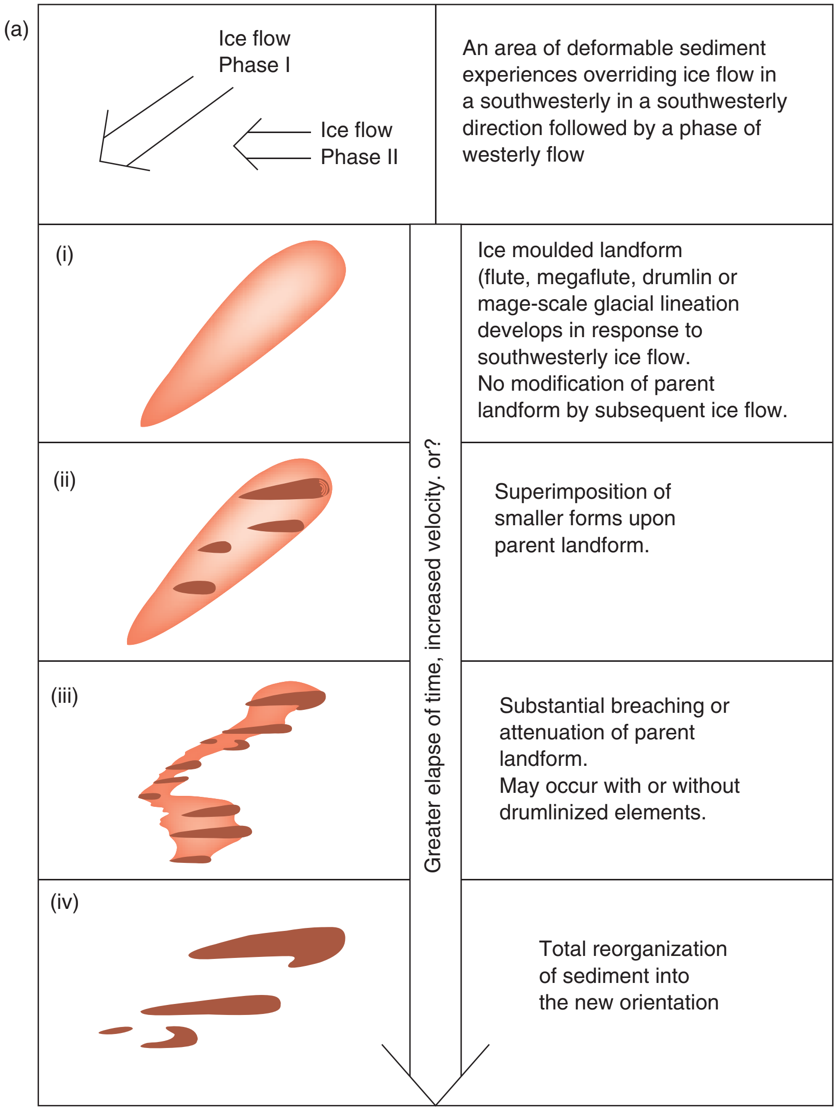
14

CHANGE TRAJECTORIES

There have been many attempts to track the change sequences that result from form development, including responses to climatic and other disturbances. These may be conceptualized diagrammatically or they may derive from physical or mathematical modelling. Some research suggests that change sequences have multiple paths and outcomes; others propose that the end results from different processes are very similar. Complexity characterizes many systems, partly because of their hierarchical nature and also because the allogenic contexts or spatial configurations in which active systems operate are very varied.



An area of deformable sediment experiences overriding ice flow in a southwesterly in a southwesterly direction followed by a phase of westerly flow

Ice moulded landform (flute, megaflute, drumlin or mage-scale glacial lineation develops in response to southwesterly ice flow.
No modification of parent landform by subsequent ice flow.

Superimposition of smaller forms upon parent landform.

Substantial breaching or attenuation of parent landform.
May occur with or without drumlinized elements.

