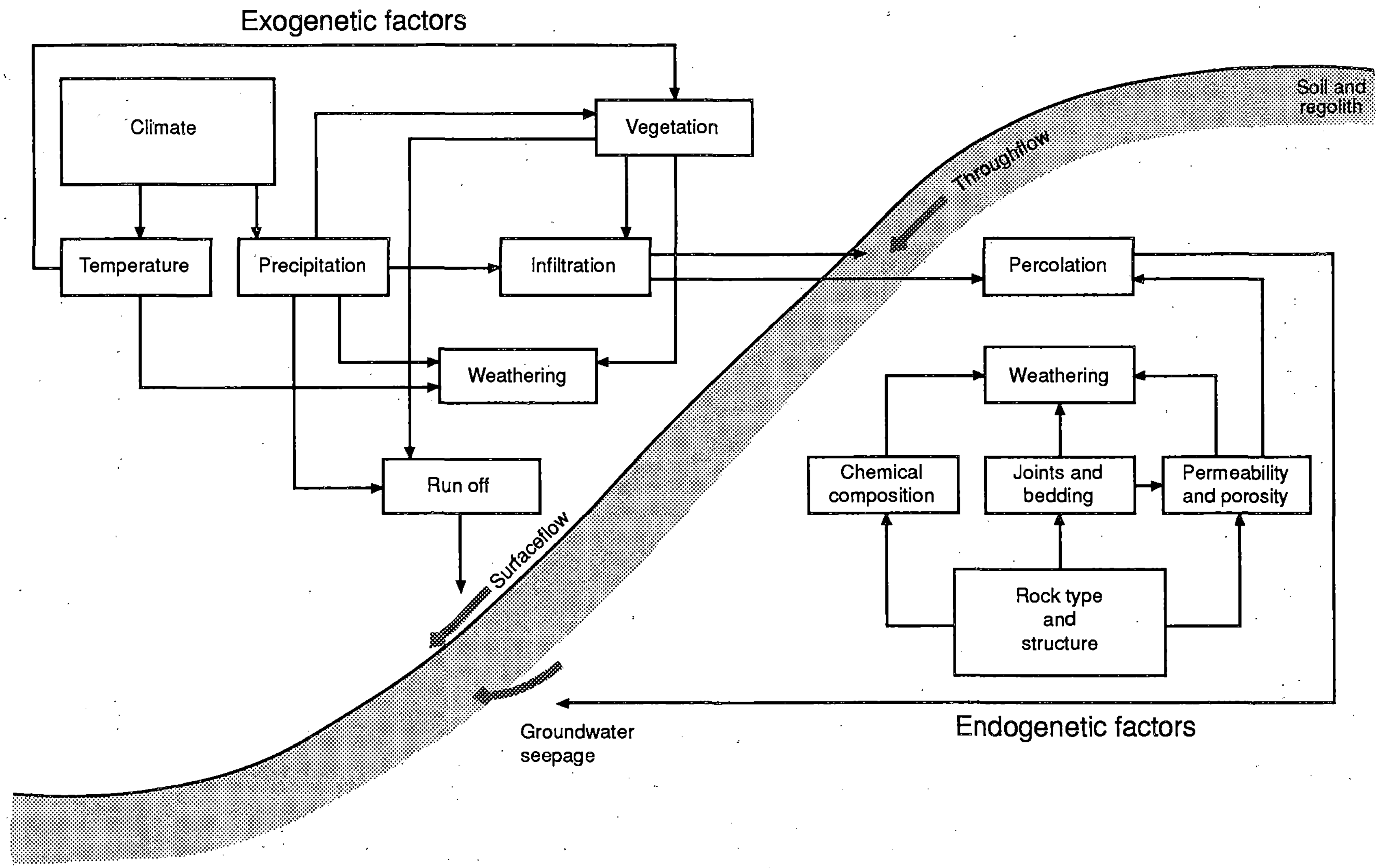
After Chorley and Kennedy (1971), p.65.

For example, the steeper the angle of slope, **generally**, the shallower the depth of the soil weathered mantle, since erosion is likely to be more active on steeper slopes so removing unconsolidated materials. The finer materials are likely to be removed more easily than the coarser ones, hence there is a relationship between depth of material and its grain size characteristics, shown in Figure 4 as a **negative** link to denote that as depth decreases so grain size increases. Similarly, with respect to the vegetation sub-system one might expect steeper slopes to be more sparsely vegetated, partly because the soils on such slopes are shallower and hence supply less moisture and nutrients for plant growth. The denser the plant cover, the greater the density (and weight) of roots in the topsoil hence there is a **positive** relationship of these two parts of the vegetation sub-system (Figure 4). Such relationships could be evaluated by field measurement and statistical analyses.

Clark and Small (1982) have presented a useful **general model** on the nature of slopes emphasising the fact that slopes are 'natural systems within which there are numerous and **complex linkages** between factors, processes and forms' (p.7). Their model of slopes (Figure 5) illustrates several important features of these elements of landscapes including:

- there are close links between the slope system and other natural systems, notably the **climatic system**, which influences weathering and movements of materials on slopes, and the **channel system**, which influences the balance between the removal and accumulation of debris on basal slopes;
- slope morphology and processes are the product of the interactions of external or EXOGENETIC factors, these comprising the climatic, hydrological and

Figure 5: A general model of a slope system



After Clark and Small (1982), p.6.

vegetation factors, and the internal or ENDOGENETIC factors, including bedrock type and regolith properties and processes of weathering and water movement in these materials;

- changes in the balance and intensity of processes affecting slopes may be brought about by **changes in the exogenetic factors**; for example, a reduction in rainfall leads to less plant cover so increasing erosion on slopes; in turn, this may increase slope angle and reduction of regolith depth;
- sometimes the prevailing exogenetic factors may **not** be those responsible for the morphology of slopes; that is, slope forms may be related to past environmental conditions and as such the slope forms are **'relic features'**; and
- given the complexity of the slope system, one cannot expect to find **simple cause-effect** relationships.

Similar arguments could be put forward for other landforms such as bornhardts (Whitlow, 1983a) and micro-scale features on such hills (Twidale, 1982). It is important in the study of these features that one tries to identify their main components and their inter-relationships at an early stage in the investigation, as outlined here for a slope system.

