2

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.

Table 2.1 Some strands for the incorporation of systems within geomorphology

Year	Contributor	Contribution
1875	E. Suess (1831–1914), Austrian geologist	Identified four spheres of lithosphere, hydrosphere, biosphere and atmosphere, although atmosphere previously specified in late 17th century: these became the focus for earth and environmental science disciplines.
1877	Grove Karl Gilbert (1843–1918)	First mooted the idea of a system in the subject, effectively taking an open systems approach in his concept of dynamic equilibrium: 'as any member of the system may influence all others, so each member is influenced by every other' (Gilbert, 1877: 123–4).
1920	Jakob Johann von Uexküll (8 September 1864–25 July 1944)	Biologist who developed a theory of biology, which decisively contradicted the mainstream of biological thought in the 20th century. Umwelt theory emerged from 19th and 20th century German anthropology, biology, physiology and psychology currently being rediscovered according to Harrison, Pile and Thrift (2004, *Patterned Ground*). Uexküll's approach became influential on the development of the *Organismic Biology* and *System Theory* of Ludwig von Bertalanffy. Uexküll introduced the term 'Umwelt' for the interactive unity of the organism and the world sensed by it. 'Umwelt' denoted the subjective world of an organism, the unique phenomenal world embracing each individual like a soap bubble. 'Umwelt' is usually translated as 'subjective universe', although in German it simply means 'environment': organisms may have different Umwelts even if they live in the same place. Each component of Umwelt has a functional meaning for an organism: it may be food, shelter, enemy, or simply an object that is used for orientation. An organism actively creates its Umwelt through repeated interaction with the world.
1932	Ludwig von Bertalanffy (1901–1972) Austrian-born biologist	Drack (2009) has shown that most of what Bertalanffy published in the field of 'organismic' biology was written in German and thus not widely known, and that his early work on an organismic programme in theoretical biology (Von Bertalanffy, 1932) led to the open system concept in the context of 'General systemology' first presented in 1937.
1935	A.G. Tansley (1871–1955)	Proposed 'ecosystem' as a general term for biome and habitat.

Year	Contributor	Contribution
1937	Ludwig von Bertalanffy (1901–1972) Austrian-born biologist	Founder of General systems theory, presented at a philosophical seminar in Chicago, which came to affect many disciplines including cybernetics, philosophy, psychiatry, psychology, and environmental sciences.
Late 1940s		Cybernetics formed as a new branch of science to study regulating and self-regulating mechanisms in nature and technology: primarily concerned with control mechanisms in systems and with communication processes.
1947	Ilya Prigogine (1917–2003)	Russian-born naturalized Belgian physical chemist and Nobel Laureate. Published his book on the thermodynamics of open systems, and also noted for his work on dissipative structures, complex systems, and irreversibility. In his 1997 book, *The End of Certainty*, he contended that determinism was no longer a viable scientific belief.
1950, 1968	Ludwig von Bertalanffy	Formalized systems theory.
1952	A.N. Strahler	Introduced open systems theory to geomorphology: 'Geomorphology will achieve its fullest development only when the forms and processes are related in terms of dynamic systems and the transformation of mass and energy are considered as functions of time' (1952: 935).
1960	J.T. Hack	Adopted Gilbert's concept of dynamic equilibrium for interpreting erosional topography in the Central Appalachians, USA. The theoretic basis for the idea of dynamic landscape equilibrium was developed by J.T. Hack in 1973. (Hack, J.T. (1973) Stream-profile analysis and stream-gradient index, *Journal of Research of the US Geological Survey,* 1: 421–9.)
1962	R.J. Chorley (1927–2002)	Advocated open systems view in geomorphology in Geomorphology and General Systems Theory, fostering a focus upon the adjustment of form and process, the multivariate character of geomorphological phenomena, the dynamic approach, and a focus on the whole landscape assemblage.

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Table 2.1 (Continued)

Year	Contributor	Contribution
1971	R.J.Chorley and B.A.Kennedy	*Physical Geography: A Systems Approach* suggested four types of medium scale system, each illustrated by geomorphological examples: morphological, cascading, process-response, and control systems.
1972	Ludwig von Bertalanffy	Distinguished three aspects of study of systems: (1) systems science which deals with the scientific investigation of systems; (2) systems technology concerned with applications in computer operations and theoretical developments such as game theory; (3) systems philosophy involving a reorientation of thought and world view consequent upon the advent of system as a new scientific paradigm.
1972	E. Lazlo	*Introduction to Systems Philosophy* distinguished a macrohierarchy of entities of astronomy, including galaxies, stars and planets, and a microhierarchy of terrestrial entities of physics, chemistry, biology which included atoms, molecules and cells.
1976	R.J. Huggett	Extended Lazlo's bipartite scheme to include a further microhierarchy that provided an evolutionary link between the atoms and planets to constitute the hierarchy of planetary and geological systems. He also suggested that the systems of atoms-to-planet and atoms-to-societies hierarchies produced a hierarchy of environmental systems.
1980	R.J. Huggett	Identified a strategy of systems analysis: (1) lexical phase, identifying system components; (2) parsing phase, establishing the links between components; (3) modelling phase, which requires establishing relationships in model and calibration of model; (4) analysis phase, attempting to solve system model.
1981	J.B.Thornes and R.I.Ferguson	Introduced approach which handled complexity, identifying and understanding systemic effects. Recognized three kinds of systems: (1) simple, involving >3 or 4 variables and handled by relatively simple techniques; (2) complex disorder, large numbers of components and variables requiring probabilistic methods of analysis; (3) complex order, with large numbers of components requiring catastrophe theory and perturbation analysis.