Total reorganization of sediment into the new orientation

Figure 14.2 Theoretical development of subglacial forms overridden and remoulded by ice flow from a different direction (after Clark, 1993)

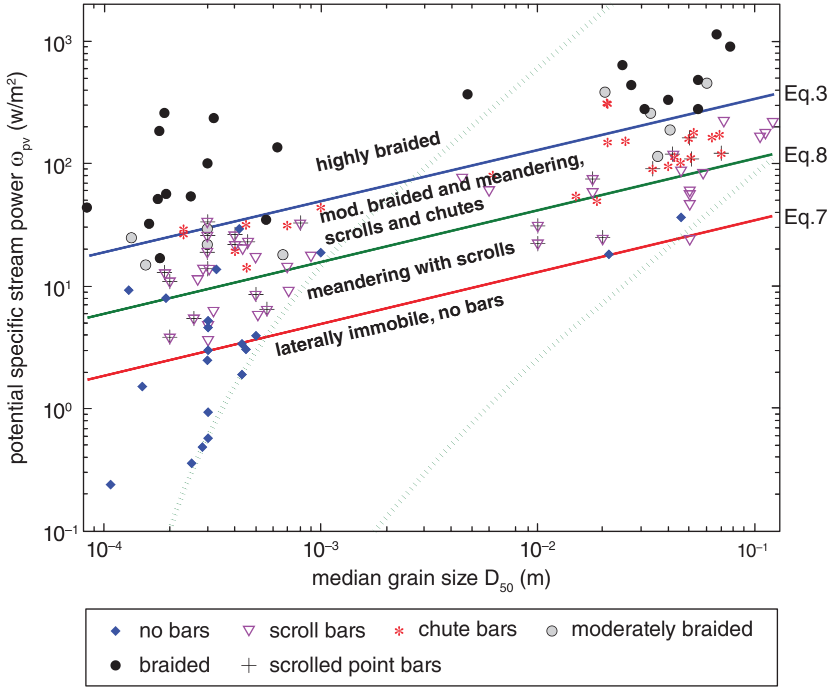


Figure 14.3 Channel forms, potential specific stream power and grain size (from Kleinhans and van den Berg, 2011: Figure 9 (A))