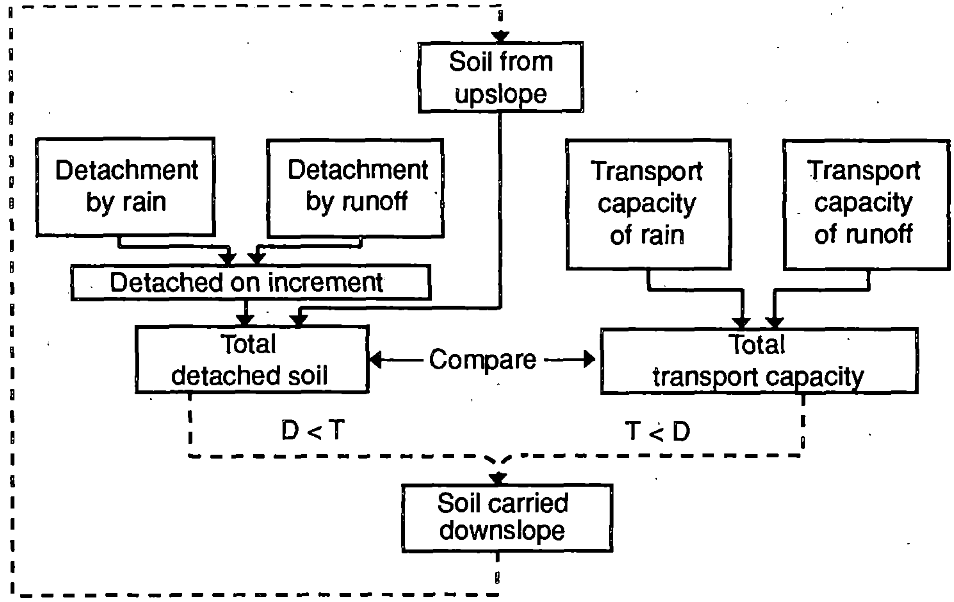
Erosion Systems

Accelerated soil erosion associated with improper utilisation or inadequate protection of arable or grazing lands has attracted the attention of physical geographers. One approach to the study of soil losses on slopes is to develop analytical and predictive models that assist in understanding the physical processes involved and determining the amounts of soil material that might be removed from a given slope. In Zimbabwe this type of research has led to the development of SLEMSA, a soil loss erosion model for Southern Africa (see Whitlow, 1988), a useful tool in conservation design and planning.

At its simplest level, erosion by water (or wind) on a slope can be seen as a function of the balance between the forces of **detachment and transport** (Figure 6). Detachment occurs primarily as a result of raindrop impact on the soil surface, but also by turbulent surface runoff. Both runoff and raindrop impact have the capacity to shift material downslope under the influence of gravity, hence they act as transporting agents as well. If the forces of detachment exceed those of transport, then there will be an accumulation of unconsolidated sediment on the soil surface. If, however, transport capacity exceeds detachment, then any material loosened by raindrops and runoff will be removed downslope. The individual processes of detachment and transport in turn, are influenced by factors such as slope angle, rainfall intensity and runoff amount (Morgan, 1979). Each of these can, and should, be investigated separately, but eventually they have to be examined as a group of processes affecting soil losses as indicated in the simple model outlined here.

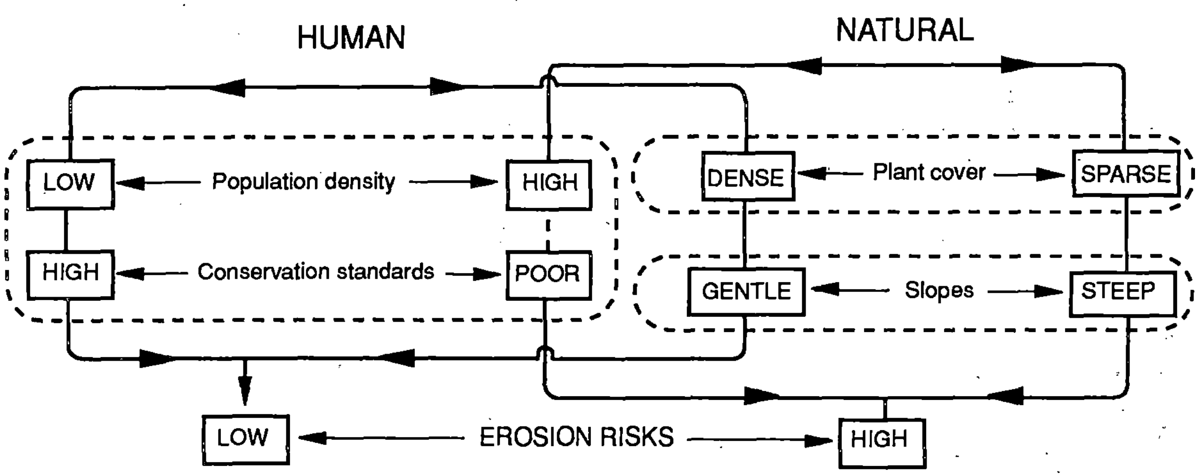
Another approach in the study of soil erosion is to assess the human and physical factors that promote land degradation, as illustrated in the erosion hazards survey of Zimbabwe (Stocking and Elwell, 1973). In the early stages of this study a simple model was devised to highlight what were considered to be the most important human and physical influences on rates of erosion in a given locality (Figure 7). Thus **population density** as a measure of pressure on land, and **conservation standards**, as an indication of how the land was used, were regarded as the most important human factors. The important physical factors at a local scale were seen as being **plant cover**, a measure of the protection of the soil against erosional processes, and **slope**, this influencing the

Figure 6: Soil erosion model in terms of detachment and transport



After Morgan (1979), p.55.

Figure 7: Human and physical factors affecting soil erosion risks in Zimbabwe



potential energy of runoff. At a local scale the factors of **rainfall erosivity**, a measure of the amount of energy of rainfall and related to intensity of precipitation, and **soil erodibility**, a measure of the resistance of soils to erosion and determined by, for example, organic matter content and clay percentage, were seen as constant.

