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Concepts with consequences in geomorphology: A fluvial perspective

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Abstract

Imagined concepts – made real by down-to-earth field verification, validated modelling, and using available technologies and empirical methods – are fundamental to research outcomes in geomorphology. This article reviews the functions that consequential concepts have served: as overall driving and embracing stimuli, or playing permissive roles at lower levels within projects; when they have come to the fore and declined in usage; how knowledge of them gets spread and tested; and where needs seem to be driving for the future. Within fluvial geomorphology there is demonstrably a multiplicity of conceptual approaches. Modern times also now involve greater external appraisal including financial and management control and research and teaching quality assessments. These are taking place in parallel with novel environmental changes that themselves pose new needs for hazard understandings and safeguarding. Challenges to address for practical reasons include forecasting the likely future geomorphic effects of climate change, tracking system impacts from the spread of human hardware across landscapes, and monitoring pollutant incursions into fluvial systems. Nevertheless, conceptual progress in understanding is also fundamentally dependent on advancing 'blue skies' research objectives. In a changing world, geomorphology has to pursue holistic goals and the multi-temporal and multi-scale spatial appreciation of landform development, and how this relates to other changing global systems, but also to grow what it conceives of doing for the public good.

KEYWORDS
analytical frameworks, concepts, discovery, geomorphic systems, values

1 | INTRODUCTION

Across the sciences there are linkages between individual research projects and the wider concepts that prompted their initiation or are essential for their execution. Many such ideas are assumed tacitly in published papers without further explication (Polanyi, 1966) and closer scrutiny is needed to work out the analytically permissive roles that the best of them play. Even well known form names in geomorphology such as erratics or levees are conceptual in origin. Some concepts have been seen as pioneering in the sense of at once appearing remarkably innovative; others take time to become demonstrably transcendent as judged from their diffused use across multiple study programmes. There are programme-setting ideas determining research directions, theorized and tested process-form relations, algorithmic models, and classifications that provide systematizations and reveal novel linkages. Permissive ones that are taken for granted lower down the concept chain have additionally proved essential for data derivation, quantitative analysis and explanation (Gregory & Lewin, 2018).

A characteristic of the best of these concepts is that they have been highly consequential; that is, they have had very much wider influence and application than simply in the papers in which they first appear. Colloquially their inception may be thought of as game-changing or revolutionary. As the relevance of the grandest of ideas has widened this can give academic researchers and even the public a polemical shock – despite or even because named concepts may give new and widespread scope for interpretation and application with different definitions and meanings. This has been the case with the Anthropocene concerning its timespan, trans-disciplinary applications and apocalyptic implications (Biermann et al., 2021; Bonneuil & Fressoz, 2016; Zalasiewicz et al., 2021).

Lower down the concept chain – as used in geomorphology but also elsewhere as keywords – are named concepts such as 'connectivity', 'sensitivity', 'cascades' and 'complexity'. These can be metaphorically described as holdall or umbrella expressions, meaning that they may shelter much discussion and many variations (cf., Williams, 1976). They are made scientifically meaningful from exploration and justification through definition, context-specific testing, and empirical verification (Fryirs, 2017; Phillips, 2016; Wohl et al., 2018). Without these stages they are only by assumption true of the physical world.

What such words may mean has also to be a part of geomorphological education (Lewin & Gregory, 2019). Spreading landform knowledge involves languaging it (taking mathematics also to have a language). Language's own mediating role has been acknowledged from Hobbes and Locke to Einstein and variants of the Sapir–Whorf hypothesis. Many contemporary expressions, such as tipping points, have also long been used under other names by geomorphologists (e.g., thresholds rather than tipping points, as in Schumm, 1977) and ambiguity and confusion are possible. The fact that most scientific work is now reported in English also means that monolingual researchers may be unaware of many named ideas, and much data, as published in other languages. As used, English also has other limitations (Lewin, 2017), including presenting concepts in metaphorical forms that can be unclear (Lewin, 2016, pp.11–12). Education has also to include field experience in identifying the forms and phenomena that have been defined and, of course, familiarity with the conceived dynamic frameworks that are used to analyse their development.

So, as in any area of research, geomorphology relies on the changing concepts it holds (Gregory & Lewin, 2015; Petch & Haines-Young, 2019). But how have they risen and fallen in use, how do usages get spread, and where are driving concepts now heading in geomorphology? These less-explored yet general themes are considered in this article after setting geomorphological concepts in a wider context of scientific and other ideas and practices. The article follows a recent series undertaken with Ken Gregory exploring aspects of conceptualization: making concepts explicit; framing their roles hierarchically; and then seeing how they might be placed within learning programmes (Gregory & Lewin, 2015, 2018, 2021; Lewin & Gregory, 2019).

