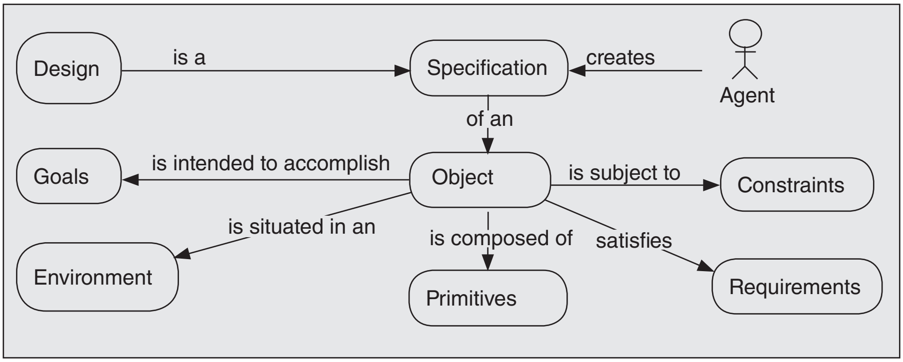
19

PREDICTION AND DESIGN

The logical culmination of geomorphology/landform science is towards prediction and design and, for both practical and scientific reasons, prediction capability is the essential benchmark of scientific quality. Although a 'forecast' is sometimes restricted to prediction in time, 'prediction' is used more generally. But for a variety of reasons forecasting or prediction in geomorphology is difficult and only partially possible in limited circumstances. This chapter first explores conceptually why this is so, and what technical matters are important where forecasts, hind-casts (where relationships are tested in relation to historically-framed data sets) or novel field, numerical and laboratory 'experimental futures' can be made. Design has been reinvigorated by a 'design with nature' philosophy, embraced by landscape architecture and by ecological engineering and, more recently, by geomorphology. Scientific prediction, working with nature, and restoration approaches lead to consideration of how the principle of uncertainty should be applied to pragmatic modelling in general.



Concept	Meaning
Design Specification	A specification is a detailed description of an object in terms of its structure, e.g., the primitives used and their connections.
Design Object	The design object is the entity (or class of entities) being designed. Note: this entity is not necessarily a physical object.
Design Agent	The design agent is the entity or group of entities that specifies the structural properties of the design object.
Environment	The *object* environment is the context or scenario in which the object is intended to exists or operate (used for the noun form). The *agent* environment is the context or scenario in which the design agent creates the design (used for the web form).
Goals	Goals describe the desired impacts of design object on its environment. Goals are optative (i.e. indicating a wish) statements that may exist at varying levels of abstraction.
Primitives	Primitives are the set of elements from which the design object may be composed (usually defined in terms of *types* of components assumed to be available).
Requirements	A requirement is a structural or behavioral property that a design object must possess. A structural property is a quality the object must possess regardless of environmental conditions or stimuli. A behavioral requirement is a required response to a *given* set of environmental conditions or stimuli. This response defines the changes that might happen in the object or the impact of these changes on its environment.
Constraints	A constraint is a structural or behavioral restriction on the design object, where "structural" and "behavioral" have the same meaning as for requirements.

Figure 19.2 Definition of design (with kind permission from Springer Science and Business Media)

Ralph and Wand (2009) analysed 33 existing definitions (their Table 9), synthesizing a new definition of design *(noun)* as a *specification* of an *object*, manifested by an *agent*, intended to accomplish *goals*, in a particular *environment*, using a set of *primitive components*, satisfying a set of *requirement*s, subject to *constraints*; or as a *verb, (transitive)* to create a design, in an environment where the designer operates. Their conceptual model of design as a noun together with definitions of design concepts is shown above in Figure 19.2.

Table 19.1 Stages in scenario planning

1. Define the issue at stake, the processes involved (including uncertainties, complexities and impacts), and the output needed.
2. Determine the driving forces (physical, political, financial, technical, etc.).
3. Cluster the driving forces.
4. Define the cluster outcomes.
5. Produce an impact/uncertainty matrix.
6. Define the extreme outcomes for key factors.
7. Scope the alternate scenarios developed.
8. Develop the scenarios – their development, key events, and reasons for what may happen.