A provisional assessment of erosion risks suggested that the greatest risks of erosion, and hence erosion rates, would be in areas where there was high population density **and** steep slopes (Figure 7). Conversely, the lowest risks of erosion and lowest rates of erosion might be expected in areas where there was low population density, high conservation standards, dense plant cover and gentle slopes. Broadly speaking, in Zimbabwe this defines the general status of erosion in the peasant farmlands, which correspond with the 'high risk' erosion areas and are characterised by widespread, locally severe erosion, as compared to the commercial farmlands where there are 'low risks' of erosion and are characterised by very localised erosion (Whitlow, 1988).

Clearly, however, there are many different combinations and types of physical and human factors that might be taken into account when assessing erosion risks. A 'systems approach' enables one to focus on those that are perhaps more important in a given study and can be measured and/or mapped readily at the scale of the particular investigation.

Hydrological systems

Hydrological systems, whether one is dealing with these on the scales of entire continents, individual drainage basins or slopes, are especially amenable to modelling, being examples of **cascading systems** in terms of Chorley and Kennedy's (1971) scheme. At its simplest level the water budget of a given site, say a small catchment, can be calculated in terms of the main inputs of water, along with any change in storage of water. This can be expressed in a simple equation as follows:

$$P = Q + E \pm \text{differences in } S$$

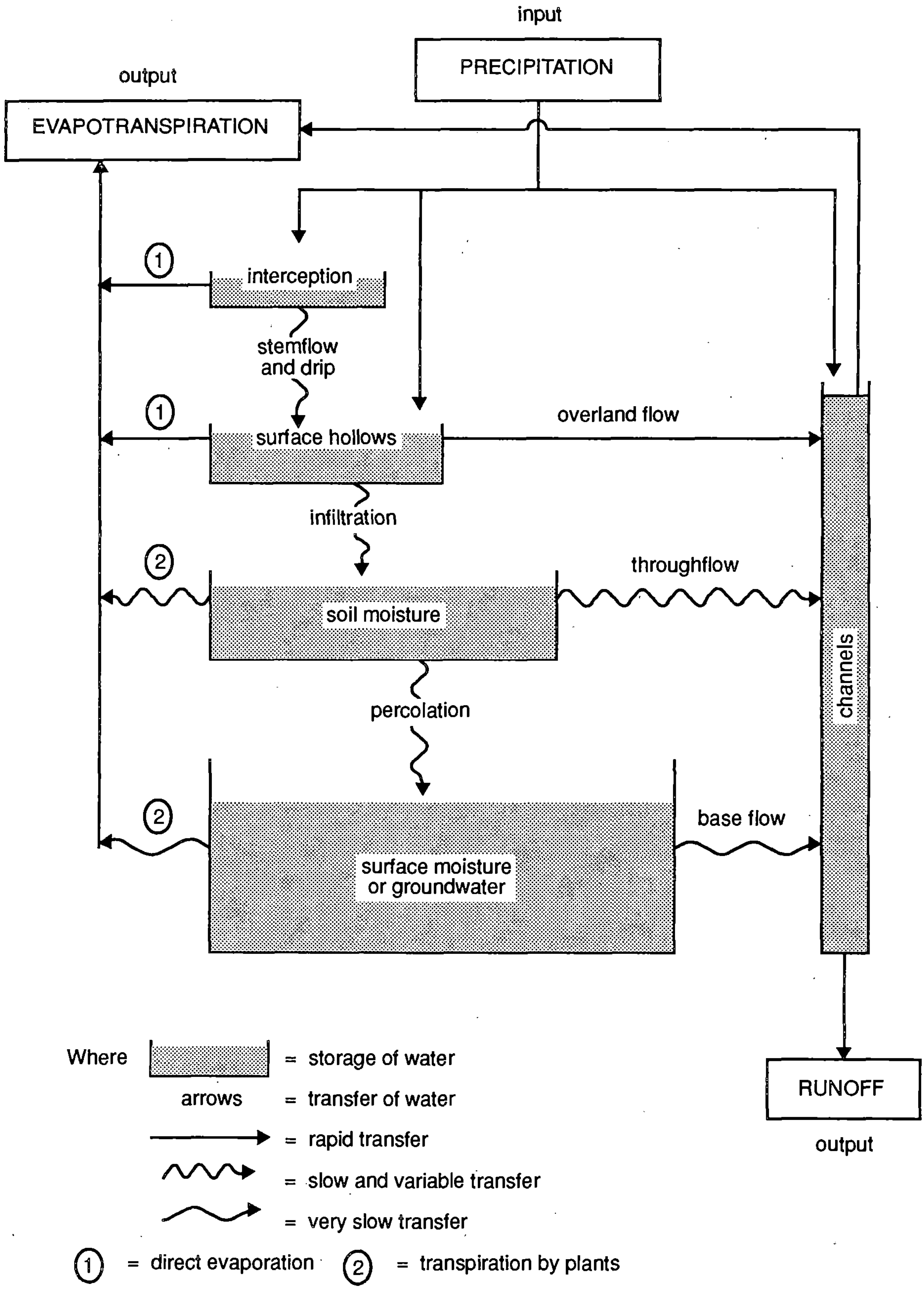
where: P = precipitation;
Q = streamflow;
E = evapotranspiration;
and S = water storage.

Such equations can be used for assessing the general routing and stores of water in the hydrological cycle of a small catchment, but clearly such a simple model does not enable proper investigation of the hydrological processes involved. It is essentially a black box model, comparing the major input (precipitation) with the main outputs (streamflow and evapotranspiration) and the retention of water in the soil and groundwater stores.

More detailed models are needed to explore the dynamics of the hydrological system, an example of which is indicated in Figure 8. This example also identifies the main inputs and outputs of the system, but incorporates more of the **stores of water** and the **processes of water movement** between these. The main stores of water within a catchment might include interception storage in the plant canopy, surface storage in irregular depressions on the ground, soil moisture storage dependent on the depth and texture of the soil and groundwater storage, governed by the nature and degree of weathering of the bedrock. Note that some of the processes of water transfer are rapid, such as surface runoff, whereas others are relatively slow, as in the case of percolation of water to the groundwater store.