2 | WHAT FRAMES CONCEPTS OF CONSEQUENCE?

Research publications in geomorphology have considerably increased in number, doubling about every decade recently, but most are not explicit about the multiple concepts they use. Consequential ones come buried within normal write-up conventions (variations of AIMRDC: Abstract, Introduction, Methods, Results, Discussion, and Conclusions). Empirically based papers in particular are presented as methodologically robust, well evidenced, and cut-and-dried in their conclusions rather than drawing attention to any underlying – but arguable – mentally constructed concepts involved. Once published, academic peers commonly mine papers for nugget-like extractable concepts of consequence as well as methods and data that can be of further use to them.

What most geomorphologists actually report on may also not be framed as the presenting and testing of 'conjectures' (i.e., untested concepts) let alone admitting in print to 'refutations' (Popper, 1972). Collectively, geomorphology publications over recent decades also show few clear alternations between 'normal science' work-patterns as disrupted by occasional paradigm-changing shocks (Kuhn, 1970). As an earth science, geomorphology has also proved pluralistic, employing diverse types of explanation (Kleinhans et al., 2005). A.C. Crombie (Crombie, 1994; Kwa, 2011) presented an in-practice way of framing actual scientific activities in six categories (Table 1, A–F). 'Styles of scientific thinking' and 'styles of knowing' are terms these authors use in their extended treatments, but they can equally be described as analytical frameworks (as here), incorporating also interpretation styles or explanatory models. Crombie's categories do seem quite faithfully to capture the range of what is being attempted in geomorphological practice and publication.

Research projects may involve an amalgam of several of these. Thus, single field case studies may be presented, loosely speaking, as the equivalent of experiments (B), perhaps concluding with summative evolutionary models (F) with some statistical support (E) from data analysis. The often-used label 'a case study' means that philosophically they are seen as 'kinds', billed as representative of something widespread. Rather more exacting experimental procedures and requirements are presented by Church (2011). Others seek to categorize and classify: allocating and explaining phenomena historically

TABLE 1 Analytical frameworks (A–F) and a concept-use hierarchy (1–5) (after Crombie, 1994; Gregory & Lewin, 2018)

Analytical frameworks ('thinking styles' after Crombie, 1994)	
A. Deductive	Logical derivation from premises.
B. Experimental	Conclusions drawn through observations under controlled conditions.
C. Hypothetical-analogical	Judged through similarity to something known and understood, as in analogue models.
D. Taxonomic	Set within an accepted classificatory framework.
E. Statistical	Inference from numerical testing of sampled populations.
F. Evolutionary	Development presented as an ordered sequence.
Concept hierarchy levels (after Gregory & Lewin, 2018)	
1. Superordinate	Major ideas used across the sciences.
2. Contextual	Field-framing research concepts (specific to geomorphology in this instance).
3. Fundamental	Related to the definition and execution of particular projects.
4. Operational	Necessary and used in the detail of analytical procedures.
5. Ancillary	Associated assumptions that may not be explained or evaluated, often from other disciplines.

within a dated stratigraphical template (Gibbard & Lewin, 2016a) as set by oxygen isotope stages or palaeoclimatic episode reconstructions (D, F); or to types of co-existing forms (Nanson & Croke, 1992), perhaps hierarchically and giving their population frequencies in different morphogenetic process conditions (D, E). A further example here would be the 'River Styles' classification of river types and component form elements for river management (Fryirs et al., 2021), whilst Scown et al. (2015) follow a statistical approach (E) in exploring floodplain form metrics.

Within these analytical frameworks, concepts may appear as postulates or hypotheses, theories, algorithms, auxiliary assumptions, or what are taken as laws from biology, physics, and chemistry. The most fundamental in the cognition of material things is probably categorization: 'this is of a kind', philosophically seen as ontology, and named linguistically as hyponyms. Drawing distinctions between and within kinds and category sets may then lead to further analytical progress, as for example in the distinction between overbank and channel sediments in alluvial systems that has been further refined subsequently (Challinor, 1946; Day et al., 2008; Wolman & Leopold, 1957).

There are also different levels at which concepts are in evident application and in Gregory and Lewin (2018) we envisaged five of them (Table 1, 1–5). These range from overarching ideas across the sciences (1) or within disciplines (2), and then to ones that permit project execution at lower levels (3–5). We related this hierarchy to study types: systems analyses, different subject fields, process domains, dynamics and change, anthropogenic relationships and management. An alternative is to consider concepts in terms of the levels at which they apply (1–5) for different Crombie styles (A–F) as given in Table 1. 'Explanations' can follow in terms of reasoned and defined empirical relationships, processes or system states.

