11

PROCESS-FORM MODELS

The interaction of process and landform is central to geomorphic investigations and a series of concepts have been associated with the models of landscape development suggested over the last century. Process investigations were enhanced by considering the way in which specific landscape features are related to processes, as illustrated by grade, characteristic angles, drainage density and river channel capacity. Technique developments, especially of cosmogenic dating, have revitalised some earlier models. The complex response concept affords the reconciliation of alternative landscape histories, and a panoply of models is now becoming available offering opportunities to realize the objectives of the original qualitative approaches.

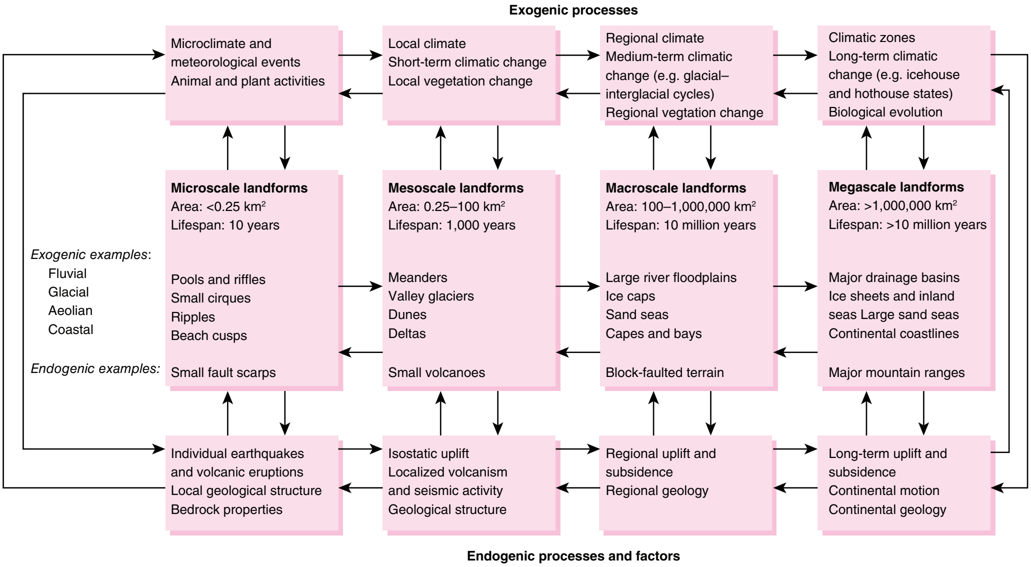
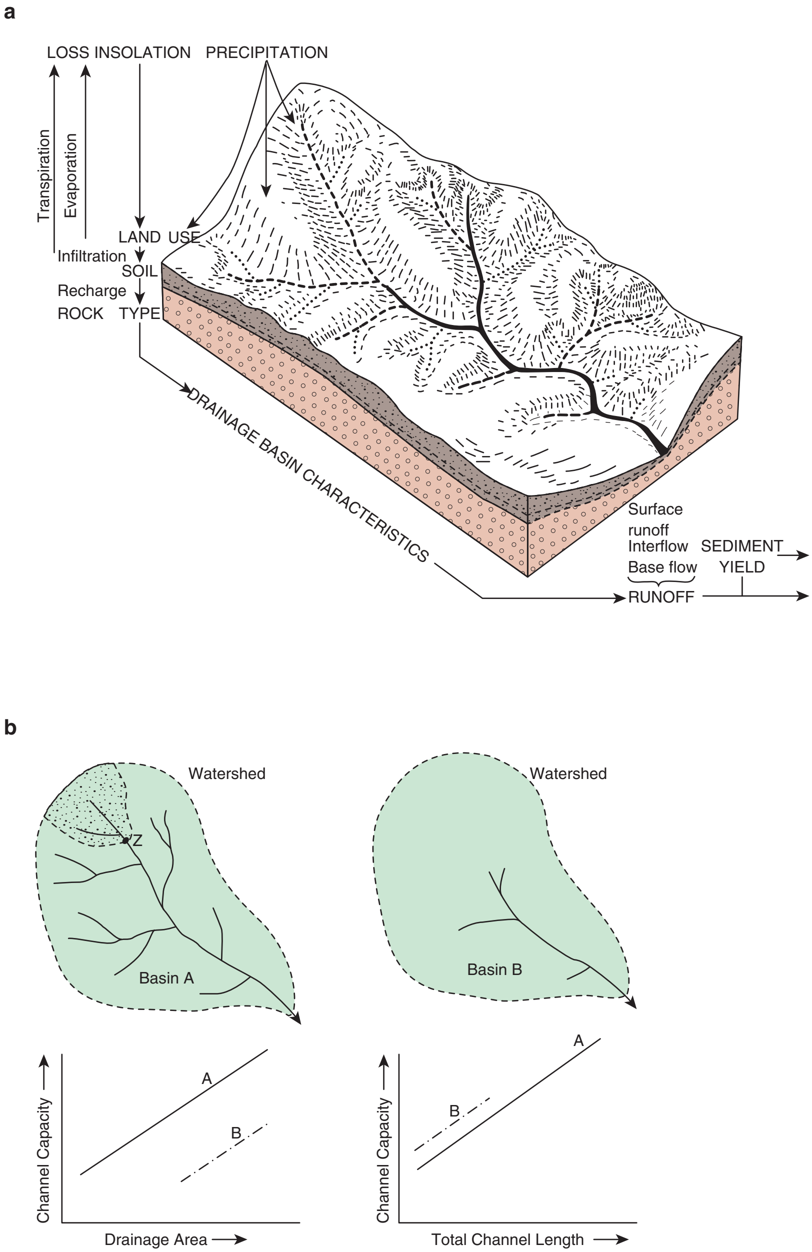