Several important features of hydrological systems can be illustrated in terms of this particular model (Figure 8) including:

Figure 8: A simple model of the hydrological system



After Whitlow (1983b), p.197.

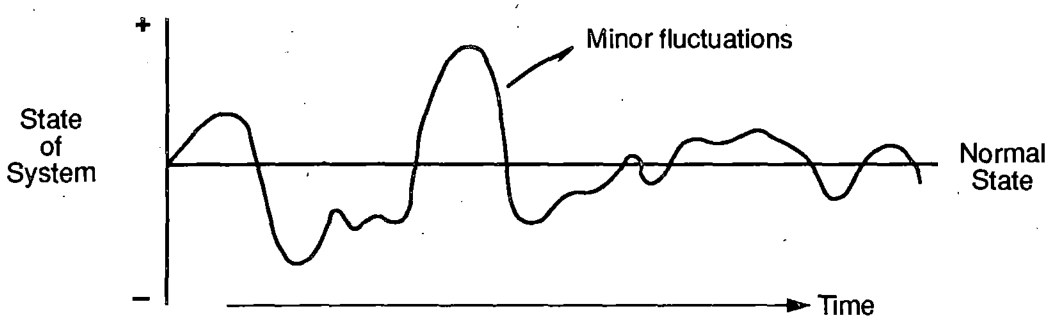
- water can follow several **different pathways** through the hydrological system;
- the amount of water entering a given store will depend on what has happened in the **preceding stages** in the system;
- the stores and transfers of water are **continuously changing** both temporally and spatially; and
- **man can intervene in the hydrological cycle** in various ways by modifying stores and transfers of water (e.g. Walling, 1979), but with respect to land use a key process is **infiltration** as this affects the relative amounts of surface runoff (Whitlow, 1983b).

In common with the examples on slopes and erosion, the hydrological systems outlined here illustrate how particular interests of an environmental system may be identified and important relationships defined. This provides a convenient reference or framework to guide detailed study of the individual components of the system which can then be brought together in the form of models as outlined here.

KEY SYSTEMS CONCEPTS

An important concept in systems theory relates to the **stability** or **equilibrium** of a system. In the context of environmental systems, Chorley and Kennedy (1971) define various types of equilibrium conditions, one of which is **dynamic equilibrium,** 'a circumstance in which fluctuations are balanced about a constantly changing system condition' (p.348). Effectively this means that no major morphological adjustments are likely to occur in a system that is in dynamic equilibrium. This does not mean that there are no changes taking place within the system, only that over a period of time these changes essentially cancel each other out and the system state remains unaltered (Figure 9). The significance of shifts in climatic conditions or man's activities is that these may produce a state of **disequilibrium** in natural systems, so bringing about adjustments to restore the balance of these systems.

Figure 9: Changes in the state of an environmental system through time



Three important concepts that assist in understanding the dynamics or behaviour of environmental systems are the concepts of **feedback, thresholds** and **relaxation time.** These concepts have been defined by Gregory and Walling (1974) (p.19) as follows:

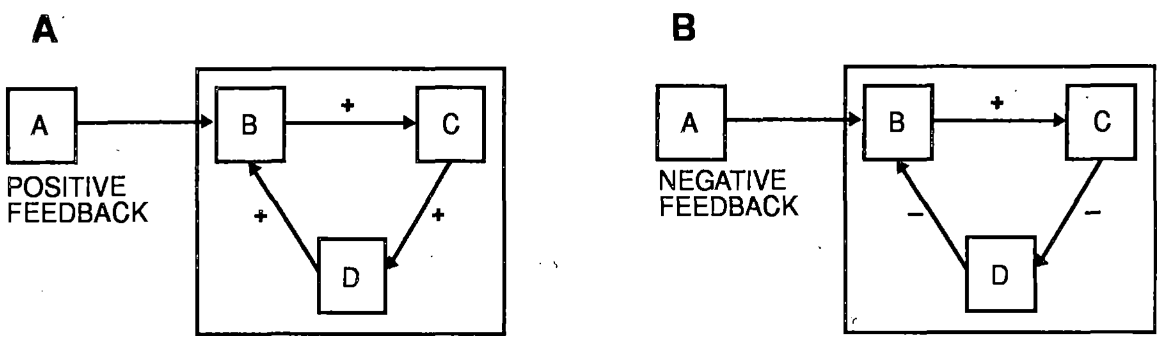
Feedback	'part of the output of a system may act as an input into another system and regulate that system either by intensifying (positive feedback) or opposing (negative feedback) the direction of change of the system'
Threshold	'a condition characterising the transition from one system state to another'
Relation time	'the time taken to realise equilibrium in a system during a change from one equilibrium condition to another one'.

Each of these is outlined here by means of examples, with further detail on these concepts being presented by Chorley and Kennedy (1971).

Concept of feedback

There are two forms of feedback in environmental systems. These are **positive feedback,** where changes in a system are reinforcing, and **negative feedback**, where the system is subject to self-regulation so restoring equilibrium. These are illustrated diagrammatically in Figures 10a and 10b, respectively.

Figure 10: Concepts of positive and negative feedback



After Chorley and Kennedy (1971), p.14.

The **concept of positive feedback** can be illustrated with the example of soil erosion and runoff processes (Figure 11a). Compaction of the ground surface by, for example, livestock or heavy machinery is likely to decrease the infiltration capacity (F) of the soil. With a decreased infiltration of water into the soil, there is likely to be greater surface runoff (Q) which in turn will increase the erosion of the topsoil (Es). If the subsoil has a higher clay content, as is often the case on the sandveld soils in Zimbabwe, then infiltration capacity of the surface material is likely to be even lower, thus continuing the sequence.

