

THE BASICS *of*
GEOMORPHOLOGY

KEY CONCEPTS

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THE SYSTEMS APPROACH

A system as a set of components and relationships between them, functioning to act as a whole, has been detectable in science and in thinking about landforms for more than a century. For geomorphology, it was formalized in 1962 when the benefits of an open systems approach were articulated. The approach has become integral to many aspects of landform science, has been accompanied by other conceptual developments, and has been succeeded by self-organizing systems with non-linear relationships and more uncertainty.

The idea of a system is not new: Newton wrote of the solar system, biologists have been concerned with living systems, geographers have implicitly used the systems concept since the early days of the subject (Gregory, 2000), and most Earth scientists have probably always thought in systems terms. In Hutton's rock cycle, from his *Theory of the Earth* (Hutton, 1788, 1795), the Earth is, in effect, being described as a system, with different system components, materials and processes through which matter is transported and recycled (Odoni and Lane, 2011). The system is now frequently employed in many scientific disciplines and, to give another example, Lovelock (2009) used Webster's *New Collegiate Dictionary* definition: 'an assemblage of objects united by some form of regular interaction or interdependence'. Geomorphological systems may now be viewed as one component of an immensely complex total Earth System including atmospheric, oceanic, biological and other elements.

As with all concepts, it is not easy to discern exactly how the **systems concept** originated and when it was first applied. In addition to early ideas about Earth systems a late 19th and early 20th century trend in the physical, especially chemistry and biological, sciences was towards a recognition of systems, and it was probably ideas from biology that led Ludwig von Bertalanffy (1901–1972) to propose *General systems theory* as an analytical framework and procedure for all sciences. Much of his published work in the field of 'organismic' biology was written in German and is thus not widely known (Drack, 2009) so that from

1932 it was not immediately absorbed elsewhere. There were several antecedents such as von Uexküll (Table 2.1) that set the stage for von Bertalanffy's 1937 *General systems theory* proposal at a philosophical seminar in Chicago and formalizing systems theory in 1950.

After outlining the adoption in geomorphology (2.1), we review the implications of systems approaches embedded in landform science (2.2), to see how this is continuing to evolve (2.3).

2.1 Adoption of the systems approach in landform science and geomorphology

Strands of ideas in geomorphology anticipated the advent of systems theory. These included those from G.K. Gilbert (1843–1918) in 1877, from J.T. Hack in 1960, and from A.N. Strahler (1918–2002) in 1952, but we could also add J.F. Nye's (1952) application of plasticity theory to the flow of ice sheets and glaciers, and the classic work of R.A. Bagnold (1896–1990) on the physics of blown sand and desert dunes (Bagnold, 1941). Such strands (Table 2.1) provided the context, but it was the classic paper by R.J. Chorley (1927–2002) in 1962 that really embedded systems thinking in geomorphology. He contrasted the open with the closed system view that was at least partly embodied in Davis's view of landscape development. Whereas open systems require an energy supply for maintenance and preservation, maintained in an equilibrium condition by the constant supply and removal of material and energy, in a closed system the given amount of initial free energy becomes less readily available as the system develops towards a state with maximum *entropy*, signifying the degree to which energy has become unable to perform work. The value of the open system approach to geomorphology was summarized as having several useful purposes (Chorley, 1962: B8):

- To show dependency on a universal tendency towards an adjustment of form and process.
- To direct investigation towards the essentially multivariate character of geomorphic phenomena.
- To admit a more liberal view of morphological changes with time, to include the possibility of non-significant or non-progressive changes of certain aspects of landscape form through time.
- To foster a dynamic approach to geomorphology to complement the historical one.
- To focus upon the whole landscape assemblage rather than those parts assumed to have evolutionary significance.

- To encourage geomorphic investigations in those areas where the evidence for erosional history may be deficient.
- To direct attention to the heterogeneity of spatial organization.