Figure 11.1 Geomorphic form and process interactions (after Huggett, 2011, following Huggett, 2007, *Fundamentals of Geomorphology* 2nd edn., Routledge, London, with permission)


a
LOSS INSOLATION
PRECIPITATION
Transpiration
Evaporation
LAND USE
Infiltration
SOIL
Recharge
ROCK TYPE
DRAINAGE BASIN CHARACTERISTICS
Surface runoff
Interflow
Base flow
SEDIMENT YIELD
RUNOFF
b
Watershed
Z
Basin A
Watershed
Basin B
Channel Capacity
A
B
Drainage Area
Channel Capacity
A
B
Total Channel Length

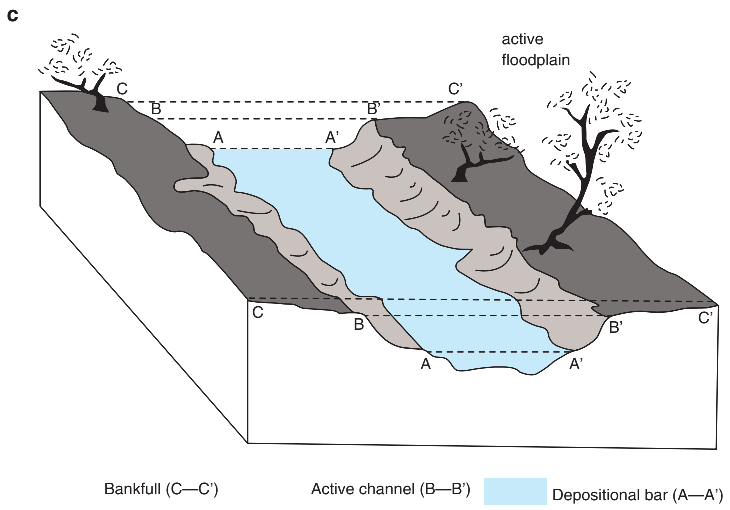


Figure 11.2

a. A view of the drainage basin showing emphemeral (dotted), intermittent (dashed) and perennial components of the drainage network;
b. relationships of channel capacity and drainage area and total channel length;
c. definition of river channel capacity (from Osterkamp and Hedman, 1982)

Table 11.1 Models of landscape development which visualise an ultimate characteristic form