Chorley and Kennedy (1971) illustrate the concept of positive feedback, with reference to the process of glacial erosion as follows:

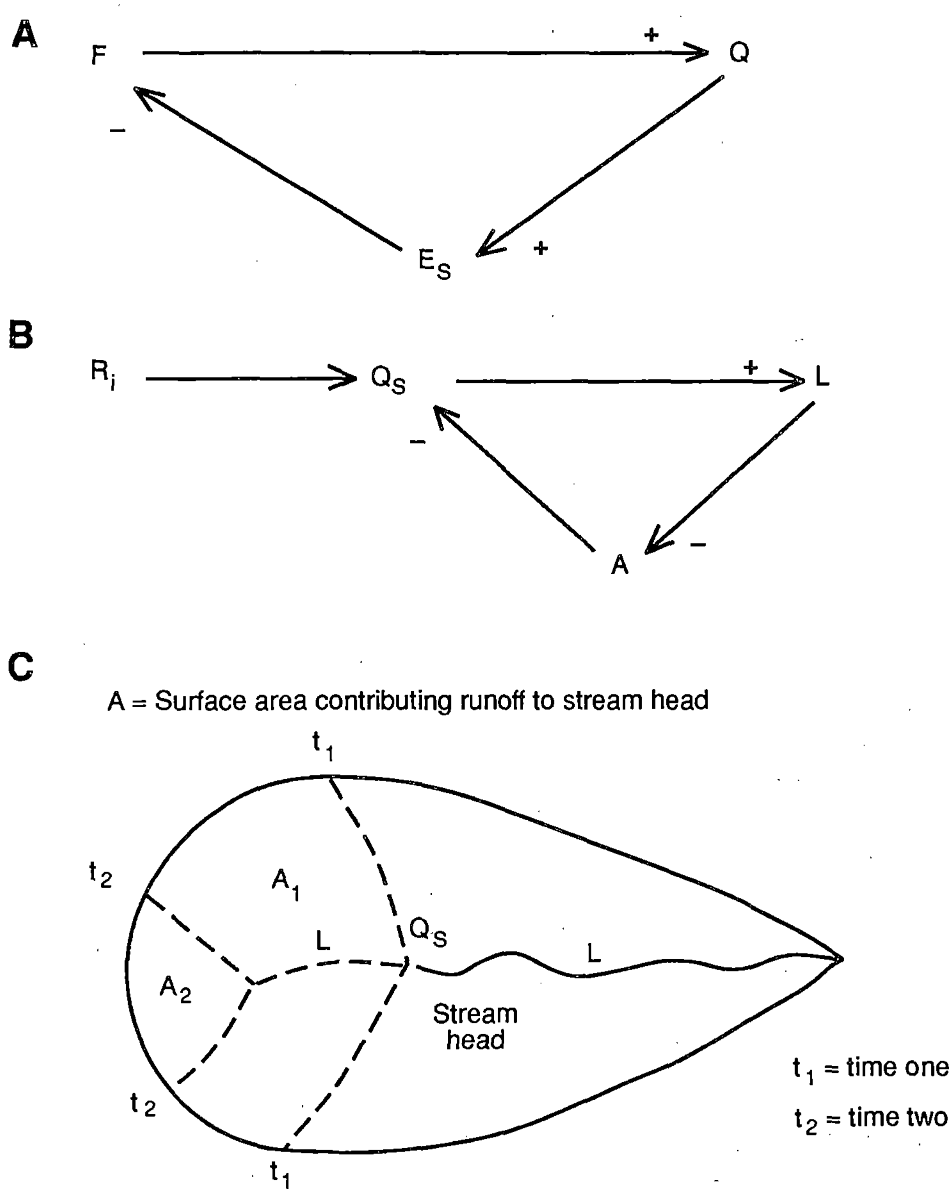
> '... local deepening of the bed of a valley glacier produces a **concave profile** leading to increasingly compressive ice flow; this in turn gives a greater tendency for basal eroded material to be carried up into the ice, leading to an **increase in concavity** and erosion. This sequence is clearly limited in time by increased debris clogging of the ice ...' (p.138).

This last point is important in so far as positive feedback conditions do not seem to persist for long periods of time in environmental systems.

The **concept of negative feedback** can be illustrated with the example of runoff in a small drainage basin during and following an intensive rainstorm (Figures 11b and 11c). The basic sequence in this situation may be as follows:

- rainfall intensity (Ri) exceeds the infiltration capacity of the soil so generating surface runoff (Qs);
- with more runoff entering the stream head, there is an extension of the channel length (L) up the axis of the drainage basin;
- as the channel length extends so the contributing area of runoff (A) decreases (as shown by A1 and A2 in Figure 11c);
- this decreases the volume of runoff entering into the channel so having a negative effect on Qs; this reduces, then, the length of the active stream and so restores the original condition of the drainage basin.

Figure 11: Examples of feedback in environmental systems



Another example of negative feedback outlined by Chorley and Kennedy (1971) relates to the undercutting of basal slopes by rivers as follows:

> '... an increase in basal stream erosion tends to steepen the angle of the associated valley-side slope, accelerating the rate at which debris is supplied to the channel and ultimately inhibiting the basal erosion.' (p.135).

An important factor to stress as far as negative feedback is concerned is that such feedback is **more common** than positive feedback in environmental systems, although it is not always easy to determine precisely how such feedback loops operate. In a given environmental system there may be a critical stage which determines whether there will be a negative or positive feedback, as illustrated by Trudgill (1977) for erosion on limestones, susceptible to solutional processes, as follows;

- percolation of rainwater into the soil takes up carbon dioxide chelates and organic acids;
- this promotes the solution of calcium carbonate in the soil and bedrock, but the progress of this sequence depends on whether the site has free drainage or not;
- IF there is **no free drainage** then the subsequent sequence may be:
  - perched waters occur on limestone;
  - carbonates leached from the soil return in capillary rise and 're-alkalise' the soil'
  - there is little or no net loss of material in solution;
  - there is limited opening up of joints in the bedrock formation of sub-surface runnels; and
  - there is no serious loss of soil.

  This represents a **negative feedback loop** since the initial removal of materials in solution is counteracted by precipitation of materials where solutions cannot drain away easily, as on flat surfaces or within depressions;
- IF there is **free drainage,** then the subsequent sequence may be:
  - there is leaching of calcium carbonates from the soil profile;
  - there is further acidification of the soil material down to the bedrock surface;
  - this promotes active solution of the bedrock, opens up joints and creates runnels;
  - this increases the drainage of water down the grikes and runnels; and
  - in turn, this increases the removal of calcium carbonates in solution, encouraging further deepening of the grikes and runnels in the limestone and soil loss.

  This represents a **positive feedback loop** since the process of calcium carbonate solution is reinforced where there is free drainage of water as occurs on a hillslope.