However, Huggett (2007), in his review of the systems approach in geomorphology, suggested that it was Strahler (1950; 1952: see also 1980), rather earlier, who introduced open systems theory to geomorphology, ushering in a revival of Gilbertian thinking. This involved concepts drawn from physics and mechanics rather than historical geology. Exemplifying the difficulty of pinpointing the actual source of concepts, the papers by Strahler and by others (Table 2.1) certainly provided foundations for a different way of analysis which then progressed to explicit systems approaches. The four types of system recognized (morphological, cascading, process-response, control) by Chorley and Kennedy (1971), as well as the four phases distinguished (lexical, parsing, modelling, analysis) by Huggett (1980) and their subsequent adoption, are described in Box 2.1.

2.2 Embedding and encompassing the systems approach

Systems ideas have prompted – or at least combined with – other conceptual developments required for the further development of landform research.

Inclusion of the systems approach was important for modelling and provided a context for ideas such as equilibrium; was parallel with other ideas such as land systems and contributed to others such as Earth system science; was helpful in reconciling timeless and time bound approaches; and could stimulate new ideas and provide the basis for new developments.

Their vital importance is shown in many aspects of **modelling**. Odoni and Lane (2011) considered that a system can be imagined as having the properties of (1) objects (e.g., a grain of sediment); (2) processes that act on objects (e.g., momentum transfer whether from a fluid or other grains, that makes the grain move) and which connect objects together, and which are often specified in the form of rules or algorithms; (3) boundaries, often introduced to make the modelling problem tractable (e.g., defining the spatial extent of the deposit over which sediment movement will be simulated); (4) boundary conditions, necessary to recognize that when boundaries are involved, additional or auxiliary information is required (e.g., the sediment feed rate); and (5) exogenous drivers that cause change in the boundary conditions (e.g., a change in

sediment feed rate). These five properties are essential for the structure of many models. Over the last four decades many geomorphic models have been structured upon a systems framework, which encourages modelling involving both forms and the transfer of energy and materials necessary to analyse dynamic changes in geomorphology.

Use in relation to other concepts included **equilibrium**: this is a concept which has been thought about for more than one hundred years, and has now been conceived of in several ways including steady state, dynamic, or metastable equilibrium (see Chapter 6). It was placed in context by the advent of systems thinking. An *open system* condition may be assumed in which quantities of stored energy or matter are adjusted so that the input, throughput and output of energy or matter are balanced. Although the conceptual frameworks of systems analysis and geomorphic equilibrium can be divergent in many respects (Mayer, 1992), it has been argued that many geomorphic system states and behaviours, often interpreted as showing a tendency towards the establishment and maintenance of steady-state equilibrium, are actually emergent outcomes of two simple principles – gradient selection and threshold-mediated modulation (Phillips, 2011b). It is explained in Chapter 6 that the contemporary interpretation of equilibrium is significant and useful but not universal, does not necessarily have a single final equilibrium state, and can be visualized in different ways including as a metaphor.

The **land systems approach** is an example of a specific development that was aided by the systems approach. Resource surveys introduced by the Australian Commonwealth Scientific Industrial Research Organization (CSIRO) in 1946, designated land systems as areas or groups of areas with recurring patterns of topography, soils and vegetation with a relatively uniform climate. The implementation of this approach, employed especially for the management of resources and modified for application to urban and suburban areas, was greatly advanced by satellite remote sensing and GIS. The approach has been adapted for other geomorphological studies of landscapes, especially those that include multiple remnant components making up an overprinted palimpsest of former conditions (see Chapter 15). Thus as the withdrawal of glacier ice exposed landscapes, usually over time-scales of 10^1 – 10^4 years, six paraglacial landsystems have been identified (Ballantyne, 2002a): rock slopes, drift-mantled slopes, glacier forelands, and alluvial, lacustrine and coastal systems – each containing a wide range of paraglacial landforms and sediment facies. **Paraglacial** (Church and Rider, 1972) may be defined as ‘non-glacial Earth surface processes, sediment accumulations, landforms, land systems and landscapes that are directly conditioned by glaciation and deglaciation’ (Ballantyne, 2002a; Ballantyne, 2003), so that the paraglacial is the period of readjustment from glacial to non glacial conditions (Church and