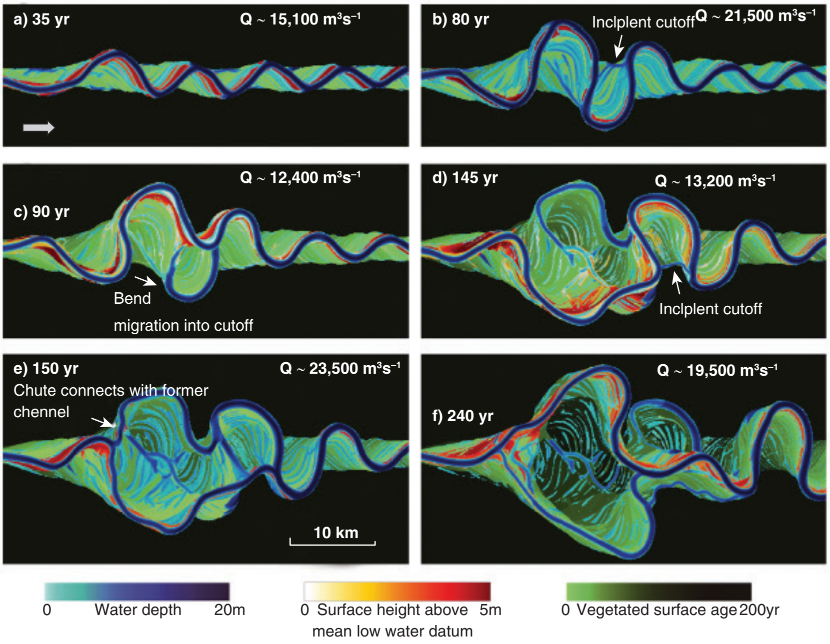
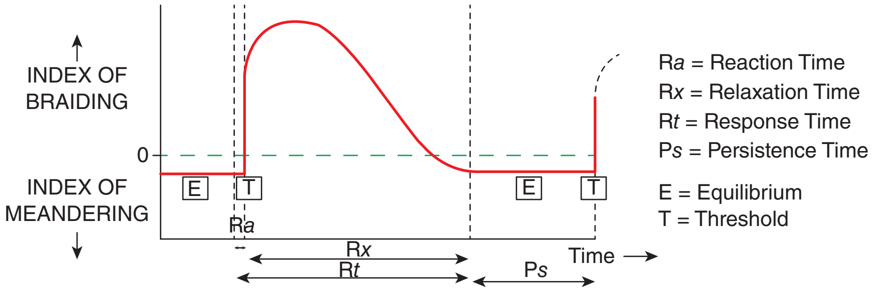
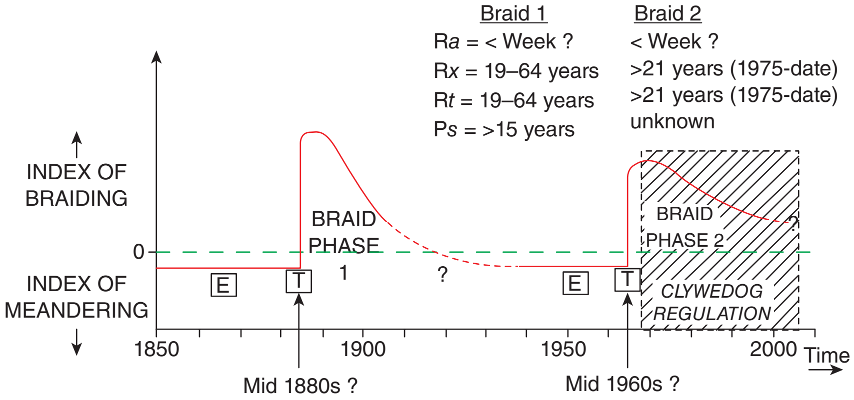


Figure 14.4 Simulated channel pattern and floodplain development (from Nicholas, 2013b)



a) Theoretical threshold-equilibrium plot (based on Bull 1991)



b) Threshold equilibrium plot for Llandinam instability zone

Figure 14.6 Channel pattern changes on a reach of the River Severn, UK, in response to large flood episodes (Brewer and Lewin, 1998)

Table 14.1 Some change-response model types followed in geomorphology (see also Table 7.3 and Figure 9.1)

Type	**Example**	**Comment**
Linear	Simple channel evolution models	As well as being in numerical form, may qualitatively specify a sequence of stages
Complex	Hysteretic sediment loops, multiple flood-response lags	Common in hierarchical and spatially diverse systems, and ones with thresholds and storage capabilities
State transition	River channel metamorphoses; fluvial-glacial transitions	Involve form transformations and catastrophic behaviour

Type	Example	Comment
Cyclical	Davisian cycle of erosion; seasonal/daily cycles of thermally driven activity	Recovering systems (feedback loops) may exhibit cyclical paths in the short term
Radiation	Colonisation and diffusion models	May apply to landscapes in course of modification by spreading human activity, as in degrading forest biomes, or physical dispersal, as of sediment
Convergence/ equifinality	Steady state attractor models (e.g., dynamic equilibrium)	Especially involve progress to common end states, as in desertification arising from multiple causes
Resilience/ steady state	Temperate slope forms unchanged from prior Pleistocene cold-climate generation	May lead to patch preservation of palaeoforms and inheritance, as well as to change insensitivity and immobility

Table 14.3 Examples of numerical landscape evolution models, 1991–2005 (from Tucker and Hancock, 2010)