Similar examples of feedback affecting landforms occur on granitic rocks, notable in the case of deepening of weathering pits or gnammas and in the development of flared slopes (Twidale, 1982; Whitlow, 1983a). In the case of predator-prey relationships, negative feedback may operate to regulate population sizes, a process referred to by ecologists as **homeostasis**.

Concept of thresholds

As defined by Chorley and Kennedy (1971) a threshold is a limit or condition 'marking the transition from one state or economy of operation to another' (p.358). Once a threshold is exceeded in a given environmental system, then changes are set in motion that may bring about morphological adjustments in the system. Two points are important in this regard. Firstly, a small change in a critical variable may force adjustments throughout a system, and secondly, crossing a threshold is normally an irreversible process. The concept of thresholds has proved especially relevant in the field of geomorphology (Schumm, 1979), hence examples will be drawn from this field to illustrate the idea of thresholds.

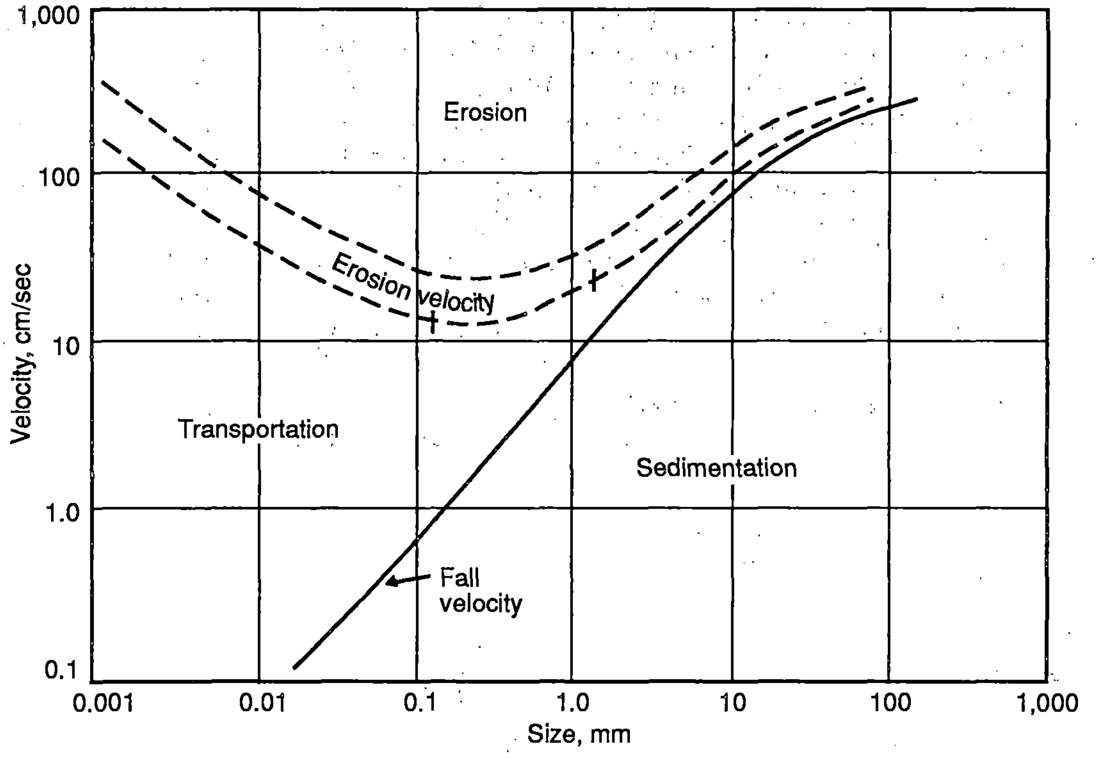
Slope instability provides good examples of the presence of **critical slope angles** or thresholds. For example, landslips occur on slopes of 38° or greater in mountainous terrain in Southern California whereas on London Clays in Southern Britain such mass movements occur on slopes of 10° or more (Chorley and Kennedy, 1971). The **'angle of repose'** of material on a hillslope is an example of a threshold (Young, 1972); thus above the angle of repose slopes are unstable and mass movements may occur to reduce the slope angle, whilst below the angle of repose slopes are likely to be stable. Generally, the courser the debris on a slope, the steeper the angle of repose. Hence one finds very steep scree slopes on glaciated areas as compared to talus slopes in tropical areas where greater weathering and comminution of material has occurred.

Another example of the existence of thresholds is given in the **movement of sediments in river channels** as represented by the Hjulstrom graph (Figure 12a). This views the balance between the **entrainment** (erosion and transport) of materials and **sedimentation** (deposition) as a function of the relationships between particle sizes of the materials and the velocity of flow of the water in a river. Very high velocities of flow are required to move the larger heavier particles, as seen in the saltation of gravels on river beds during peak flows or floods. As discharge decreases on the recession limb of the flood hydrograph, velocities of flow generally decrease (although one may get turbulent flow in a river, with locally high velocities). This promotes the deposition of the coarser, heavier suspended load in the river. In contrast, the finer silt and clay material will remain in suspension at low flow velocities and so will be transported further down the river. At the same time such fine material is often cohesive, so needs relatively high velocities of flow to get it into suspension in the first place. The most easily eroded materials comprise the fine sands which are not as cohesive as the clays and silts and not as heavy as the coarser sands and gravels. Consequently, one finds that there is differential movement and deposition of materials within and along rivers related to the nature of the thresholds required to move different sized sediments (Gregory and Walling, 1974).