With some exceptions that consider geomorphological practice overall (e.g. Petch & Haines-Young, 2019; Phillips, 2021), most explicit discussion of concepts in geomorphology have recently concerned mid-range contextual ones (2/3): system states such as (dis)equilibrium, (dis)connectivity, and intrinsic system thresholds (Richards & Clifford, 2011). Table 2 gives illustrative examples (others are given in Lewin, 2016, table IV). These may provide cover for, or retrospectively embrace, empirical research activities that have been going on for a long time. For example, connectivity may include sediment 'provenancing' (or 'track-and-trace') as with the river sourcing of bed material, suspended sediment, or now microplastics (Walling & Woodward, 1995; Woodward et al., 1992, Woodward et al., 2021). What James (2013) defines as anthropogenic 'legacy sediment' has equally been studied under other names.

TABLE 2 Concepts involved in the state of fluvial systems. Cyclicity may relate to large-scale and long-term landform production or to processing cycles include 'leads and lags', relaxation, and hysteresis. Complexity is taken also to incorporate inheritance, contingency and emergence

System states	Selected geomorphological references
Grade	Mackin, 1948; Dury, 1966.
Cyclicity	Davis, 1899; Huggett, 1988.
Equilibrium	Schumm, 1977; Church & Ferguson, 2015.
Cascades	Chorley & Kennedy, 1971; Fryirs, 2013.
Sediment budgets	Trimble, 1983; Warburton, 2011.
Hierarchy	Nanson & Croke, 1992; Gibbard & Lewin, 2016a.
Connectivity	Brierley et al., 2006; Wohl et al., 2018.
Sensitivity	Brunsden & Thornes, 1979; Fryirs, 2017.
Complexity	Kleinhans et al., 2005; Phillips, 2016, 2021.
Sustainability	Brookes & Shields, 1996; Gregory & Downs, 2008.
Resilience	Fuller et al., 2019.

Above these at an across-system level, concepts have included hierarchical arrangement, scale invariance or otherwise, process efficiency, and evolutionary stage. Phillips (2016) has emphasized the complex behaviours of geomorphic systems overall, including inheritance effects and geographical contingency that make general forecasting difficult. Lower down, system behaviours were addressed by Schumm including a particular kind of complex response (Schumm, 1977). Whilst his propositions are frequently cited in texts and reviews, comparatively few attempts to validate or quantify them against field evidence have been made above the level of sediment transport thresholds.

What researchers are up to – across the sciences but as applicable to geomorphology as well – has additionally been subject to alternative forms of investigation. Discussions have been extending beyond the 'methodists' studying how investigation are being, or should be, performed (Kuhn, 1970; Lipton, 2004; Popper, 1972; Strevens, 2020). There are 'behaviourists' concerned with discourses, what scientists are motivated to do, and how they commonly conduct themselves in practice (Foucault, 1972; Latour & Woolgar, 1986); and then 'inventionists' focussing on how creativity is generated in the mind (Feyerabend, 1975; Giere, 1986; Polanyi, 1966; Wilson, 2017; Wootton, 2015). Each of these also involves concepts – about the appropriate things to study, how best to perform within a scientific community, and about the seat of creativity. Some of these wider considerations are now entering geomorphological discussions (Lave et al., 2018).

External judgements are also being made about what is publicly seen as consequential. Political and social judgements – with motivational, financial, and other practical implications for researchers – come from the perceived stakeholder needs of societies and governments in expecting useful strategic and applied research. This may be to address the conflicted goals of economic growth, environmental safety, and the preservation or restoration of natural heritage. Thus, the UK Natural Environment Research Council funds both 'discovery science – driven by curiosity – and strategic research which helps society benefit from natural resources, build resilience to natural hazards and manage our changing environment' (*nerc.ukri.org*, online statement, 2021).

In the present changing and complex environment, this list is increasingly a tall order, and it could be argued that only occasionally has geomorphology itself risen to the challenge of future forecasting (Coulthard & Van De Wiel, 2017), now urgently needed for facing what appears to be increasingly hazardous on a decade-to-century timescale. This 'future' forecasting under changing conditions is more than the 'spatial' forecasting commonly valued informally in geomorphology: awareness of what may be expected in new places on the basis of prior studies elsewhere. Futures research may be motivated for its useful benefit, a form of 'consequentialism' ethically speaking (contrasting with ‘deontological knowing’ taken as a kind of secular academic duty, the seeking of knowledge as good in itself).