Model	Ultimate Form Visualised	Author
Davisian model	**Peneplain** – 'a plain without relief' (Davis,1899: 497) and the culmination of the normal cycle of erosion which could be used to classify any landscape according to the stage that it had reached in the erosion cycle, whether youthful, mature, or old age. In addition to proposing that landscape was a function of structure, process and time (or stage) Davis suggested that whereas the normal cycle was the work of rain and rivers, arid landscapes were fashioned under the arid cycle of erosion, and in the marine cycle particular attention was given to shorelines of emergence or of submergence. In addition there were two principal accidents to the normal cycle, volcanic activity and the glacial accident.	W.M. Davis (1850–1934)
Penck model	**Slope replacement** – each slope segment retreating upslope parallel to itself, but being replaced by one at a lower angle advancing upslope. Viewed the shape of landforms as the product of the ratio between the rate of endogenous movement and the rate of erosion. Did not see landforms following predictable sequences, but rather following possible pathways that reflected the changing interplay between uplift and erosional intensity (rates). His model focused primarily on slope development with uniform rates of downcutting by rivers into an uplifting surface producing straight slopes, accelerating rates of downcutting during accelerated uplift (waxing development) producing slopes of convex profile, and decreasing rates of downcutting during periods of decreasing uplift (waning development) producing slopes of concave profile.	W. Penck (1888-–1923)
King model	**Pediplain** – produced by coalescence of pediments and dominated by concavities with residual landforms referred to as inselbergs or bornhardts. Parallel retreat of slopes, pediplanation and the processes of lower latitudes were the norm rather than temperate areas (of the Davisian normal cycle), and correlated surfaces from Africa, to South America and Australia. Process produced time-transgressive upland surfaces and involved large-scale crustal deformation dominated by vertical movement that does not greatly disturb rock structures called cymatogeny.	Lester C. King (1907–1989)

(*Continued*)

Table 11.1 (Continued)

Model	Ultimate Form Visualised	Author
Peltier morphogenetic regimes	**Periglacial cycle** – identified nine possible world morphogenetic regimes, each distinguished by a characteristic assemblage of geomorphological processes, developed from earlier ideas of Davis and Penck but by implying a periglacial cycle attracted all the criticisms levelled against the Davisian cycle.	Peltier, 1950
Hack dynamic equilibrium	**Dynamic equilibrium** – achieved between process, lithology and gradient with the implication that topographic variability is derived from spatial variation in rock resistance and process intensity rather than from long-term cyclical development.	J.T.Hack
Büdel climate-genetic geomorphology	**Double etchplain** – deep weathering profiles focus on two surfaces where change potentially occurs, or what Büdel (1957) referred to as a double surface of levelling (*doppelten einebnungsflachen*). Deep weathering continues to extend the basal weathering front or surface, the line at variable depth below the surface that marks the contact of sound rock beneath from weathered rock above. The shape of this weathering front, often at depths as much as 30–50m below the surface, depends upon rock composition and structure, the hydrological conditions, and the recent history of the area. In addition to change occurring at this lower surface, there is also denudation on the upper land surface, by weathering, erosion and deposition and especially by water in fluvial processes.	J. Büdel (1903–1983)