Erosional activity also provides good examples of the existence of thresholds. Runoff, for example, occurs once the rainfall intensity exceeds the infiltration capacity of the soil, that is, more water reaches the ground surface than can enter into the soil, with the surplus water draining away as runoff. There may be critical levels of plant cover above which erosion is limited and below which there is active erosion. In Zimbabwe observations have shown that below 30% sub-aerial plant cover there is rapid increase in soil loss, possibly because of greater rainsplash on sparsely vegetated sites. The presence of **gullies** may be related to critical valley axis slopes, as occur in the south-western parts of the USA (Schumm, 1979). Here, under semi-arid climatic conditions, there is an accumulation of sediment in valley floors so locally increasing the gradients of the valley axes. This creates unstable conditions and leads to the development of discontinuous gullies to lower the valley axis gradients and restore stability (Figure 12b). This

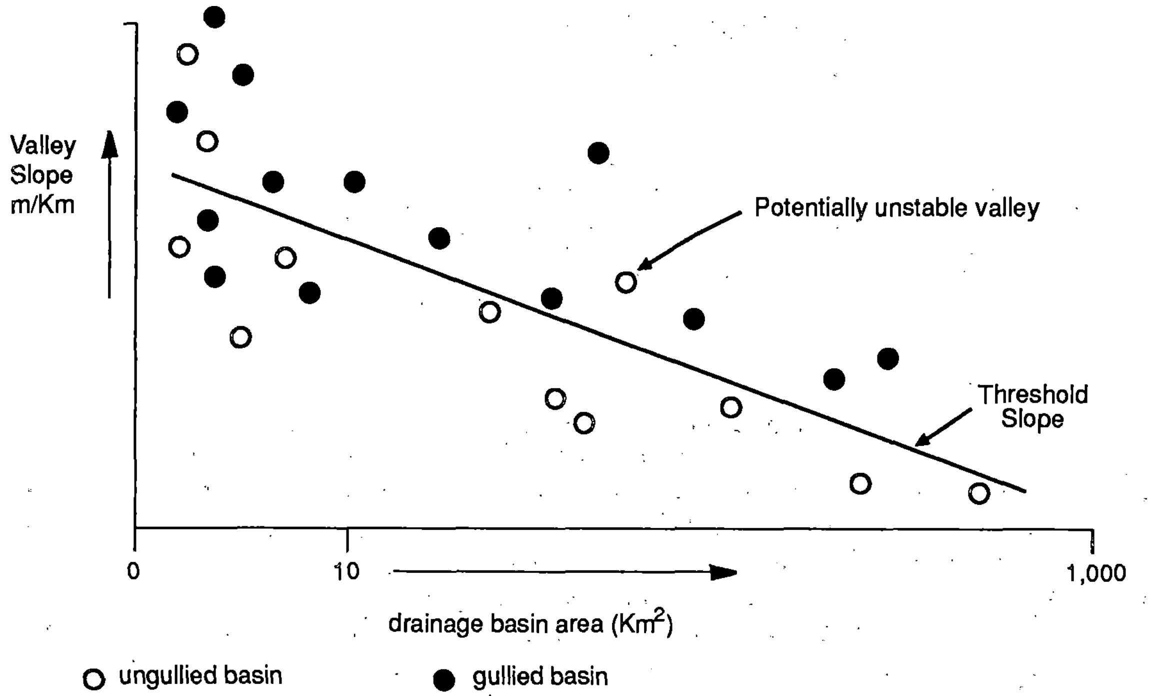
Figure 12: Examples of thresholds in environmental systems

A



NOTE: This is diagrammatic and not a replica of the original graph.

B



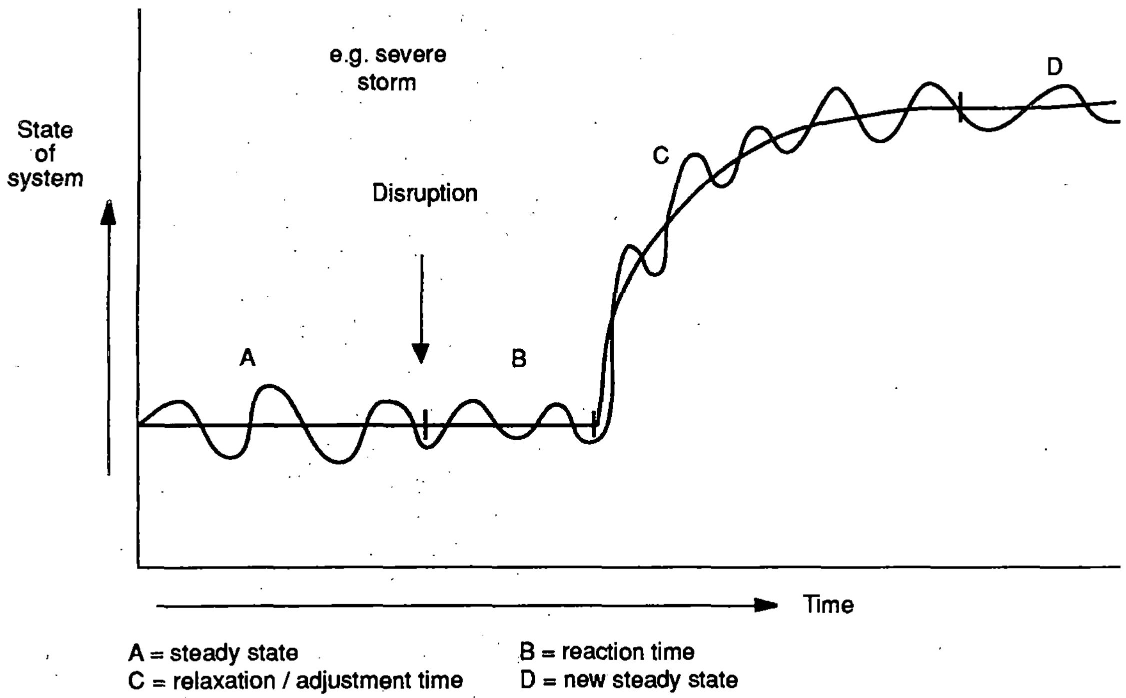
After Schumm (1979), p.489.

relationship seems to apply to larger drainage basins (over 10 square kilometres) and not to smaller basins, where the pattern of gullying is independent of the valley axis slope. The reasons for this are not clear.

Relaxation time

Relation time as defined by Chorley and Kennedy (1971) is the 'time taken by a system reorganisation to achieve a new equilibrium, following a change in input' (p.355). The basic ideas involved in this concept are illustrated by Graf (1977) in the context of the onset of gullying and the time taken for gullies to stabilise in south-western United States (Figure 13). One can envisage that gullying might be initiated by very intensive rainstorms, a form of 'disruption' that upsets the equilibrium of the valley floors. There may be a period of 'reaction time' following a period of severe storms as gully headcuts become established and before the gullies start to extend up the valleys (Figure 13). Then there is the 'relaxation time', as the gullies extend up the valleys and gradually become stabilised, so establishing a new steady state in the valley floors.