Categorizing, monitoring and interpreting present and past natural landforms and process systems have understandably dominated geomorphological paradigms to date. The rapidity of atmospheric, oceanic, cryogenic, hydrological and ecological responses to system change doubtlessly also encourages greater urgency about their futures rather than that of the more durable ground surface morphologies over which they pass or on which they develop. But some landforms in fluvial, dryland, cold-climate and coastal environments are liable to change rapidly and catastrophically, and they are increasingly manipulated and built-over with at-risk landscape-scale human hardware. Landforms also provide the physical and ordered habitat elements that continental life builds on. There is the need to survive hazards and degradation there, and it is humanly prudent as well as intellectually compelling to understand land forming, and to debate the changing concepts lying behind such understandings.

3 | DISCOVERIES UNFOLDING

Earth and geographical sciences have characteristically involved centuries of ‘discovery learning’, whether in far-travelled places, or now of the previously unobserved and undefined through innovative remote sensing methods, microscopy, and physical, chemical or biological technologies (Viles, 2016). Discovery may actually be envisaged in two ways: (i) the finding of previously entirely unknown material phenomena and their properties. This has commonly been through field expeditions, globally or locally, and using the technological means of their day for observation and measurement. Semi-automated remote survey data processing, coupled with travel restrictions, are currently increasing desk-based discovery as well. (ii) Hypotheses and theories have made previously unrealized linkages between defined phenomena, with process relationships and structures developed theoretically and proposed deterministically or by statistical association. For most geomorphologists, both routes to discovery have formed a greater part of ‘laboratory life’ (Latour & Woolgar, 1986) than working in indoor laboratories.

Process systems of diverse kinds and scales have formed a core component in recent overviews of geomorphological assemblages (e.g., Gregory & Goudie, 2011; Gregory & Lewin, 2014; Inkpen & Wilson, 2013). These identify ontologies, states, components, behaviours and interactions, and included are feedbacks, energy and material transfers, resilience and adaptability under change. Such a focus on process in fluvial geomorphology – almost at the expense of form definition – really only came of age from the mid-twentieth century (e.g., Leopold et al., 1964). Before then some influential geomorphologists sought their security as academics by claiming independent study territory, something justified through filling an explanatory gap between ‘solid’ geology, with its sedimentary and evolutionary record, and engineering approaches that dealt with managing and transforming present land surface processes. The then reasonably novel idea that helped was to infer process and evolutionary stage from form itself. Ideas on form and growth in biology were notably developing at a similar time (Thompson, 1917). Later geomorphologists have, of course, come to analyse ‘superficial deposits’ and to research quantitative relationships between forms, processes and materials over different timescales. Also, frequently to work permeably with other disciplines rather than securing an academic niche between them.

Returning to Discovery type (i) again, geomorphologists have often proved to be well-travelled detectives – stimulated by travelling, measuring, recording, and (with things going on in their minds) interpreting their way across the Earth. Global travel for centuries was facilitated for some through colonialism and political reach, including for the United States’ longest-ever serving ambassador George Perkins Marsh (1801–1882) exploring lands around the Mediterranean, and for Europeans, landform study in British and other empires. General theory may be biased by the discoverer’s experience. Thus W.M. Davis’s ‘normal’ cycle (others were termed ‘special’; Davis, 1899, 1905) clearly relates to humid mid-latitude climates, rather than the widespread arid or tropical ones with which he was less familiar. Early on, it was colonial and politically motivated expeditions to drylands in Africa and the American West that facilitated studies of their characteristic landforms. Locational study bias across the globe, of course, still exists (cf., Burt & McDonnell, 2015, figure 2), but regional discovery in recent decades has now been progressed more evenly by indigenous researchers in independent states, and facilitated for all through remotely examining global and local world morphologies. Other solid celestial bodies including the Martian surface are equally being examined (e.g., Baker et al., 2015; Luo et al., 2017), an advance into the cosmos beyond the nominal geo- of geomorphology itself.

In Discovery type (ii), modelling facilitated especially by burgeoning computer power constitutes a different deductive process followed by inferential checking against the real world. Models – qualitative, hardware or numerical – are constructed as analogues of reality. They are also basic to future forecasting. Thus, for fluvial geomorphology numerical models commonly operate with empirical law-like algorithms and their performances are commonly ‘validated’ in terms of physical justification, sensitivity analysis and levels of uncertainty (Van De Wiel et al., 2011). They are less comprehensively ‘verified’ against field data to infer model and field equivalence (Oreskes et al., 1994). Such geomorphic model verification of what has happened is at least possible (Briant et al., 2018; Wong et al., 2021) whereas for future change verification must wait on time. However, especially if futures are hazardous, ‘as-good-as-possible’ estimates for what is to come have become an urgent practical objective for society. Research to establish likely future trajectories of geomorphic change currently seems more important than joining the conceptual debate as to when or whether Earth has entered a new geological era that occupies much publishing space.