Table 11.2 Examples of the application of cosmogenic dating

Area Studied	Conclusions	Reference
Rio Puerco Basin, New Mexico	Analysis of *in-situ*-produced ^{10}Be and ^{26}Al in 52 fluvial sediment samples shows how millennial-scale rates of erosion vary widely (7 to 366 m Ma^{-1}). Using isotopic analysis of both headwater and downstream samples, determined that the semi-arid Rio Puerco Basin is eroding, on average, about 100 m Ma^{-1}.	Bierman et al., 2005
Granite dome, north east of Seoul, South Korea	Measured concentrations of ^{10}Be and ^{26}Al produced in situ at bare bedrock surface and calculated exfoliation rate of sheeting joints to average 5.6cm.ka^{-1}	Wakasa et al., 2006
North west Tibet	Concentrations of in situ produced cosmogenic nuclides ^{10}Be and ^{26}Al in quartz measured basalts and sandstones giving effective exposure ages between 23 and 134ka (^{10}Be) and erosion rates between 4.0 and 24 mm ka-1.	Kong et al., 2007
Colorado River, Glen Canyon, Utah	Calculate episodic incision rates between c.500 ka and c. 250 ka to be 0.4m ka^{-1} and between c.250 ka to present to be c.0.7 m ka^{-1} These rates more than 2x the rates reported in the Grand Canyon.	Garvin et al., 2005
Dolly Sods, West Virginia, a classic Appalachian paleoperiglacial plateau	Measured erosion rates using ^{10}Be from bare-bedrock surfaces, giving mean erosion rate from nine samples of 5.7 m/m.y., significantly lower than previously estimated periglacial erosion rates in this region.	Hancock and Kirwan, 2007
Cascades mountains of Washington state	Show that strongly varying long-term (>10^6–10^7 yr) erosion rates across the Cascades mountains of Washington State closely track modern mean annual precipitation rates. Erosion and precipitation rates vary over an order of magnitude across the range, with maxima of 0.33mm yr^{-1} and 3.5 mm yr^{-1} respectively.	Reiners et al., 2003
Eastern Altiplano, Bolivia	Agreement between the denudation rates and published modern sediment discharge data suggests steady landscape evolution of the eastern Altiplano from the latest Pleistocene until today. Results show the importance of sediment storage even over short distances, and that long-lived ^{10}Be and ^{26}Al nuclides can provide adequate estimates on long-term denudation rates even if sediment transport is not fast but interrupted by several thousands of years of storage.	Hippe, K. et al., 2012

(*Continued*)

Table 11.2 (Continued)

Area Studied	Conclusions	Reference
Exhumation and incision history of the Lahul Himalaya, northern India	Provide a first approximation of long-term (10^4–10^6 years) exhumation rates for the High Himalayan Crystalline Series (HHCS) for northern India. For two sites along the Chandra River show maximum incision rates of 12 and 5.5 mm/a. Plio-Pleistocene erosion and exhumation can be characterized by disequilibrium, where longer term rates are relatively slower and shorter term fluvial erosion is highly variable over time and distance. Significant variances are possible in Himalayan river incision, highlighting the complexity of Himalayan environments.	Adams, B. et al., 2009
Exposure ages of tors and erratics, Cairngorm Mountains, Scotland	Test for the preservation of pre-Quaternary landscapes, with cosmogenic surface exposure dating of tors, reveal that these landforms are more dynamic and younger than previously suspected. Many Cairngorm tors have been bulldozed and toppled along horizontal joints by ice motion, leaving event surfaces on tor remnants and erratics that can be dated with cosmogenic nuclides. Show that dry-based ice caps are capable of substantially eroding tors by entraining blocks previously detached by weathering processes. While many Cairngorm tors have survived multiple glacial cycles, rates of regolith stripping and bedrock erosion are too high to permit the widespread preservation of pre-Quaternary rock surfaces.	Phillips, W.M. et al., 2006

Table 11.3 A synopsis of the development of the concept of grade

Has been described as 'one of the most confusing concepts in geomorphology because of its inextricable relationship with gradient' (Kennedy, 2000), but is generally thought of as a concept of equilibrium in which a river or slope is just capable of maintaining a balance between erosion, transport and deposition.

Stage	Development
Precursors (see Chapter 6)	Engineers concerned with the regulation of natural rivers or with the construction and operation of artificial channels that would exhibit stability of geometry. This stability or equilibrium, which came to be termed 'grade', was thought to occur when significant features of hydraulic geometry remained more or less constant over a recognized period of time or were subject to oscillation only within a narrow range. Stability tended to be associated with either some sort of balance between sets of factors and major contributors were *Guglielmini* (1697), *Brahams* (1753), *Chézy* (1775), *Du Buat* (1786), *Surell* (1841), *Dausse* (1857 and 1872), and *Sternberg* (1875). Grade was concerned largely with alluvial channel processes and forms, concentrated on the balance of factors which tended to produce stable alluvial channels, largely concerned with equilibrium in sedimentary transport, and on short-term changes and adjustments (see Chorley, Dunn and Beckinsale, 1964).
G.K.Gilbert (1877)	Believed that a graded stream is one on the verge of erosion and deposition which is fully loaded (i.e., at maximum capacity), in the sense that it has all the load of a given degree of comminution which it is capable of carrying and has all its energy consumed by the translation of water and load, with none being applied to corrosion. The important implication of a stream being at grade was that additional load will decrease velocity, cause deposition, increase bedslope and, thus, through negative feedback, increase velocity until the new load can be transported. According to Pyne (1980: 89), Gilbert viewed whole landscapes as operating in a steady state within which streams behaved like engines performing work according to the laws of thermodynamics. Conducted flume experiments (Gilbert, 1914) attempting to isolate the individual controls exercised by slope, discharge, bedload and channel form over stream capacity.

