6

EQUILIBRIUM

The concept of equilibrium emerged in geomorphology once ideas of catastrophism had been succeeded by the understanding that gradual land-forming processes were responsible for the shape of the Earth's surface, and the idea of a 'balance of nature' prevailed. This was expressed first through the graded profile of rivers for time-bound studies, and subsequently by the definition of other types of equilibrium such as dynamic, quasi-, metastable and steady state equilibrium to account for results obtained from observation. The contemporary interpretation is that equilibrium is a significant and useful concept but that it is not universally applicable. There is not necessarily a single or final equilibrium state, and equilibria can be visualised in different ways, including as a metaphor.

Table 6.1 Progress in the identification of equilibrium states in geomorphology

Concept	Statement	Source
Equilibrium	'Streams erode or build up their beds until equilibrium is attained between force and resistance …'	Domenico Guglielmini, 1697, quoted Baulig, 1926
Equilibrium	'A river has equilibrium (stability), or its speed and that of grade, when in times of greatest flood its rapidity is such that the tenacity of its bed is equal to the force and opposes the erosion not only of the bottom but also of the sides of bed and the foot of its banks … Thus by equilibrium we mean the relation between velocity of flow and resistance of bed-rock …'	Du Buat, 1786, I: 110.
	'A river from its source to the sea depicts the different ages of man. Its BEGINNING is a mere nothing … Its INFANCY is frolicsome and capricious … Its YOUTH is impetuous and hasty; it buffets uproots and overturns. Its MIDDLE COURSE is serious and wise; it makes detours and yields to circumstances. In OLD AGE its step is measured, peaceful, majestic and silent …'	Du Buat, 1786, I: xxxii–xxxiii
Equilibrium	'A period of erosion and building-up which prepares the bed of the thalweg and everywhere brings the gradients into equilibrium with the resistance of the ground and the friction of the water …'	Alexandre Surell, 1841: 126
Equilibrium	'The gradient of the stream and the form of each of its sections are the result of an equilibrium between the force of the current and the resistance of the materials of the river beds … The forms of the solids which suffer attack from atmospheric agents also follow from it; they are also the result of an equilibrium which endeavour to carry off the particles of these solids and the forces which hold them back …'	M. Dausse, 1872: 321

Concept	Statement	Source
Grade Equilibrium	'… a stream which has a supply of debris equal to its capacity, tends to build up the gentler slopes of its bed and cut away the steeper. It tends to establish single, uniform grade. Where hard rocks have produced declivities, there the capacity for corrosion will be increased. The differentiation will proceed until the capacity for corrasion is everywhere proportional to the resistance, and no further, – that is until there is an equilibrium of action'.	G.K. Gilbert, 1877: 112 G.K. Gilbert, 1877: 113
Equilibrium	'In youth of cycle of erosion no part of a river has reached equilibrium between its velocity and the amount of material carried, but maturity is when equilibrium is approached between the river's transporting power and load'.	W.M. Davis, 1884
	'Following certain French writers, the profile of the stream when this balanced condition is reached has been called "the profile of equilibrium" … "Mr Gilbert has recently suggested to me that a stream in this condition of balance between degrading and aggrading might be called a "graded stream" and its slope a "graded slope" …'	W.M. Davis, 1894
Equilibrium	'The concept of equilibrium of slopes is thus inseparable from the idea of the vegetation which determines it …'	De La Noe and De Margerie, 1888: 47

Table 6.2 Developments of equilibrium after Davis

Concept	Statement	Source
Graded stream	'There is no time when graded conditions are attainable; thus defines grade in terms of profile so that a graded stream should be taken as one without waterfalls or rapids'.	J.E. Kesseli, 1941
Graded stream	'A graded stream is one in which, over a period of years, the slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium'.	J.H. Mackin, 1948
Equilibrium theory of erosional slopes	'The concept of equilibrium has long been applied to graded streams and their associated slopes but the nature of this equilibrium and its basic similarities with other systems of equilibrium in nature seem not to have been fully examined. A graded system is perhaps best described as an open system in a steady state …'	A.N. Strahler, 1950: 676
Dynamical basis of geomorphology	Outlined as 'a system of geomorphology founded in basic principles of mechanics and fluid dynamics, that will enable geomorphic processes to be treated as manifestations of various types of shear stresses, both gravitational and molecular, acting upon any type of earth material to produce the varieties of strain, or failure, which we recognize as the manifold processes of weathering, erosion, transportation and deposition'.	A.N. Strahler, 1952: 923
Equilibrium in regime	'A variety of terminology has been used to express this condition. A stream in equilibrium is said to be a graded stream, a poised or balanced stream, or to be a regime stream or a stream in regime. For engineering purposes a section of a stream may, therefore, be said to be in equilibrium, even though it may continually fluctuate between aggradation and degradation, and over a long period of years, the net amount of change is not sufficiently large to be detected by quantitative measurements. It is believed that most alluvial streams, where not affected by the works of man, may thus be said to be in this equilibrium or graded condition'.	E.W. Lane, 1955

Concept	Statement	Source
Dynamic equilibrium	'It is assumed that within a single erosional system, all elements of the topography are mutually adjusted so that they are down-wasting at the same rate. The forms and processes are in a steady state of balance and may be considered as time-independent'.	J.T. Hack, 1960: 81
Concept of grade	Is 'unserviceable both in the study of actual terrains and the theoretical analysis of landform generally'.	G.H. Dury, 1966
Grade	Grade is generally considered synonymous with equilibrium. Despite difficulties of definition the concept of equilibrium is a useful one.	Leopold, Wolman and Miller, 1964

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Allison, R.J. (1996) Slopes and slope processes, *Progress in Physical Geography,* 20: 453–65.

Church, M. and Mark, D.M. (1980) On size and scale in geomorphology, *Progress in Physical Geography,* 4: 342–90.

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

UPDATES

Transient adjustment, whether between equilibrium states or indefinitely, is to be expected in a world in which hydrology, sediment supply, and base level are not fixed and this paper elaborates the episodic nature of bed material transport and the production of river morphology: Church, M. and Ferguson, R.I. (2015) Morphodynamics: Rivers beyond steady state, *Water Resources Research*, 51: 1883–97.

Building upon empirical evidence which shows that many geomorphic systems are in transient state or out of equilibrium with respect to the external driving forces, a paper which presents a mathematical concept based on reservoir theory to model residence time of sediment using millennial scale sediment budgets and aims to estimate the sediment residence time in storages is Hoffmann, T. (2015) Sediment residence time and connectivity in non-equilibrium and transient geomorphic systems, *Earth-Science Reviews*, 150: 609–27.

Study of a small glacier in central Austria indicates evolution of the glacier geometry towards steady state so that the glacier disappears by the year 2040: Carrivick, J.L., Berry, K., Geilhausen, M., Rippin, D.M. and Carver, S.J. (2015) Decadal-scale changes of the Ödenwinkelkees, Central Austria, suggest increasing control of topography and evolution towards steady state, *Geografiska Annaler, Series A: Physical Geography*, 97: 543–62.

Turing's model published in 1952 on 'The chemical basis of morphogenesis' showed how random fluctuations can drive the emergence of pattern and structure from initial uniformity. As the spontaneous appearance of pattern and form in a system far away from its equilibrium state occurs

in many types of natural process it is pertinent to geomorphology: Ball, P. (2015) Forging patterns and making waves from biology to geology: A commentary on Turing (1952) The chemical basis of morphogenesis, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 370: 1666.