Slymaker, 1989; Slymaker and Kelly, 2007:167), and research data on rates of operation of some paraglacial systems have been compiled (Ballantyne, 2002a). Striking landforms in the area of the southern Laurentide ice sheet were analysed in terms of seven land systems (Colgan et al., 2003). The Satujökull foreland of the northern Hofsjökull ice cap in central Iceland shows a clear signature of glacial land system overprinting as a result of complex glacier behaviour during the historical period. Landsystem 1, comprising a wide arc of ice-cored moraine and controlled ridges lying outside fluted and drumlinized terrain, is indicative of polythermal conditions. Landsystem 2 contains most of the diagnostic criteria for a surging glacier landsystem with records of two separate surges. Observation of landsystem overprinting, especially in response to changing thermal regimes and/or glacier dynamics, and particularly by different flow units in the same glacier, is rarely reported but is crucial to the critical application of modern landsystem analogues to Quaternary palaeo-glaciological reconstruction (Evans, 2011).

More recently developed is **Earth System Science**. Appearing in 1988 (NASA, 1988) and stated in the Amsterdam declaration of 2001, this is the study of Earth as a total system with various components, such as the atmosphere, hydrosphere, biosphere and lithosphere. It therefore embraces geomorphology. It has been suggested (Lovelock, 2009) that this concept grew within the Earth science community to form an intellectual environment for explaining the flood of new knowledge about the Earth. It arose from Gaia theory but did not encompass habitability as the goal for the self-regulation of the Earth's climate and chemistry. Although it is seen as an all-embracing science envelope, Clifford and Richards (2005) concluded that earth system science (ESS) constitutes an oxymoron; it should be seen neither as an alternative to the traditional scientific disciplines, nor regarded as a wholesale replacement for a traditional vision of environmental science, but rather as an adjunct approach. Subsequently it was suggested (Richards and Clifford, 2008) that LESS (local environmental systems science) would be a more appropriate focus for geomorphology. Perhaps **Gaia theory** – introduced by Lovelock in the 1980s as 'a view of the Earth that sees it as a self-regulating system made up from the totality of organisms, the surface rocks, the ocean and the atmosphere tightly coupled as an evolving system' (Lovelock, 2009) – is the best example of an idea that had developed from systems and provides a context for them. Lovelock (2009) quotes the Nobel Prizewinner Jacques Monod (1970) who drew attention to holistic schools which, phoenix-like, are reborn in every generation, and the analytical attitude (reductionist) was doomed to fail in its attempts to reduce the properties of a very complex organization to the 'sum of its parts'. However, a systems approach can accommodate both holistic and reductionist approaches.

The systems approach could reconcile **timeless** and **time bound** approaches. When the systems approach was developed in the 1960s it was associated with the surge of process geomorphology (timeless) and, at that stage, was almost independent from research undertaken on landscape development (time bound). However, systems can be the basis for a reunification of the two approaches, as exemplified by the use of land systems which may include inherited elements. The likelihood of any landscape or geomorphic system existing at a particular place and time with such effect as to exclude all its predecessors is negligibly small. This idea has also been extended in terms of the 'perfect landscape', conceptualized as being the result of the combined interacting effects of multiple environmental controls and forcings to produce an outcome that is highly improbable, in the sense of duplication at any other place or time. Geomorphic systems have multiple and variable environmental controls and forcings, which allow for many possible landscapes and system states (Phillips, 2006a). The analogy here is with 'the perfect storm' that arises when all possible formative factors occur together. A perfect landscape perspective (Phillips, 2007) leads toward a world view that landforms and landscapes are circumstantial, contingent results of deterministic laws operating in a specific environmental context such that multiple outcomes are possible (see Chapters 7 and 15). This contrasts with the earlier view embracing single outcomes for a given set of laws and initial conditions. Thus Huggett (2007) sees this as a powerful and integrative new view, proposing landscapes and landforms as circumstantial and contingent outcomes of deterministic laws operating in a specific environmental and historical context, with several outcomes possible for each set of processes and boundary conditions. If capable of reconciling different geomorphological traditions, this could be a great success for the systems approach.