(*Continued*)

Table 11.3 (Continued)

W.M.Davis (1902)	Encompassed Gilbert's ideas on grade into his cycle of erosion, but according to Chorley (2000: 567) based his concept of grade on a number of half-truths including that velocity is entirely controlled by slope; a complete negative-feedback relationship between slope and velocity; and the ability to perform work is largely a function of velocity. Thus removing the multivariate difficulties the concept of grade was reduced to a relatively simple part of Davis's straightforward vision of landform development. Therefore the condition of grade was entirely achieved through modifications of gradient, such that the elimination of breaks of slope became for Davis the hallmark of the graded condition. Applied the concept to slopes as well, suggesting a balance between the material to be moved and the potential to move it.
J. Kesseli (1941)	Described by Chorley (2000: 568) as 'a most cynical geomorphologist', he proposed that the concept of grade should be abandoned both for streams and slopes.
J.H. Mackin (1948)	His concept of the graded river, providing a foundation for the development of quantitative geomorphology, focused on the external (load and discharge) and internal variables and gave a definition of a graded river as 'one in which, over a period of years, slope [and channel characteristics are] delicately adjusted to provide, with available discharge just the velocity required for the transportation of the load supplied from the drainage basin. The diagnostic characteristic of a graded stream is that any change in any of the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change' (Mackin, 1948: 471). Mackin also proposed the relation between different timespans on the one hand, and processes and change on the other, an idea later explored by Schumm and Lichty (1965) as shown in Chapter 12.
L.B. Leopold and T. Maddock (1953)	Elaborated Mackin's definition to 'A graded stream is one in which, over a period of years, slope, velocity, depth, width, roughness, pattern and channel morphology delicately and mutually adjust to provide the power and efficiency necessary to transport the load supplied from the drainage basin without aggradation or degradation of the channels' (after Leopold and Bull, 1979: 195), and having identified some 10 variables in the tendency for a river to maintain Mackin's graded state divided them into three groups (i.e., independent, semi-dependent and dependent).

G.H. Dury, (1966)	Emphasised the dual origin of concept – from the work of civil engineers concerned with stabilizing channels, and work on the channels of natural streams, as included in the Davisian cycle. In light of recent work concludes that the concept is unserviceable both in the study of actual terrains and in theoretical analysis of landform generally.

Several strands emerged in the development of the concept: graded condition connoting equilibrium/balance between processes of subaerial erosion and deposition, graded profile as an end state, relation between process and form equilibrium, graded time. Although now part of the history of geomorphological ideas it is necessary to know of the concept, its duality, its role in equilibrium, and the effect that it had on shaping other ideas. The notion of equilibrium in channels is pertinent to explanations sought including LAP (see Chapter 10), and featured as an important element in process-response system analysis because graded stream is a process response system in steady state equilibrium (see Chapter 6).

Table 11.4 Reasons for recent transformations in process-response and form-process investigations