Year	Contributor	Contribution
1985	R.J. Huggett	Three main kinds of system following Thornes and Ferguson (1981).
1988	R.J. Huggett	Speculated about the dissipative structures and revolution they could cause when applied to geomorphological systems.
1989	J.B. Thornes	Systems analysis described as a popular concept enjoyed by many but whose deeper ramifications are understood by relatively few.
1992	J.D. Phillips	Outlined the application of nonlinear dynamical systems (NDS) theory to geomorphic systems (see Chapter 7 and Table 7.3).
1999	J.D. Phillips	Book on *Earth Surface Systems* suggests 11 principles (see Chapter 7 and Table 7.2).
2003	D. Favis-Mortlock and D. de Boer	Proposed that landscape be considered as a self-organizing complex system (see Chapter 7 and Table 7.3).
2009 and previously from 1979 onwards	J. Lovelock	In *The Vanishing Face of Gaia: A Final Warning,* Lovelock comments that 'The evidence that the Earth behaves like a living system is now strong. It can either resist climate change or enhance it, and unless we take this into account we can neither understand nor forecast the Earth's behaviour. Keep in mind that it is hubris to think that we know how to save the Earth: our planet looks after itself. All that we can do is try to save ourselves'.
2011	K. von Elverfeldt and T. Glade	Focused on what a system is and what the basic assumptions are with regard to geomorphological systems theory. Also asked whether these still applied to present knowledge.
2012	J.D. Phillips	Showed how geomorphic systems consisted of coupled subsystems with traits of small-world networks (SWN).
2012	K. von Elverfeldt	Outlined the implications of systems approach since Newton wrote on the solar system. Distinguished first order system theories based on the general system theory of von Bertalanffy focused on inputs and outputs, steady states, and linear relations between single components, from second order system theories which involve self-organization, dissipative structures, fractals and autopoieses.

BOX 2.1

DETAILED ADOPTION OF THE SYSTEMS APPROACH

Whatever the actual source, open systems thinking produced a new typology of systems, outlined in *Physical Geography: A Systems Approach* (Chorley and Kennedy, 1971), and showed how physical geography, including geomorphology, could be rationalized and perhaps given new coherence in terms of systems theory. The four types of system recognized were:

- *Morphological systems* which comprise ones of form with formal instantaneous properties integrated to form recognizable operational parts of physical reality, with the strength and direction of connectivity revealed by correlation analysis;
- *Cascading systems* composed of chains of subsystems which are dynamically linked by a cascade of mass or energy so that the output from one subsystem becomes the input for the adjacent subsystem;
- *Process-response systems* formed by the intersection of morphological and cascading systems and involving an emphasis upon processes and the resulting forms;
- *Control systems* where intelligence can intervene to produce operational changes in the distribution of energy and mass.

The systems approach provided a fundamental new paradigm, forging a link between others that had emerged, including quantification and modelling. It is perhaps significant that correlation analysis has been involved: what has been called 'the quantitative revolution' also impacted geomorphology in the mid 20th century, and the application of statistical techniques became very widely applied at the same time as system approaches were conceived. However, it is important to distinguish (Von Bertalanffy, 1972) *systems science* which deals with the scientific investigation of systems and with theory in various sciences; *systems technology* concerned with applications in computer operations and theoretical developments such as game theory; and *systems philosophy* which involves a reorientation of thought and world view consequent upon the advent of system as a new scientific paradigm. A system has been defined as:

- a set of elements with variable characteristics;
- the relationships between the characteristics of the elements;
- the relationships between the environment and the characteristics of the elements.

Huggett (1980) helpfully distinguished four phases:

- the *lexical phase* identifies system components;
- the *parsing phase* establishes the relationships between system components;
- the *modelling phase* expresses relationships in the context of a model and then calibrates the model;
- the *analysis phase* attempts to apply the system model.

Although the systems approach found fertile ground in geomorphology, not everyone welcomed it with open arms. One view considered it unnecessary in the earth sciences and responsible for confusion rather than clarification in empirical investigations (Smalley and Vita-Finzi, 1969), while another accepted the ideas of systems theories as valuable but argued that they were applied without formal knowledge of theory (Jennings, 1973: 124). Systems analysis was described as a popular concept enjoyed by many but whose deeper ramifications were understood by relatively few (Thornes, 1989: 6). Discussion about the values of systems in several related disciplines were not always serious, as shown by Van Dyne's comment (1980: 889, cited by Huggett, 1985) that 'In instances where there are from one to two variables in a study you have a science, where there are from four to seven variables you have an art, and where there are more than seven variables you have a system'.