For the future, both modelling insights and knowledge of unrealized and generationally un-experienced historical precedents can be helpful. The word ‘unprecedented’ is frequently used of rare events, but it usually means unknown to those who use the word, given both short community memories and short-run records. Managing the material environment is most effective through knowing how it is at work now, but also how it has been, especially during low frequency high magnitude events *in extremis*. This applies, for example, to using sedimentary records to establish the reality and impacts of flood rich or drought periods (Benito et al., 2015; Toonen et al., 2017; Bauch et al., 2020: Blöschl et al., 2020). Defeasible concepts frame approaches, here concepts involving time (Gibbard &

Lewin, 2016a). Periodization is one approach; identifying trajectories and evolution with their discontinuities and disruptions is another.

Strevens (2020, p. 97) has observed that the kinds of research patterns followed have concerned 'doing' rather than 'thinking' as scientists have engaged with and assessed observational facts. Wootton (2015, chapter 7) usefully discusses what such 'facts' have historically been taken to be. Such matters as reliable data availability and the capabilities and vagaries of apparatus greatly affect the evidence on which geomorphologists rely. Professional academic sceptics may thus dispute both the 'facticity' of the facts (the veracity of evidence) and their representativeness, but then also the plausibility of interpretations based usually on prior experience. But through replicated use, valued interpretation styles have gradually achieved consensual endorsement and epistemic strength even if modified along the way.

The timescales over which geomorphological processes operate can be fast or slow; extreme formative events are difficult (and sometimes very hazardous) to observe and measure as they actually happen. Field evidence is often vestigial (coming from the Latin *vestigium* meaning footprint or the track left by animals) and differently interpretable – largely by inductive inference (Lipton, 2004). The soundness of this reasoning remains a philosophical conundrum across the sciences, as in the 'black swan' theory of unexpected events, such swans having been assumed not to exist until such creatures were later 'discovered'. Interpretive strengthening by repeated findings in numerous independent projects does happen and may be seen as a form of 'Baconian convergence' (after Francis Bacon, 1561–1626 CE). In effect this narrows the perceived need for alternatives, even though a majority following (or 'group think') does not logically and necessarily bear witness to truths. By contrast, Taleb (2007) regarded all genuine scientific discoveries as 'black swans': they are by definition unexpected and unpredicted. This points to the need both for 'normal' geomorphological science, refining and confirming the value of approaches and their results, but also paradigm-changing conceptual ones if leaps in understanding are to be made, or circumstances turn attention to new study directions.

4 | THE PROGRESS OF CONSEQUENTIAL CONCEPTS

The usage fluidity of concept terms in geomorphology may be illustrated by examples captured through Google Ngram data for word use in books. Usages have come and gone, so giving different frequencies in name use (Figure 1). These have metaphorically been viewed as a braiding multiplicity of ideas, branching and changing historically (Grant et al., 2013). As with technologies (Edgerton, 2019), it is usage that matters as much as innovation. Some well-used concepts can have lifespans that come into their own much later than their originators put them forward. Alfred Wegener's continental drift, Milutin Milanković's climate cycles and Grove Karl Gilbert's ideas were notably more honoured by later generations after some delay.

This was not the case with the rapid spread of Davisian geomorphology (Davis, 1899) involving stream terminologies related to supposed developmental stage in a theoretical cycle of erosion (e.g., subsequent rivers and graded rivers in Figure 1; modal years for use were 1902 and 1916). With its biological and evolutionary transfers, Davis's concepts seem to have been easily taken up; children can grasp his ideas, and they have their echoes in school level teaching today. For decades, Davisian 'youth, maturity and old age' and other terminology (Davis, 1899) featured widely as temporal stages in landform evolution, but little research interest in such on-sight analogies would be forthcoming today.

The graded river as a concept was later redefined by debate from the 1940s onwards for a while (Figure 1), the term being teased into different meanings in two main phases by G.K. Gilbert, W.M. Davis, J.E. Kesseli, E.W. Lane and others (Dury, 1966; Mackin, 1948). Denudation chronologies followed, essentially based on empirical reasoning involving staircases of planation levels created over lengthy but undated periods in the Cenozoic. This term use reached a peak in the 1960s. With chronometric techniques and closer stratigraphical analysis, dated environmental histories over a range of timescales became more significant, for example involving reasoned linkages to geotectonics, glaciation events, marine isotope stages, global climate oscillations and human history (Gibbard and Lewin 2009, 2016a, 2016b; Macklin & Lewin, 2019).