Table 19.2 Examples of works summarizing human impacts (see also Table 16.1)

Deforestation	Goudie (1981)
Cultivation and drainage	Morgan (2005); Starkel (1987)
Reservoir construction & river regulation	Petts (1984); Petts and Wood (1988); Brookes (1988)
Urbanization	Douglas (1983); Chin (2006)
Engineering infrastructure	Newson (1992)
Pollutant dispersal	Macklin et al. (2006)
Erosion protection	Thorne et al. (1997)

Table 19.3 Some landmarks in the evolution of river restoration (Downs and Gregory, 2004, developed from Brookes and Shields, 1996a)

Focus of Approach	Approximate Year of Initiation	Examples
Water quality restoration	1950	Ohio River, USA (Pearson, 1992); Thames estuary, UK (Gameson and Wheeler, 1977) Various sites, USA (Patrick, 1982)
Biological rehabilitation of regulated river by compensation flows	1960	Compensation flows required since first reservoirs in UK, specific biological criteria later (e.g., Baxter, 1961)
Mitigation & enhancement of channels impacted by engineering works	1970	Various sites, USA (Shields Jnr, 1982)
Single species restoration/ rehabilitation of small rivers & streams	1975	Wisconsin, USA (White, 1975)
Geomorphological restoration/ rehabilitation of small rivers & streams	1975	North Carolina, USA (Keller, 1975); (Nunnally and Keller, 1979); Jutland, Denmark (Brookes, 1987) Bavaria, Germany (Binder et al., 1983)
Habitat rehabilitation of regulated rivers based on high flow releases	1980s	Various sites, including western USA (e.g. Reiser et al., 1989)

(Continued)

Table 19.3 (Continued)

Focus of Approach	Approximate Year of Initiation	Examples
Scientific demonstration projects of restoration	1985	Kissimmee River, Florida USA (Toth et al., 1993); River Brede, Denmark; Rivers Cole and Skerne, UK (Holmes and Nielsen, 1998; Vivash et al., 1998)
Large river & floodplain restoration projects	Late 1990s	Kissimmee River, Florida, USA (Toth et al., 1993)
Integrated catchment approaches to restoration	Proposed but no significant projects to date	See for example National Research Council (1999)

Table 19.4 Terms used for river restoration (after Gregory, 2002; Downs and Gregory, 2004)

Approach	Specific term	Definition
General	*Restoration*	The act of restoring (a river) to a former or original condition. The complete structural and functional return of a biophysical system to a pre-disturbance state (NRC, 1992).
More natural condition	*Re-establishment*	To make (a river) secure in a former condition.
	Enhancement	Any improvement of a structural or functional attribute (NRC, 1992: 520). Any improvement in environmental quality (Brookes and Shields, 1996a: 4).
	Rehabilitation	To help (a river) adapt to a new environment. A partial structural or functional return to the pre-disturbance state (Cairns, 1991; NRC, 1992). Putting (a river) back into good condition or working order (NRC, 1992: 522). (An approach to management having) due regard to the catchment geomorphological system (i.e. recreating form with function) whilst acknowledging the constraints to design and assessment existing in a multi-functional river management environment (Downs and Thorne, 1998: 35).

(Continued)

Table 19.4 (Continued)

Approach	Specific term	Definition
	Creation	Bringing into being a new ecosystem that previously did not exist at the site (NRC, 1992: 520). Development of a resource that did not previously exist at the site. Includes the term 'naturalization' which determines morphological and ecological configuration with contemporary magnitudes and rates of fluvial processes (Brookes and Shields, 1996: 4).
	Naturalization	Recognizes that the concept of 'natural' is defined by the community relative to the modified state of the system, and that the goal of naturalization is to drive the system as a whole toward a state of increasing morphological, hydraulic and ecological diversity, but to do so in a manner that is acceptable to the local community and sustainable by natural processes, including human intervention (Rhoads et al.,1999).
	Mitigation	Action taken to avoid, reduce or compensate for the effects of environmental damage (Holmes, 1998).
Full restoration	*Recovery*	The act of restoration (of a river) to an improved/former condition.
	Full restoration	The complete structural and functional return to a pre-disturbance state (Brookes and Shields, 1996a: 4).
	Reinstatement	To restore (a river) to a former condition.