Approach	Type of Contribution	Source
Modelling	**Numerical modelling** of landscape evolution following plate tectonics revolution and developments in analytical and geochronological techniques. One of the most stimulating of recent conceptual advances has followed the considerations of the relationships between tectonics, climate and surface processes, and especially the recognition of the importance of denudational isostasy in driving rock uplift (i.e., in driving tectonics and crustal processes). As we begin to ask again some of the grand questions that lay at the heart of geomorphology in its earliest days, large-scale geomorphology is on the threshold of another 'golden' era to match that of the first half of the 20th century, when cyclical approaches underpinned virtually all geomorphological work.	Bishop, 2007
	The response of a surface processes model (SPM) to tectonic forcing using Linear systems analysis and a number of model experiments illustrate the importance of 'fundamental form', which is an expression of the conformity of antecedent topography with the current tectonic regime. A lack of conformity leads to models that exhibit internal thresholds and a complex response.	Kooi and Beaumont, 1996
	Numerical surface process models (SPMs) of long-term landscape evolution, especially in relation to the links between tectonics and topography.	Codilean et al., 2006
	Quantitative models for the formation of lateral shear margin moraines.	Hindmarsh and Stokes, 2008
	Predictive models incorporating the behavioural and mechanical characteristics of coastal cliffs for coastal recession model.	Castedo et al., 2012
	Statistical, process-response model of soft cliff erosion is proposed.	Hackney et al., 2013
	Spatially lumped process–response model which calculates long time series (10^3–10^6 years) of fluvial water discharge and sediment load at the river catchment outlet, based on climatic data, drainage basin characteristics and user-defined parameters.	Forzoni et al., 2013
	Digital elevation models (DEMs) applied to gully system, digital photogrammetry; digital elevation model (DEM) applied to glacial recession and landform production.	Betts et al., 2003

Approach	Type of Contribution	Source
	Progress with **new models** revealing how interactions between hydrology, fluvial erosion, slope processes, tectonic uplift, climate and hydrology influence the drainage network and catchment form.	Coulthard, 2001
	Cellular models that simulate the processes operating within river channels and drive their geomorphic evolution.	Coulthard et al., 2007
	Coherent **inversion model** for derivation of flow patterns and interior ice-sheet configuration from geomorphological data.	Kleman and Borgstrom, 1996
	A resurgence of **interest in landscape evolution** has occurred as computational technology has made possible spatially and temporally extended numerical modelling.	Martin and Church, 2004
	Create models capable of revealing **emergent aspects of spatially distributed interactions between form and process**, is common to all geomorphologists engaged with the meso-scale for coastal geomorphology.	French and Burningham, 2009
Advances in techniques	**Airborne lidar** enabling a more effective conceptualisation of landforms in the field.	Roering et al., 2013
	Tentative initial application of the **sediment budget approach** to Pleistocene terrace staircase in unglaciated basins is discussed. It is argued that only now do we have the techniques available to be able to produce accurate sediment budget estimations at spatial scales greater than that of zero order basins and over time periods greater than that covered by direct observations.	Brown et al., 2009
	Empirical field and wind tunnel data have allowed the calibration of mathematical models which are now at a stage where the flow field around dunes can be calculated.	Wiggs, 2009
Conceptual	**Conceptual** model for complex river responses.	Dust and Wohl, 2012
	Mathematically reviewing reasons for missing peneplains.	Phillips, 2002
	Conceptual frameworks emphasizing single path outcome trajectories of change have been supplemented by multi-path, multi-outcome perspectives.	Phillips, 2009
GIS	Potential of GIS enables a range of modelling applications. (See Figure 4.3.)	Oguchi and Wasklewicz, 2011

BOX 11.1

The Davisian model

Some reactions

‘Geomorphology will probably retain his stamp longer than that of any other single person’ (Thornbury, 1954).

Davis stated ‘both organized and systematized geography in the United States and won recognition for the subject as a mature science and as an academic discipline’ (Chorley, Beckinsale and Dunn, 1973: 734).

‘For more than half a century it remained the dominant template for landscape interpretation. It portrayed landscape as a staged sequence of erosional transformations of an initially elevated landmass’ (Church,1996: 149).

‘Perhaps the most enduring element of the application of the Cycle is the peneplain, the low relief surface that Davis argued characterizes the Cycle’s end stage (‘old age’)’(Bishop, 2011: 492).

Reasons for success (12 reasons suggested by Higgins,1975):

1. Simplicity – in particular the initial uplift.
2. Applicability – by students to a wide range of erosional landscapes.
3. Presentation in a lucid, compelling and disarming style – the style of writing and the numerous line drawings and sketches.
4. Apparent basis of careful field observations – although no measurements were made, did relate to actual examples; particularly in relation to the geological community.
5. It filled a void – and complemented uniformitarianism.
6. It synthesized contemporary geological thought – it incorporated concepts that had been introduced by others including base level (Powell, 1834–1902), graded stream (Gilbert, 1843–1918), and the profile of equilibrium advocated by French engineers.
7. It provided a basis for prediction and historical interpretation – this enabled geomorphology to use land form study as a tool for deciphering the later stages of earth history and to function as a part of historical geology; reasons that influenced the popularity of Davis’s concepts.
8. It was rational – and appealed to positivists.
9. It was consistent with evolution.
10. It appeared to confirm stratigraphic thought of the time – namely a tectonic model of rapid diastrophism followed by a long period of coastal stability and rest.

