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The perfect landscape

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Abstract

The "perfect storm" metaphor describes the improbable coincidence of several different forces or factors to produce an unusual outcome. The perfect landscape is conceptualized as a result of the combined, interacting effects of multiple environmental controls and forcings to produce an outcome that is highly improbable, in the sense of the likelihood of duplication at any other place or time. Geomorphic systems have multiple environmental controls and forcings, and degrees of freedom in responding to them. This allows for many possible landscapes and system states. Further, some controls and forcings are causally contingent. These contingencies are specific to time and place. Dynamical instability in many geomorphic systems creates and enhances some of this contingency by causing the effects of minor initial variations and small disturbances to persist, and grow disproportionately large, over time. The joint probability of any particular set of global controls is low, as the individual probabilities are <1, and the probability of any set of local, contingent controls is even lower. Thus, the probability of existence of any landscape or earth surface system state at a particular place and time is negligibly small: all landscapes are perfect. Recognition of the perfection of landscapes leads away from a worldview holding that landforms and landscapes are the inevitable outcomes of deterministic laws, such that only one outcome is possible for a given set of laws and initial conditions. A perfect landscape perspective leads toward a worldview that landforms and landscapes are circumstantial, contingent results of deterministic laws operating in a specific environmental context, such that multiple outcomes are possible.

Keywords: Perfect landscape; Contingency; Geomorphic system; Instability; Probability

1. Introduction

In his book by the same title, journalist Sebastian Junger (1997) used the term "perfect storm" to refer to a rare convergence in space and time of three different weather systems to create a rare, if not unique, meteorological event. Since the publication of Junger's book and a movie based on it, "perfect storm" has come into general use as a metaphor for the improbable convergence or coincidence of several different forces or factors to produce an unusual outcome. While the colloquial use of the perfect storm metaphor often connotes potential trouble or disaster, in this essay, I wish to pursue the other aspect of perfect storms: the improbable combination of several individual factors to create a singular outcome. The "perfect landscape," in this sense, would be the result of the combined, interacting effects of multiple environmental controls and forcings to produce an outcome that is highly improbable, in the sense of the likelihood of duplication at any other place or time.

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The idea that no two landscapes are identical in minute detail is hardly novel. The argument developed here seeks to go beyond this common wisdom to outline a view of geomorphology (and indeed field-based environmental sciences and geography in general) that integrates local, contingent, historical explanation with global, nomothetic, deterministic explanation. This approach shifts the focus from a search for common, general universal laws which attempt to bring different landforms and landscapes under a common explanatory umbrella, to an attempt to explain the spatial variability of earth surface systems. Models, generalizations and laws are based on the principle of ceteris paribus, all other things being equal. In a perfect landscape, all other things are never equal.

Despite the fact that no two locations are exactly alike, similarities do exist, commonalities can be identified, and there are physical and chemical laws that apply everywhere and always—and a far larger set of looser laws, principles and generalizations that are widely if not universally applicable Culling (1987, 1988) pointed out that landforms, landscapes and indeed spatial patterns in general virtually always have regularities or identifiable patterns which can be explained with general laws, overlaid or combined with irregularities and complexities. The focus on one or the other–for instance the general concavo-convex hillslope profile or the fractal irregularities of the detailed topographic profile–is largely a function of purpose and/or personal preference. Analogously, one can legitimately focus on those aspects of earth surface systems explicable on the basis of general principles and common to other systems, or on those aspects that are local and historically contingent.

The argument here will be developed as follows:

(i) Landscapes and earth surface systems have multiple environmental controls and forcings, and degrees of freedom in responding to them. This allows for many possible landscapes and system states.
(ii) Some of the controls and forcings are causally contingent. These contingencies are specific to time and place. Dynamical instability in many geomorphic systems creates and enhances some of this contingency by causing the effects of minor initial variations and small disturbances to persist, and grow disproportionately large, over time.
(iii) The joint probability of any particular set of global controls is low, as the individual probabilities are ≤ 1.
(iv) The joint probability of any particular set of local, contingent controls is very low, as the individual probabilities are $\ll 1$.
(v) The probability of existence of any landscape or earth surface system state at a particular place and time is negligibly small: all landscapes are perfect.
(vi) Recognition of the perfection of landscapes leads away from a worldview holding that landforms and landscapes are the inevitable outcomes of deterministic laws, such that only one outcome is possible for a given set of laws and initial conditions. A perfect landscape perspective leads toward a worldview that landforms and landscapes are circumstantial, contingent results of deterministic laws operating in a specific environmental context, such that multiple outcomes are possible.
(vii) These different worldviews are associated with fundamentally different research approaches.