Model	Example	Notes
SIBERIA	Willgoose et al. (1991)	Transport-limited
DRAINAL	Beaumont et al. (1992)	Transport based on undercapacity'
GILBERT	Chase (1992)	Cellular automaton
DELIM	Howard (1994)	Detachment-limited
GOLEM	Tucker & Slingerland (1994)	Regolith & landsliding algorithm
CASCADE	Braun & Sambridge (1997)	Irregular discretization
CAESAR	Coulthard et al. (1997)	Cellular automaton
ZSCAPE	Densmore et al. (1998)	Stochastic bedrock/landsliding
CHILD	Tucker & Bras (2000)	Stochastic rainfall/runoff
EROS	Crave & Davey (2001)	Modified precipitation algorithm
APERO/CIDRE	Carretier & Lucazeau (2005)	Single/multiple flow directions

Table 14.4 A classification of glacial erosion forms (from Benn and Evans, 2010)

Small-scale	1. Striae and polished surfaces 2. Rat tails 3. Chattermarks, gouges and fractures 4. P-forms
Intermediate	1. Roches moutonnées 2. Whalebacks and rock drumlins 3. Crag and tails 4. Channels
Large-scale	1. Rock basins and overdeepenings 2. Basins and overdeepenings in fine sediment 3. Troughs and fjords 4. Cirques 5. Strandflats

Table 14.5 Alluvial elements according to various authors (from Lewin and Ashworth, 2013)

Happ et al. (1940)	**Beerbower (1964)**	**Miall (1985)**	**Brierley (1991)**	**Nanson and Croke (1992)**
Deposits	Environmental elements	*Architectural elements*	*Morphostratigraphic elements*	*Processes of floodplain formation*
1. Channel-fill 2. Vertical accretion 3. Floodplain (splays) 4. Colluvium 5. Lateral accretion 6. Channel lag	1. Channel (a) Floor (b) Point bar (c) Margin 2. Crevasse channel 3. Levee 4. Channel bar, tops 5. Crevasse distributary 6. Abandoned channel 7. Floodplain (a) Backswamp (b) Swamp (c) Lake (d) Collection	1. Channels (CH) 2. Gravel bars and bedforms (GB) 3. Sandy bedforms (SB) 4. Foreset macroforms (FM) 5. Lateral accretion deposits (LA) 6. Sediment gravity flows (SG) 7. Laminated sheet sands (LS) 8. Overbank fines (OF)	1. Top stratum (a) Sand wedge (b) Poximal (c) Distal 2. Ridge 3. Chute channel 4. Bar platform 5. Basal channel gravels	1. Lateral point-bar 2. Overbank vertical 3. Braid channel 4. Oblique 5. Counterpoint 6. Abandoned channel

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Baosheng Wu, Shan Zheng 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.

Bishop, P. (1995) Drainage rearrangement by river capture, beheading and diversion, *Progress in Physical Geography,* 19: 449–473.

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

Ferguson, R.I. (1986) Hydraulics and hydraulic geometry, *Progress in Physical Geography,* 10: 1–31.

Hewitt, K. (2006) Disturbance regime landscapes: mountain drainage systems interrupted by large rockslides, *Progress in Physical Geography,* 30: 365–93.

Kennedy, B.A. (1997) Schumm, S.A. and Lichty, R.W. 1965: Time, space and causality in geomorphology, *American Journal of Science* 263, 110–19, *Progress in Physical Geography,* 21: 419–23.

Martin, Y. and Church, M. (2004) Numerical modelling of landscape evolution: geomorphological perspectives, *Progress in Physical Geography,* 28: 317–39.

Montgomery, K. (1989) Concepts of equilibrium and evolution in geomorphology: the model of branch systems, *Progress in Physical Geography,* 13: 47–66.

Mosley, M.P. and Zimpfer, G.L. (1978) Hardware models in geomorphology, *Progress in Physical Geography,* 2: 438–61.

Paine, A.D.M. (1985) ‘Ergodic’ reasoning in geomorphology: time for a review of the term?, *Progress in Physical Geography,* 9: 1–15.