11 It set humid temperate as ‘normal’ and this was attractive to many earth scientists.

12 The cyclic approach was also attractive to many earth scientists.

Criticisms levelled

a. Technical difficulties – not a cycle at all but a one-way movement of mass from a higher to a lower elevation; assumes initial uplift; led to a dogma of progressive, irreversible and sequential change; although reflecting the idea of Darwinian evolution did not have a solid scientific foundation.

b. Partial – did not allow for the climate change of the Quaternary and so inclined students to focus upon landscape development prior to the last two million years; focused upon the remnants of prior landscapes which make up as little as 10% of landscape.

c. Insufficient awareness of land-forming processes – and what was included was very qualitative.

d. Could not allow for human activity – effects of climate change including periglaciation.

BOX 11.2

Drainage density

The *river channel network*, especially its dynamic properties, has frequently been considered at the basin scale in terms of flood routing and hydrological basin modelling, separate from the channel at a cross section (the hydraulic geometry), and from the river channel pattern along a specific reach, including the relationship with the floodplain. A drainage network is dynamic, embracing perennial, intermittent and ephemeral channels (see Figure 11.2a), and in a humid area drainage basin the range of density of the network composed of these three types of channel varies, according to storm events and to prevailing antecedent conditions from 1.0 to 5.0 km.km^{-2}; whereas in arid regions, although the density of perennial channels is usually very low, the density of all channels, including the ephemeral ones, is comparatively high (up to 10 km.km^{-2}) because low vegetation density affords little resistance to the production of ephemeral channels during the infrequent storms with high rainfall

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(*Continued*)

intensities. Such variations in drainage density between different areas, and within a single basin according to prevailing hydrological conditions, have to be related to the channel and floodplain dynamics elsewhere in the drainage basin (Gregory, 1976). In a humid basin discharge increases downstream because there are no effluent or transmission losses below the channel bed. However, in arid areas or on permeable rocks such as limestone, where the saturation level is not at the channel bed, the discharge may decrease downstream as a consequence of effluent seepage or transmission losses into the bed. In March 1978 a flood lasting several days, with a peak of 3500 m^3s^{-1} along the Salt River in central Arizona, had transmission losses of 17% (Aldridge and Eychaner, 1984). Such transmission losses vary over time as the saturation level fluctuates, emphasizing the need for a three-dimensional view of the dynamics of the river channel network within the drainage basin (Figure 11.2b). Some past interpretations of the relationships of drainage density with climate or with streamflow parameters have been incorrect because they have treated drainage density as a static and unchanging parameter, whereas it changes during storm events (e.g., Gregory and Walling, 1968) and analyses must take this into account.

BOX 11.3

River channel capacity

Definition of river channel capacity is not easy because channels can be compound in cross section, they may be not clearly differentiated from the floodplain, and they may alter due to short-term storm events (Figure 11.2c).

Definition of the river channel cross section can be based upon:

- morphology – guided by minimum width-depth ratio, bench index, definition of the active channel (Osterkamp et al., 1983) or overtopping level (Wharton, 1995);
- sedimentological evidence – including the height of point and alluvial bars;
- ecological/biotic evidence – using trees, grass, shrubs, indicator species, or lichen limits (Gregory, 1976b);
- evidence from recent flood events – by referring to trash lines.