The approach was soon utilized in textbooks concerned with hillslopes (Carson and Kirkby, 1972), drainage basins (Gregory and Walling, 1973) and with glaciers and landscape (Sugden and John, 1976). *Energy*, *force* and *power* had also become recognized as key process variables, concepts very familiar to physicists. There were also links back to the engineering background of G.K.Gilbert and to the quantitative analysis of drainage basin networks by the agricultural engineer R.E.Horton (1875–1945). In the field of glacial geomorphology a very imaginative approach was devised by Andrews (1972), who provided an analysis of total glacier power (WT) as the product of basal shear stress and the average velocity (see Chapter 10). The implication which followed, that the glacial erosional forms produced by arctic and by temperate glaciers differ in size and geometry, received support from the glacial geomorphology literature. This was later placed in the context of *Glacier Systems* (Andrews, 1975). Subsequently Sugden (1982) utilized a systems framework for his synthesis of the character of the Arctic and Antarctic, using an open systems approach involving input, storage, and output relationships. He demonstrated the utility of system hierarchies and of concepts such as thresholds and relaxation times. Although a concise book had already presented the geosystem as a single planetary system in which land, sea

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and air are dynamically integrated (Rumney, 1970), the organizational structure of many physical geography textbooks subsequently embraced the systems approach (e.g. Strahler and Strahler, 1976; King, 1980; Dury, 1981). *Environmental Systems: An Introductory Text* (White et al., 1984; 1992) explained why a systems approach was employed with matter, force and energy central to it, thus putting geomorphology into a similar framework as other branches of physical geography such as climatology. The systems approach was central to *Geomorphology* (Chorley et al., 1984), and to *Fundamentals of Geomorphology* (Huggett, 2002). Later books often had additional emphases, including plate tectonics in *Global Geomorphology* (Summerfield, 1991), global change (Slaymaker and Spencer, 1998; Slaymaker et al., 2009) and earth surface environments (Gregory, 2010). In addition to being incorporated in research and teaching in geomorphology, general reviews continue to appear. Von Elverfeldt (2012) identified an outstanding challenge to geomorphology by distinguishing 'first order' system theories, based on the general system theory of von Bertalanffy focused on inputs and outputs, steady states, and linear relations between single components, from 'second order' system theories which involve self-organization, dissipative structures, fractals and autopoieses, the processes whereby an organization produces itself (see Chapter 7).

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Chorley, R.J. (1971) The role and relations of physical geography, *Progress in Physical Geography,* 3: 87–109.

Dadson, S. (2010) Geomorphology and Earth system science, *Progress in Physical Geography,* 34: 385–98.

Phillips, J.D. (2009) Changes, perturbations, and responses in geomorphic systems, *Progress in Physical Geography,* 33: 1–14.

Wu, B., Zheng, S. and Thorne, C.R. (2012) A general framework for using the rate law to simulate morphological response to disturbance in the fluvial system, *Progress in Physical Geography,* 36: 575–97.

UPDATES

Recent discussions often relate to developments in physical geography as a whole as shown in a review of a significant paper:

Malanson, G.P. (2014) Physical geography on the methodological fence: David Stoddart (1965) Geography and the ecological approach: The ecosystem as a geographic principle and method, *Geography*, 50: 242–51. *Progress in Physical Geography*, 38: 251–58.

The concept of land systems, referred to in Section 2.2 (pp. 16–17) has been employed in relation to paraglacial environments and the complex paraglacial landsystem of the Fraser Lowland Canada is interpreted by:

Dori Kovanen, D. and Slaymaker, O. (2015) The paraglacial geomorphology of the Fraser Lowland, southwest British Columbia and northwest Washington, *Geomorphology*, 232: 78–93.

Phillips, J.D. (2015) Badass geomorphology, *Earth Surface Processes and Landforms*, 40: 22–33 gives a thought-provoking read applying the badass concept (an individualistic, non-conformist, able to produce disproportionate results) to geomorphology, introducing the individualistic concept of landscape evolution (ICLE) and arguing that the badass traits of many geomorphic systems have implications for the systems themselves, attitudes toward geomorphic practice, and appreciation of landforms. It is suggested that badass geomorphology and the ICLE reflect a view, and approach to the study of, landforms as the outcome of the interplay of general laws, place-specific controls, and history.

From the perspective of multiple response pathways and outcomes a paper addressing the challenge of mapping the feedback structure of processes controlling geomorphic system behaviour with reference to illustrative applications of Causal Loop Analysis for coastal two study cases is provided by Payo, A., Hall, J.W., French, J., Nicholls, R.J. and Reeve, D.E. (2016) Causal Loop Analysis of coastal geomorphological systems, *Geomorphology*, 256: 36–48.