From the 1940s and especially from the 1960s quantitative morphometric studies became ascendant (Gregory, 2000), initially exploring statistical form metrics and relations between them, such as stream order, but then moving to form–process relationships. For rivers this often meant working more with hydrology and steady-state hydraulics, as epitomized in Figure 1 by hydraulic geometry (Ferguson, 1986; modal period 1971–1981). Earlier ideas of grade evolved further into quantitative multi-factor analyses of river profiles and channel patterns, including relationships with sediment size, downstream fining and transport (a phase tracked in Figure 1 by river dynamics; modal period 1991–2007). Rather less precisely defined (and often ecosystem-related) contemporary concepts such as the river continuum, connectivity, sustainability, resilience, heterogeneity and complexity came into frequent use a little later (represented in Figure 1 by river continuum, peaking in 1993–1997). In general, system and process thinking has come to the fore, especially now focussing on non-steady-state conditions and complexity (Church & Ferguson, 2015; Phillips, 2016, 2021). Most, though not all, research is also focussed on shorter timescales than the Cenozoic landform interpreters earlier in the last century.

This briefly outlined history suggests that changes in approach often come from outside: evolution and life cycles in the late nineteenth century, hydraulic engineering and systems analysis in the twentieth, and currently a plethora of interactions with public issues and research concerns in parallel with river sciences in archaeology, ecology, environmental management and geophysics. Concept usages have peaked at different times and hypothetical ideas without evidential support or usage eventually become devalued (like phlogiston, the ether and miasmas). If once they were imagined as Talebian 'black swans' they have become dead ones (cf., Kennedy, 1994).

As ideas have been repeatedly explored, they have also been subjected to conceptual shifts in the meanings behind namings, with fragmentation and dispute as well as abandonment as researched applications or elaborations peter out. It is words through which we communicate, and their intended meanings do change sometimes to the confusion of later readers (Lewin, 2016). Thus in Newton's day, even to call some proposal a 'hypothesis' could be taken to suggest that it was just fanciful or unsupportable, and this could be viewed as

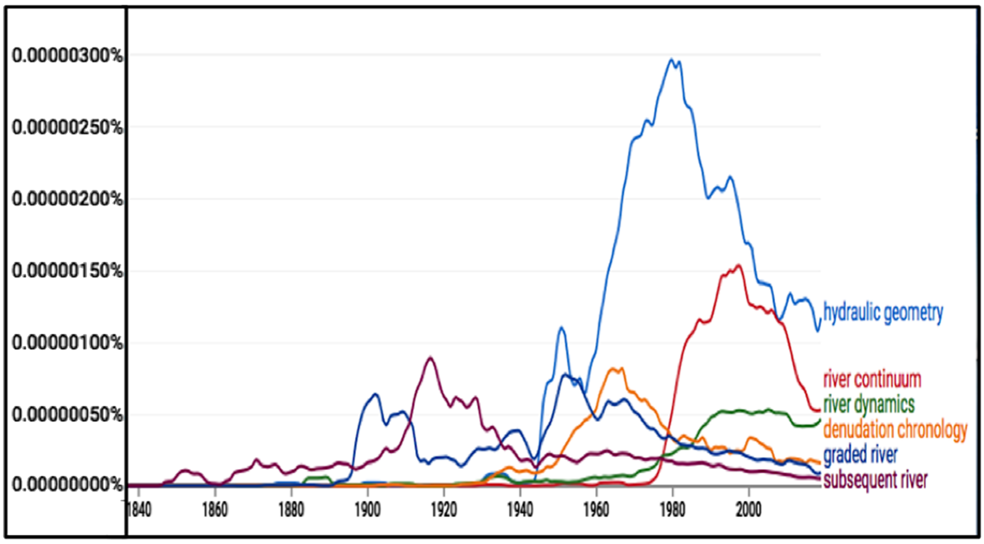

FIGURE 1 Google Ngram© book use frequencies for terms in fluvial geomorphology [Color figure can be viewed at wileyonlinelibrary.com]

an insult (Wootton, 2015, pp. 380–391). Hence Newton's statement that he proposed no hypotheses, whereas today we might think that this was exactly what he offered and which got tested. But whatever they are called, and although all knowledge is defeasible, tested conceptions that are innovatory and imagined join adventuring discovery to be at the root of scientific progress (Strevens, 2020). Where they came from to permeate geomorphology has been favoured by wide contacts and openness. Progress involving the absorption, but essentially also the revision, of concepts is also true of personal learning during education itself (Chi, 2008; Vosniadou, 2007).