The **development of new ideas** has been fostered by the adoption of the systems approach, as shown by some of the above examples. Some have developed within geomorphology as illustrated by the instability principle developed by Scheidegger (1983) to connote the way in which equilibrium in geomorphic systems is commonly unstable. Any deviation from the equilibrium state may be self-reinforcing, causing the deviation to grow with increasing irregularity over time, as illustrated by the growth of cirques. Linking ecological and geomorphological systems, often previously largely conceptualized as independent, has fostered other ideas. Ecological 'memory', which encompasses how a subset of abiotic and biotic components are selected and reproduced by recursive constraints on each other, is reflected in the way that on-going interactions between ecology and geomorphology become encoded in the landscape (Stallins, 2006). What this means is that repeated interactions make up a history or trajectory of change in which what follows at each

stage is determined by the interactions which have taken place before, and not just the ones that can be observed at particular points in time. Disturbance regimes are a further example showing how non-linear systems react to human-induced and natural disturbances, illustrated by arid hillslopes, weathering systems in deglaciated areas and vegetated dunes in drylands (Viles et al., 2008). More widely, ‘disturbance’ can refer to any externally driven perturbation: geomorphology can be concerned with how landforms and landscapes respond to disturbances and to variable boundary conditions, and hence to how geomorphic systems co-evolve with climate, ecosystems, soils and other environmental systems (Phillips, 2011a). This allows the assessment of geomorphic changes and responses to be based on *response* (reaction and relaxation times), *resistance*, *resilience* (recovery ability) and *recursion* (positive and/or negative feedbacks) – the 4 Rs put forward by Phillips (2009; 2011). Small-World Networks (SWN) are networks with a special structure that model the relationships in the real world including those in ecosystems, so that it is possible to visualize geomorphic systems as coupled subsystems with SWN traits characterized by tightly connected clusters of components, with fewer connections between the clusters (Phillips, 2012a).

Thus Thornes and Ferguson (1981) extended conceived applications from *simple systems* (which involve no more than three or four variables, utilize Newtonian laws, and can be handled by relatively simple techniques, including regression models and partial differential equations possibly extending to finite difference methods) to *systems of complex disorder* (involving large numbers of components/variables but only weak linkages between them, requiring probabilistic methods of statistical mechanics, including probabilistic approaches to soil creep and to stream networks, coastal spit simulation and Box Jenkins models). Systems of complex order were also recognized and these have been developed in conjunction with non-linear dynamical systems in a complexity approach to the interpretation of landforms (see Chapter 7).

2.3 Conclusion

Systems are now an integral part of geomorphology. The concept originated in other sciences and especially biology, but now embedded in geomorphology it is fundamental in facilitating significant developments in the discipline, especially those associated with non-linear dynamical systems. Furthermore, as Chorley (1962) stated in his seminal paper, ‘It is only through . . . application of systems analysis that considerations of the management of the natural environment can be elevated above mere *ad hoc* book-keeping to form part of a broader scholarly discipline which focuses on the conservational aspects of geographical

control systems'. As geomorphology is increasingly concerned with the application of research results, perhaps this may provide the greatest justification for the systems approach. However, systems continue to be debated. Von Elverfeldt and Glade (2011) argued that the theoretical foundation as well as the definitions and basic assumptions are rarely (if at all) questioned, subsequently suggesting (von Elverfeldt, 2012) a view of systems as being open but at the same time operationally closed, as self-organized structure-building and potentially self-referential.

FURTHER READING

Chorley, R.J. and Kennedy, B.A. (1971) *Physical Geography: A Systems Approach*. London: Prentice Hall.

Gregory, K.J. (2000) *The Changing Nature of Physical Geography*. London: Arnold. (See especially Chapter 4.)

Huggett, R.J. (2007) A history of the systems approach in geomorphology, *Géomorphologie: Relief, Processus, Environnement*, 2: 145–58.

Phillips J.D. (1999) *Earth Surface Systems: Complexity, Order, and Scale*. Oxford: Blackwell.

von Elverfeldt, K. and Glade, T. (2011) Systems theory in geomorphology; a challenge, *Zeitschrift für Geomorphologie, Supplementary Issues*, 55: 87–108.

TOPICS

1. Consider the proposals in von Elverfeldt and Glade (2011) and von Elverfeldt (2012) – are they likely to advance systems underpinning of geomorphology or are they a distraction?



WEBSITE

For this chapter the accompanying website study.sagepub.com/gregoryandlewin includes Table 2.1; Box 2.1; and useful articles in *Progress in Physical Geography*. References for this chapter are included in the reference list on the website.