2. Multiple controls

That geomorphic systems are affected by multiple controls is axiomatic. While particular controls such as lithology, climate or sea-level change may be emphasized, even the simplest conceptual frameworks of landscape evolution implicitly or explicitly view landscapes as product of a combination of factors. W.M. Davis (1909), for example, viewed the land surface as the result of the combined effects of structure, process, and stage (time). Davis' structure–process–time framework was implicitly and explicitly adopted by numerous earth scientists, regardless of the extent to which they adhered to Davis' cyclical model of landscape evolution. Recognizing that "structure" can represent a variety of geological controls, that there are multiple processes in most landscapes, and that even the time factor can be conceptualized in various ways, the structure–process–time trinity is fully consistent with notions of multiple controls and forcings.

Similarly, the "clorpt" model of Jenny (1941), ultimately derived from the pedological work of Dokuchaev (1883), sees soils as the product of the combined, interacting effects of climate, organisms, relief (topography), parent material (geology), time and other factors which may be locally important. Johnson and Hole (1994), Retallack (1994) and Holliday (1994) have outlined how this conceptual and operational model has been influential not just in pedology and soil geomorphology, but in geomorphology more generally, Quaternary geology, palaeoenvironmental studies, geoarchaeology and physical geography. A more recent development which recognizes not only multiple causality but also mutual adjustment is the “brash” model of Huggett (1995, 1997), which views the biosphere (b), toposphere (r, relief), atmosphere (a), pedosphere (s, soil) and hydrosphere (h) as a dynamical system where each component may influence, and be influenced by, each of the others.

2.1. Degrees of freedom

It is equally axiomatic that many geomorphic systems have numerous degrees of freedom, modes or mechanisms to respond to environmental controls and external forcings. Barrier islands, for example, may respond to sea-level rise by landward migration and/or drowning in place. In the case of landward migration, the necessary sediment transfer may be accomplished by storm overwash, flood tidal delta formation and inlet migration, and aeolian processes—or some combination (Davis, 1994; Bird, 2000; Woodroffe, 2002).

Hydraulic geometry–stream channel response to changes in imposed flow–is a canonical example of multiple degrees of freedom. Even in the most simplified models, there are at least nine variables at the reach scale and five at a single cross-section which may be adjusted, alone or in innumerable combinations, to a given change (Hey, 1978, 1979; Ferguson, 1986; Phillips, 1990, 1991; Miller, 1991; Huang and Nanson, 2000).

Exactly how will barrier islands respond to sea-level rise, or stream channels respond to changes in flow? The answer, as in many analogous questions in geomorphology, is “it depends.” While the responses are certainly constrained by invariant laws that apply to any barrier island or stream channel, there remain many possibilities that are determined by local, specific, factors linked to particular places and times—that is, by contingencies.

3. Contingency and instability

3.1. Inheritance, conditionality and instability

Historical contingency exists where the current state of the landscape is uniquely dependent on a specific past event or sequence of events. Historical contingency arises from inheritance, conditionality and instability. Inheritance involves features inherited from parent material or from previous environmental regimes which differ from the contemporary environment. Many landscapes include inherited landforms, for example, and Twidale (1999) argues convincingly that such inherited forms are relatively common.

Conditionality occurs when an earth surface system can proceed along two or more different developmental pathways, according to the occurrence or magnitude of a particular phenomenon—for instance, whether fires are suppressed or not. Whether or not thresholds are exceeded can result in different developmental pathways in geomorphic systems and contingent outcomes, termed landform singularities by Begin and Schumm (1984). Johnson and Watson-Stegner (1987) provide several examples of how soils might follow regressive or progressive pedogenetic trends according to whether or not particular events occur.

Instability in this case refers to dynamical instabilities, whereby the effects of small perturbations or variations in initial conditions persist or grow over time, resulting in divergent evolution. This is a form of historical contingency because it means landscapes have a “memory” of perturbations that is disproportionately large or long-lasting relative to the magnitude or longevity of the disturbance. Dynamical instabilities are common enough in earth surface systems that Scheidegger (1983) formulated the “instability principle” of geomorphic equilibrium, and Huggett (2003) incorporated instability in a set of principles of geomorphic systems in a geomorphology textbook.