Defining river channel cross-section end points to a consistent level is necessary so that channels can be compared spatially, throughout one drainage basin or between drainage basins. Channel capacity is usually defined as the cross-sectional area of the river channel as far as the sharp morphological break in slope at the contact with the floodplain. Considerable variety of river channel form, including bedrock channels, is now appreciated so that the channel capacity simply determined in many hydraulic analyses by connecting four points is an oversimplification. Therefore the several possible definitions of capacity need to be kept in mind (Figure 11.2c), particularly when relating channel capacity (m^2) to controlling variables including discharge (e.g. Wharton, 1995). Incised channels, that at some point in their history have undergone, or are currently undergoing, bed-level lowering (Simon and Darby, 1999), present a particular problem. Relationships between the dimensions of the cross-section, such as width, depth and slope as dependent variables, with independent variables such as discharge, give a set of hydraulic geometry relationships, providing a basis for comparisons of rivers (Park, 1977). The morphological character of river channel form in a specific basin can be provided by the regression relation between drainage area as the independent variable and channel capacity as the dependent variable (Figure 11.2b); data from 60 different basins (Gregory and Maizels, 1991) showed how channel capacity varies within particular basins and from one to another. A decision about channel size appropriate for a particular location needs to consider not only position in the basin but also characteristics of that basin – there can be up to 10 times difference in channel size, with ephemeral channels in arid basins larger than equivalent ones in humid temperate areas (Chin and Gregory, 2001).

At any specific location along a river, river channel capacity reflects the interaction of water and sediment discharge with local factors including sediment in the bed and banks, vegetation and slope. The frequency of discharge at the bankfull stage, or the channel capacity discharge, was thought to be a ‘dominant discharge’ corresponding broadly to the mean annual flood with a recurrence interval of 1.58 years on the annual flood frequency series (Gregory and Madew, 1982). However, subsequent research showed that the frequency of occurrence of the bankfull discharge was a range of flows with recurrence intervals in the range 1 to 10 years (Williams, 1978). Whereas early research concluded that dominant discharge with a particular recurrence interval accounted for the cross-sectional area of the channel, it was subsequently realized that a range of flows controls channel landform, that the significant controlling discharges can vary along the course of any one river, and, in some areas, short-term sequences of events of differing magnitude (e.g., flood- or drought-dominated) may affect channel morphology.

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Cockburn, H.A.P. and Summerfield, M.A. (2004) Geomorphological applications of cosmogenic isotope analysis, *Progress in Physical Geography,* 28: 1–42.

Codilean, A.T., Bishop, P. and Hoey, T.B. (2006) Surface process models and the links between tectonics and topography, *Progress in Physical Geography,* 30: 307–33.

Ebert, K. (2009) Terminology of long-term geomorphology: a Scandinavian perspective, *Progress in Physical Geography,* 33:163–82.

Graf, W.L. (2013) James C. Knox (1977) Human impacts on Wisconsin stream channels, Annals of the Association of American Geographers, 67: 224–244, *Progress in Physical Geography,* 37: 422–31.

Wiggs, G.F.S. (2009) Desert dune processes and dynamics, *Progress in Physical Geography,* 25: 53–79.

UPDATES

The use of long-term landscape evolution models are often thought of as of theoretical interest (Section 11.1, p. 115) but can be used to simulate and assess the geomorphic stability of a conceptual rehabilitated landform illustrated for the Ranger uranium mine in the Northern Territory, Australia, for a simulated period of up to 1000 years as shown by:

Hancock, G.R., Lowry J.B.C. and Coulthard, T.J. (2015) Catchment reconstruction – erosional stability at millennial time scales using landscape evolution models, *Geomorphology*, 231: 15–27.

A study linking form to process is made through conceptualizing form–process relationships for riffle-pool couplets into geomorphic covariance structures (GCSs) that are then quantitatively embedded in a synthetic channel model, showing that GCSs are a useful way to translate conceptualizations of form–process linkages into quantitative models of channel form: Brown, R.A., Pasternack, G.B. and Lin, T. (2016) The topographic design of river channels for form–process linkages, *Environmental Management*, 57: 929–42.

Although landscape evolution models (LEMs) do not explicitly consider spatially explicit solar radiation as model forcing a paper which designs a set of comparative LEM simulations to investigate the role of spatially explicit solar radiation on landscape ecohydro-geomorphic development under different uplift scenarios is: Yetemen, O., Istanbulluoglu, E., Flores-Cervantes, J.H., Vivoni, E.R. and Bras, R.L. (2015) Ecohydrologic role of solar radiation on landscape evolution, *Water Resources Research*, 51: 1127–57.