Table 19.5 Elements of design for river channel landscapes (from Gregory, 2006, with permission from Elsevier)

Major Design Stage	Requirement Involved
Preliminary stage	The basis for an approach • *Importance of place* – construct strategy with awareness of the spatial environmental context. • *Implications of scale* – use catchment-scale integrated basin planning with a holistic approach to channel and flood management. • *Situation in time* – refer to the temporal position in the sequence of channel development, with any detectable phases in the palaeohydrology or sediment budget record. • *Cultural context* – cultural differences between countries and regions may require differential responses to river channel management challenges. • *Political framework* – including requirements for legal implementation ensuring that institutional organization and structures are sufficiently flexible.
	Environmental assessment • *Collect historical data* on floods, flood hazard and flood mitigation measures, channel behaviour and channel adjustments. • *Consider the period of records* used as the basis for earlier channel management decisions. • *Review* causes of possible change and potential effects. • *Take into account high spatial and temporal variability* of floods and flood impacts, and their feedback effects. • *Select appropriate time scale*, augmenting the continuous record as necessary.
	Outline planning • *Use integrated, basin wide planning*, and a holistic approach for channel management. • *Use any detectable phases in the palaeohydrology or sediment budget record* to set the management into a temporal pattern.
Implementation	Reviewing alternatives • *Utilize a basin framework* to identify homogeneous reaches requiring similar management activity, reaches of channel that are unstable/sensitive, as a result of mitigation or management measures or impact of human activity, including those that may become sensitive in the future. • *Set the pattern of sensitive reaches in a dynamic basin context* by taking account of changes in sediment history including phases of storage and exhaustion and past river channel adjustments.

Major Design Stage	Requirement Involved
	• *Use environmental condition of reaches to select approaches and identify assessment techniques* – based on principles of preservation and natural recovery, restoring flow and sediment transport, prompted recovery, morphological reconstruction, and instability management. • *Identify hazards* created by erosion and sedimentation together with those of flood discharges, with structures designed for high sediment loads. • *Adopt non-structural and do nothing approaches wherever possible*, using sustainable procedures that have least damaging environmental impacts. • *Work with nature and not against it*, emulating nature in river designs using knowledge of past and present to determine what is 'natural'; restore environmental (habitat) heterogeneity but let the river do the work. • *When restoring channels give careful consideration to*: Is restoration feasible for the particular channel? Is restoration to be to a more natural state or to some specific prior condition, and if the latter what is the basis for the decision? Does the restored state present the most stable channel which will avoid impacts downstream or upstream? Consider 'natural' in any area as a social construct which must be negotiated with the local community giving opportunity for education of that community in relation to palaeohydrology. • *Ensure that the scheme implemented is as sustainable as possible* and capable of adaptive modification. • *Rationalize risk to support decision-making* and assess the risks involved. • *Management with stakeholders* – including formulation of shared visions, and stakeholder education. • *Set priorities in relation to competing claims*, *statutory obligations.* • *Employ a detailed appraisal process*, consult widely, considering all the environmental issues at the range of appropriate scales alongside the engineering and economic objectives.
Effecting the design	*Catchment scale approach to design with nature* including: 1. Catchment and corridor policies. 2. Methods for improving network connectivity. 3. In-stream measures. 4. Channel reconstruction. 5. Methods for reinforcing the channel perimeter.