The theory and mathematics of dynamical instability in a geomorphic context have been discussed extensively elsewhere, along with the link between instability and deterministic chaos (Slingerland, 1981; Scheidegger, 1983, 1990; Phillips, 1992, 1999a). Specific examples of dynamical instability and chaos based on field measurements (as opposed to models) are numerous, and include fluvial and aeolian bedforms (Nelson, 1990; Seminara, 1991; Rubin, 1992), evolution of gully systems (Haigh, 1989), river planform change (Hooke and Redmond, 1992; Hooke, 2003), fluvial sediment transport (Gomez and Phillips, 1999; Sivakumar and Jayawardena, 2002), solute transport (Kempel-Eggenberger, 1993), karst processes (Baker and Brunsdon, 2003), salt marsh response to sea-level rise (Phillips, 1992), evolution of fluviokarst landscapes (Phillips et al., 2004; Phillips and Walls, 2004), beach dynamics (Holman, 2001), proglacial sedimentation (Richards et al., 2000), glacial cycles (Liu, 1995), and development of rock weathering features (Viles, 2001; Turkington and Phillips, 2004) and weathering profiles (Phillips, 2000, 2001). These are only a few examples, and the list grows even larger when instability in related hydrological, pedological, climatic and ecological phenomena is considered.

Spatial contingency occurs where the state of a landscape depends on local conditions unlikely to be duplicated or closely approximated elsewhere. Spatial contingency is partly a straightforward function of the geographical variability in environmental processes and controls. In addition, geomorphic systems may exhibit spatial contingency due to local histories and thus historical contingency. It is unlikely that any two sites very far apart have the same history of environmental change and disturbances. Just as a particular landform may be dependent on its history up to that time, the spatial variation of landforms may be dependent on variable local histories that are independent of contemporary geographic variations in environmental controls. If history is anisotropic, historical contingency must lead to spatial contingency. Contingency can also arise from processes, which create and modify spatial structures. This includes processes leading to spatial persistence or contagion (for example catenary relationships linked to hillslope processes), processes associated with spatial aggregation (for instance, the development of non-eroding vegetated "islands" in otherwise erosional landscapes) and those promoting dispersal (for example, spacing of river meanders). These phenomena may lead to environmental characteristics at a location which are sensitively dependent on those at other locations, and a change at any point may be spatially propagated through the landscape.

3.2. Contingent convergence

Several distinct paths of inquiry in the geosciences are converging toward an increasing recognition that historical and spatial contingencies are ubiquitous and must be engaged on their own terms (that is, the contingencies cannot be subsumed under global laws). In quantitative geography, the focus has shifted from a search for global laws and generalizations within spatial data to attempts to explain spatial variability by explicitly incorporating local factors, using methods such as the expansion method and geographically weighted regression. This shift has been motivated chiefly by a cumulative failure to uncover global laws, and the difficulty–or inability–to transfer results from one location, situation or data set to any other without explicit adjustments for local contingencies (Fotheringham and Brunsdon, 1999). Examples of fruitful applications of these techniques in geomorphology and physical geography include Atkinson et al. (2003) and Nelson (2001).

Soil geography, pedometrics and landscape ecology have likewise focussed on modeling and explaining local spatial variability rather than a search for global laws, and in fact have developed based on paradigms stressing the search for applicable process laws within local and regional contexts (Ibanez et al., 1995; Haines-Young and Chopping, 1996; Goovaerts, 1999; Christakos, 2002). Walsh et al. (1998) have explicitly addressed the relevance of this approach in geomorphology. The techniques in these subfields typically focus on quantifying landscape fragmentation and variability as opposed to teasing out underlying regularities, and the Bayesian maximum entropy technique, for example, is intended to explicitly incorporate local or problem-specific "soft" knowledge into statistical models (Christakos, 2002).

Within geomorphology, the undeniable role of history has increasingly come to the forefront as concern over global change has rejuvenated research into palaeoenvironmental reconstructions. The contingent, path-dependent nature of landscape and environmental evolution calls for an approach to science fundamentally different from that of the reductionist ideal (e.g., Baker, 1996; Spedding, 1997; Bishop, 1998; Harrison, 1999). Examples which explicitly address the need to address historical contingency in geomorphic problems include Lane and Richards (1997) and Fryirs (2002) on fluvial geomorphology, Bishop (1998) on highland landscape evolution, Sauchyn (2001) on disturbance of soil landscapes, Thomas (2001) on landscape sensitivity, and Vandenberghe (2002) on palaeohydrology. Corollary are an increasing number of studies which show that a synoptic approach is necessary in many instances; e.g., the geomorphic processes and responses cannot be understood without reference to the specific temporal and spatial context. Examples include Knox's (2000) work on floods, Knighton and Nanson (2001) on arid stream systems, Miller et al. (2003) on stream sediment fluxes, and Slattery et al. (in press) on agricultural runoff and soil erosion.