5 | SPREADING CONSEQUENTIAL CONCEPTS

As in our previous concept-focussed papers together (Gregory & Lewin, 2015, 2018), the concern here is with shared science community activities and communicating about them – and to enable meaningful dialogue, this involves the codifying, structuring, testing, valuing, discussing and then the possibly common adoption (or rejection and abandonment) of ideas. Stages in concept adoption and abandonment are briefly outlined in Table 3. This all takes place over time and through public discourse, especially as made accessible to global participants through research papers and dissemination via other media. 'Communication' includes face-to-face conversation in the field, orally and graphically as in lecture deliveries, written down and printed on paper, and via electronic media. This is the territory of the 'behaviourists' and 'inventionists' referred to earlier. There is perhaps a greater need for geomorphologists to articulate what inspires them to do what is worthwhile, and how they go about it, and so justify the urgency and cost of their work. As circumstances change they may also move from their accustomed territories to areas of public research need. There is the counter impulse to safely 'stay in lane' where there is research group empathy accomplished through what is called 'homophilous sorting' of the like-minded.

External scrutiny is both individual, by any receiving contemplator, but also collectively by a communicating population of professionally sceptical scientists, politicians and others. Evaluation depends on judgements, and most of this follows from academic 'exposure', most

TABLE 3 The public progress of consequential concepts

Conceptual origin comes through imaginative mental conjecture; this may be prompted by deliberated observation and measurement or arise through accidental inspiration (serendipity).
Novelty may arise from inspired new thoughts, particularly at scientific margins. It may be prompted by technical advances and novel data; from the realization of new linkages between phenomena, processes and systems; or synergies between concepts already known.
Entry into ***common discourse*** requires codification, but some of this also relies on scientists' freedom to think and discuss matters beyond existing and accepted knowledge. This may be influenced by institutional controls and by dissemination opportunities and restrictions (in publication through language and communication, and by political facilitation or otherwise).
Testing and acceptance rely on evidence, not only from the author(s) as published, but later through communal consideration. This is gradually confirmed as situational applications are diffused and reliable concept power is realized in multiple projects. The personal authority of supporters or critics also plays a role, particularly over evidence interpretation and ideas that challenge current beliefs.
Value may notionally come from attaining some sort of landmark threshold for significant scientific advancement, as well as relating to reliability in use, breadth of application, and satisfying an important society or stakeholder need.
Abandonment happens when an idea's potential is believed to be worked out, is found to be wanting in applications, or is replaced for active attention by different ideas and programmes.

evaluation being out of public sight. Much happens to follow the cerebral and psychological activities to which Petch and Haines-Young (2019) have drawn attention as the creative seat from which innovations come. Six progress stages are suggested in Table 3. Only part of testing and acceptance (as in research assessments and peer review for journal publication) is formal and framed by a judgement category (4* research, 'requires minor revision', etc.). Value and abandonment can be numerically assessed via citation data although frequencies do vary from field to field and journal to journal. They get boosted for review papers and have other limitations. Evaluation also comes during use in applied projects by agencies and consultants as well as in academic research. Overall, a subjective judgemental element for believing in, and therefore supporting, much of scientific activity is wide and in public, publication being part of a wider testing process as much as a matter of terminated announcements of findings by their authors.

By contrast, limitations on the spread of transformative concepts actually arise from the growing volume of academic communication. The increasing numbers of specialist groups and publications for geomorphologists (*Earth Surface Processes and Landforms*, *Journal of Geophysical Research*, *Quaternary Research*, *The Holocene*, *River Research and Applications*, etc.) selectively cover some of the thinking and explanatory styles in Table 1. It can be difficult for working geomorphologists to cover and absorb what is of interest going on in many sub-areas and parallel disciplines. Specialization is associated with what is called 'complex contagion' in the spread of ideas through social contact, with strong contact links in focussed communities coalescing around common propositions and explanatory models (Guilbeault et al., 2018). Novel ideas and approaches can come from outside as well as inside working groups, as we have seen for geomorphology, but they have been shown to spread more widely where communities overlap rather than having grown apart. The message for geomorphologists lies in the advantages to be gained from networking and wide media browsing beyond their specialist contacts to gain lateral-thinking support for the innovative research they wish to undertake.

6 | PREMONITIONS

Forecasting future geomorphologies can hardly be accurate given the unknowable unfolding of events, technical progress, and social change. But nevertheless premonitions – presentiments and forewarnings – may be informative for lively disciplines that recognize the need perpetually to modernize themselves reflexively to remain successful. Three observations can be made.