Figure 13: Concept of relaxation time in environmental systems

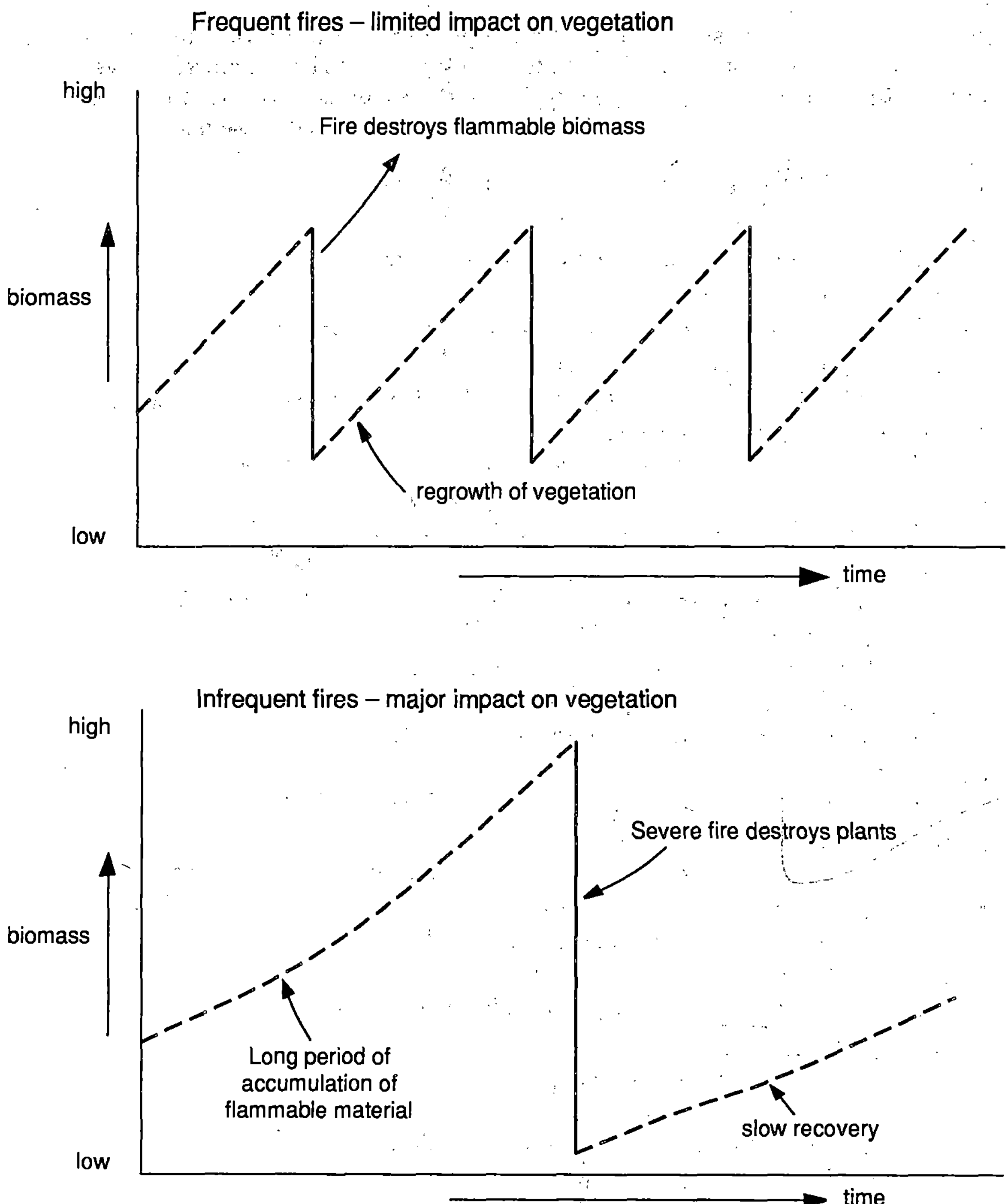


After Graf (1977).

Recognition of the relaxation time taken for features to adjust to new conditions following some form of disturbance is important in physical geography, particularly where one is attempting to establish cause-effect type relationships. An illustration of this is the initiation of soil erosion following the felling of eucalyptus forests in Australia. Erosion did not begin straight after the clearance of the woody vegetation. Rather it took 15 to 20 years for the organic material in the soil to gradually decompose and so weaken soil structures, thus making the soil susceptible to erosion during intensive rainstorms.

The intensity of the 'disturbance' factor may influence the rate at which an environmental system recovers, as illustrated in the example of frequencies of fires in ecosystems (Figure 14). With frequent, regular fires there is limited build up of organic material and, as a consequence, the fires are relatively 'cool'. This means that no serious damage is done to plants and there is relatively rapid regrowth of vegetation following a fire. If an area is protected from burning for an extended period, there is likely to be an accumulation of a large amount of organic material or 'fuel'. When a fire does occur, it will be very hot and do greater damage to the plants. This will result in a slower rate of recovery of the vegetation after the fire. Another factor that influences the effect of fire on the savannas of southern Africa is the timing of the fires in the dry season, with late season burns being hotter than early season burns.

Figure 14: Impacts of fire on biomass in ecosystems



After Trudgill (1987).

CONCLUSION

Physical geography is a wide-ranging discipline that explores the nature and dynamics of the physical landscape and the role of man in modifying this landscape. The systems approach is only one way of studying the physical landscape, but does provide a useful conceptual framework for the description and analysis of features and processes. In particular, it provides a basis for selection and modelling of key elements of the physical environment relevant at a given scale of study and enables more effective generalisations to be drawn from scientific study. The concepts of positive and negative feedback, thresholds and relaxation time provide a basis for the study of the functions of environmental systems.

Note: This paper is based on the introductory lectures for the Part I Physical Geography course at the University of Zimbabwe. It is not intended to be a comprehensive review of the current status of physical geography or the systems approach to this discipline. Rather it presents a **framework** for further reading around these issues.

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