(Continued)

Table 19.5 (Continued)

Major Design Stage	Requirement Involved
Post project consideration stage	Keep areas under review by adaptive ecosystem management including: • *Post-project appraisal* so that the knowledge about impacts of river management and significance of river channel change continues to grow. • *Incorporating future conditions* – including managing natural recovery and created environments and developing improved predicted models. • *Coping with uncertainties* – requiring adaptive management and education of river managers. • *Ensure continuing proactive involvement of the range of management bodies.*

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Hillman, M. and Brierley, G. (2005) A critical review of catchment-scale stream rehabilitation programmes, *Progress in Physical Geography*, 29: 50–76.

Hughes, F.M.R. (1997) Floodplain biogeomorphology, *Progress in Physical Geography*, 21: 501–29.

Lundy, L. and Wade, R. (2011) Integrating sciences to sustain urban ecosystem services, *Progress in Physical Geography*, 35: 653–69.

Small, M.J. and Doyle, M.W. (2012) Historical perspectives on river restoration design in the USA, *Progress in Physical Geography*, 36:138–53.

Stott, T. (2013) Review of research in fluvial geomorphology 2010–2011, *Progress in Physical Geography*, 37: 248–58.

UPDATES

An excellent illustration showing why the geomorphic approach is becoming widely accepted as an alternative method for reclaiming disturbed landforms, in the southwestern United States at surface mine sites, identifies the potential challenges that exist when applying geomorphic design principles and these include the fact that geomorphic design criteria must be measured locally.

DePriest, N.C., Hopkinson, L.C., Quaranta, J.D., Michael, P.R. and Ziemkiewicz, P.F. (2015) Geomorphic landform design alternatives for an existing valley fill in central Appalachia, USA: Quantifying the key issues, *Ecological Engineering*, 81: 19–29.

Geomorphologists may increasingly get involved in designing whole new landscapes following rehabilitation. These may both have to 'look good' and to function satisfactorily. Issues are discussed in:

Brown, R.A., Pasternack, G.B. and Wallender W.W. (2014) Synthetic river valleys: Creating prescribed topography for form-process inquiry and river rehabilitation design, *Geomorphology*, 214: 40–55.

A study of large-scale dam removal shows how the response of the river affords a unique opportunity to observe and quantify fundamental geomorphic processes associated with a massive sediment influx, so that it can provide important lessons for future river-restoration.

East, A.E., Pess, G.R., Bountry, J.A., Magirl, C.S., Ritchie, A.C., Logan, J.B., Randle, T.J., Mastin, M.C., Minear, J.T., Duda, J.J., Liermann, M.C., McHenry, M.L., Beechie, T.J. and Shafroth, P.B. (2015) Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change, *Geomorphology*, 228: 765–86.

A specific example of river topography design to creating riffle-pool topography is provided in: 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.

Whereas rapid geomorphic assessment tools to assess natural channel design projects seldom include watershed-level parameters, a paper employing Artificial Neural Network (ANN) models to integrate complex non-linear relationships between the aquatic ecosystem health indices and key watershed-scale and reach-scale parameters enables consideration of watershed properties in the stream assessment and can be useful for watershed managers: Gazendam, E., Gharabaghi, B., Ackerman, J.D. and Whiteley, H. (2016) Integrative neural networks models for stream assessment in restoration projects, *Journal of Hydrology*, 536: 339–50.

A consideration of fluvial hydrogeomorphology in management of streams affected by urbanisation is given in:

Vietz, G.J., Walsh, C.J. and Fletcher, T.D. (2016) Urban hydrogeomorphology and the urban stream syndrome Treating the symptoms and causes of geomorphic change, *Progress in Physical Geography*, 40: 480–92.

Holistic focus on physical environment is now possible to succeed past emphasis on physical environment, its dynamics, and how it evolved. Methods are now available for characterization of physical environment at a range of interlinked scales so that design is an imperative, not just to respond to the legacy of past and present problems, but also to anticipate potential future change as argued in:

Gregory, K. J. (2017) Putting physical environments in their place: The next chapter?*, The Canadian Geographer/ Le Géographe canadien,* 61: 11–18.