In the first observation, does geomorphology now need more of a theme shift towards forecasting the future, not in theological or teleological terms, or through apocalyptic agitation, but as far as possible as a scientific matter? How are rivers and their catchments going to be changed in the near future? For example, East and Sankey (2020) discuss the geomorphic detection of modern climatic change impacts in the western United States, no easy matter given data availability and the pace of change itself. The future can only be modelled, but geomorphology has yet to see any strong rebalancing between field studies (largely explanatory-descriptive, or types D, E and F) in favour of numerical or physical modelling (A or B) as has been true of hydrology (Burt & McDonnell, 2015). State transitions, such as changes in river channel pattern, are likely to be crucial, as in the past (Lewin & Macklin, 2010; Phillips, 2014). The environmental challenges of climate change, the dispersal of human wastes and the constructed human hardware transforming natural processes also suggest closer links with the social causes of such changes. This need not be purposefully anthropocentric, but rather a detailed recognition of the drivers, timings and processes by social agencies that lead to physical change, on a par with the ones from natural processes. Ecological agencies, however, have received considerable recent attention (e.g., Gurnell, 2014), and climatic changes also operate alongside other 'place' factors (Phillips, 2021) such as tectonics and bedrock type (Wolf et al., 2021).

A second observation is that research has become ever more costly especially given the technologies now being used. The funding and working frameworks within which researchers operate is also one of increasingly monitored performance and the supervision of objectives at government or institution levels. Badly done, this can lead to vertical subordination rather than horizontal cooperation between researchers. But like others, geomorphologists must compete for funding, and the more sophisticated their technologies become, the more is the need for resourcing, with external selectivity on what research gets supported. Paradoxically perhaps, geomorphologists have become less free to do research of their own choosing, simply because projects have to compete with others to gain necessary support and funding provision well before any useful results can be fully assured. Successful research projects involve much self-marketing, paperwork and 'bidding time': having new research concepts to offer may be crucial.

In the third observation, the dissolution of institutionalized disciplinary boundaries and collaborative links across physical, biological and social sciences may further be underpinned by a public shift away from the long-enduring perception of the natural environment as a neutral and exploitable resource. Sustaining the natural functioning of earth-systems must be accommodated if the diversity of life forms is to survive in strength (including, but not only, humans themselves). Younger generations seem more urgently aware of this than older ones. The interactions of landforms and lifeforms at different scales of time and space are extremely diverse and only beginning to be understood. For example, Aguilar et al. (2020) have proposed a critical zone from the top of the vegetation canopy to the base of the groundwater system, including human impacts, as an appropriate study domain. Geomorphology can promote collaborative understanding more directly and explicitly, essentially as a public good, satisfying also the extra-science justifications that governments commonly have in mind. A problem is that here geomorphological knowledge largely saves costs (borne especially by later unwary generations long after developments occur in hazardous places) rather than generating new profits from investment, or erecting the iconic constructions so useful for politicians to declare when in office. Both economists and sociologists have historically paid little attention to human habitat constraints, but this is something no longer affordable (Catton & Dunlap, 1978). Thus, in economics there has been a reviewing of capitalism and a redefining of 'value' beyond that determined by the market in the short term (Carney, 2021; Mazzucato, 2018). Trust in science has, however, also wavered (Oreskes, 2019) at least until at a time of global pandemic when its value has been publicly reinforced. Communicating the value of a relatively minor science like geomorphology is necessary but challenging, especially amidst the many competing self-marketing voices now communicating in English internationally across the sciences (Gregory et al., 2014; Lewin, 2017).

7 | CONCLUSIONS

In recent decades aspirational groups of fluvial geomorphologists have mostly concerned themselves with empirical observation and method development in sub-field 'case studies', together with an increasing investment in equipment, numerical analyses and modelling. Vital concepts have been dispersed amongst different kinds of study: form classifications, system states, physical processes, ecological interactions, and interpreting dated Quaternary and decadal histories. These have covered considerable temporal and spatial scales, with a large volume of research at the river reach and catchment scales, and generally with fewer longer-term Cenozoic studies. Technical advances have provided much greater availability of analytical and observational data for sub-groups that have different conceptual foci.

But circumstances change, and as this article has outlined, consequential concepts have historically changed along with them. Global transmutations arising from civilizational activities past and present (including climate change but also population growth, cultivation extension, urbanization, wildlife habitat destruction, pollution, waste disposal and the precariousness of many human habitats) now pose additional needs. These include future forecasting and the means of social/ecological resilience in risky fluvial domains but also in other ones. Geomorphology is concept-driven at many levels and for different functional purposes, and these need to be further thought-through to accommodate new holistic perspectives and cross-disciplinary collaborations as well as pursuing the impressive methodological and technical advances of recent decades.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable – no new data generated.

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