Phillips, J.D. (1995) Self-organisation and landscape evolution, *Progress in Physical Geography,* 19: 309–21.

Phillips, J.D. (2003) Sources of nonlinearity and complexity in geomorphic systems, *Progress in Physical Geography,* 27: 1–23.

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

UPDATES

A classic paper that questions the possibility of genuinely 'verifying' and 'validating' numerical models of natural systems is:

Oreskes N., Shrader-Frechette K. and Belitz K. (1994) Verification, validation and confirmation of numerical models in the Earth sciences, *Science*, 263: 641–46.

The theme of simplicity versus complexity in modelling is further explored in:

Larsen, L., Thomas, C., Eppinga, M. and Coulthard, T. (2014) Exploratory modeling: Extracting causality from complexity, *Eos*, 95: 285–92.

For the mathematically-minded, numerical 'landscape evolution models' (LEMs) are reviewed in detail in:

Chen, A., Darbon, J. and Morel, J-M. (2015) Landscape evolution models: A review of their fundamental equations, *Geomorphology*, 219: 68–86.

A growing concern is for forecasting change in what may be called 'socio-biophysical landscapes', that is, ones where both 'human' and 'natural' processes combine to produce outcomes. Van Dyke (2015) demonstrates that what are called 'state-and-transition' models may provide an appropriate framework for this.

A shift from equilibrium thinking towards multiple path and multiple outcome possibilities makes trajectory identification more challenging. In the context of coastal systems, Payo et al. (2016) examine feedback structures via 'causal loop analysis'. Van Maanen et al. (2016) advocate a combination of reduced complexity and reductionist models for simulating change over timescales appropriate for coastal management. Other papers in the same issue of Geomorphology similarly consider the challenge of trajectory forecasting.

Assessing change trajectories is also important in considering river restoration. Change has involved a history of human agency (Lespez et al., 2015), with non-human activities being supressed. Restoration to a pristine state may not be possible, whilst on-going climate change requires attention to future instabilities (James, 2015). Trajectories of change, both human and non-human, are the context in which future designs will be placed.

James (2017) illustrates the importance of establishing change trajectories involving both 'drivers' and 'inhibitors' (the latter including the nature of vegetation, and anthropogenic structures like river bank revetments and dams). Removal of inhibitors could lead to unforeseen consequences. James illustrates this with examples from California; whilst in the UK Howard et al. (2017) provide a modelling study of the possible wider consequences to come from weir removal.

Howard, A.J., Coulthard, T.J. and Knight, D. (2017) The potential impact of green agendas on historic river landscapes: Numerical modelling of multiple weir removal in the Derwent Valley Mills World heritage Site, UK, *Geomorphology*, 293: 37–52.

James, L.A. (2015) Designing forward with an eye to the past: Morphogenesis of the lower Yuba River, *Geomorphology*, 251: 31–49.

James, L.A. (2017) Geomorphic trajectories and the long-term hidden potential for change, *Journal of Environmental Management*, 1–12 (in press, available online).

Lespez, L., Viel, V., Rollet, A.J. and Delahaye, D. (2015) The anthropogenic nature of present-day low energy rivers in western France and implications for current restoration projects, *Geomorphology*, 251: 64–76.

Payo, A., Hall, J.W., French, J., Sutherland, J., van Maanen, B., Nicholls, R.J. and Reeive, D.E. (2016) Causal Loop Analysis of coastal geomorphological systems, *Geomorphology*, 256: 36–48.

Van Dyke, C. (2015) Boxing daze – using state-and-transition models to explore the evolution of socio-biophysical landscapes, *Progress in Physical Geography*, 5: 594–621.

Van Maanan, B. et al. (2016) Simulating mesoscale coastal evolution for decadal coastal management: a new framework integrating multiple, complementary modelling approaches, *Geomorphology*, 256: 68–80.