Another line of inquiry leading toward contingency is the study of the geomorphic effect of high-magnitude, low-frequency events. With respect to floods, for example, factors such as event timing, sequence, and initial conditions–inherently and irreducibly historically and spatially contingent controls–are often found to be of comparable or greater importance in determining geomorphic impacts than factors such as event magnitude or force/resistance relationships which can be addressed with global laws. Magilligan et al. (1998) provide a case study along with a review of the relevant literature on this theme, which also applies to events such as hurricanes (Phillips, 1999b).

Perhaps most convincing to geomorphologists, who tend to believe empirical evidence first and foremost, is the cumulative failure of (strictly) law-based approaches to provide adequate explanation, or the aggregate difficulty in developing reliable generalizations. Schumm et al.'s (2000) book on tectonic influences on alluvial rivers, for example, relies heavily on four case studies, but generalizations are hard to come by: "Because the four rivers are subjected to different types of active tectonism and each river is different, the only firm conclusion that can be reached is that deformation causes river variability" (p. 151). Likewise for a comprehensive, multinational effort to link landslides to climate change in Europe: "…the complexity of the relationship between climate and landsliding seems to make it not feasible to establish 'universal laws' all over Europe" (Dikau and Schrott, 1999, p. 1). Even in a relatively restricted regional context (U.S. Great Plains), Friedman et al. (1998) could discern no generalizations re downstream geomorphic effects of dams on large rivers, concluding that each must addressed case by case.

Finally, returning to the instability theme, nonlinear dynamical system-based analyses in geomorphology have become increasingly common, and repeatedly show that dynamical instability and deterministic chaos are common and relevant to many geomorphic systems and related phenomena (see reviews by Phillips, 1999a; Sivakumar, 2000; Paillard, 2001; Hergarten, 2002; Phillips, 2003). The persistence and growth of minor variations in initial conditions, or of disturbance effects, is the source of many of the contingencies noted by geomorphologists, and no doubt exacerbates many others.

4. Probabilities and perfection

Geomorphic systems are characterized by multiple controls and influences, multiple degrees of freedom, and significant effects of both governing laws and contingencies. We can therefore conceptualize a landscape or geomorphic system (S) as a function of multiple general (global, or place- and time-independent) controls, and local, contingent, place- and time-dependent controls. Symbolically,

$$S = f(G_1, G_2, \ldots, G_n)(L_1, L_2, \ldots, L_m) \qquad (1)$$

where there are $i=1, 2, \ldots, n$ general or global controls G_i, and $j=1, 2, \ldots, m$ local or contingent controls L_j.

An aeolian dune, for example, is determined in part by global laws pertaining to the physics of sediment transport and deposition, interactions of wind flows and surface properties, and relationships between aeolian sediment movement and soil moisture and vegetation (G factors). The state of the dune (as defined, for example, by its size, shape, mass balance, and rate, direction or mode of movement) is also partly determined by a number of local, contingent (L) factors such as current vegetation state and history, proximity to sand sources, juxtaposition with other dunes, moisture status and history, wind and storm climatology and history, faunal trampling, and numerous other factors.

The probability of any given specific system $p(S)$ is a function of the joint probabilities of the G_i, L_j:

$$p(S) = \overset{n}{\Pi} p(G_i) \overset{m}{\Pi} p(L_j), \qquad p(G_i), p(L_j) < 1 \qquad (2)$$

In some cases, $p(G_i)=1$ in theory—for example, shear stress vs. shear strength principles should always apply. In analytical and predictive practice, however, there is a significant amount of uncertainty (for example, several different sediment transport laws), and the vast majority of predictive equations or models are characterized by contingencies built into parameters or coefficients and/or by simplifying assumptions. Even if all applicable global laws are known and can be applied with certainty, however, all $p(L_j)<0$ and typically $p(L_j) \ll 0$. The joint probabilities show that $p(S)<0$.

Even an unrealistically simple situation illustrates the point. Suppose that for a given landscape all $p(G_i)=1$ and that $p(S)$ is thus determined by the a local combination of structure, process-regime and age, with each of these having a 50–50 chance of occurrence anywhere on the land surface. Even here $p(S)=0.125$; real probabilities are likely to be far lower.

Eq. (2) also shows that introducing more variables, factors or controls can only reduce $p(S)$. The key to identifying commonalities among landscapes or geomorphic systems (i.e., to identifying landscapes with greater $p(S)$, or conditions under which $p(S)$ may increase) is not identification of new and more variables or controls, but the reduction or elimination of G_i and L_j.

An example is the development of karst fractures. Dreybrodt and Gabrovsek (2002) present a model of karst fracture evolution starting with a single isolated fracture with constant hydraulic head driving Ca-aggressive water. The system is characterized by instabilities associated with nonlinear dissolution kinetics and positive feedbacks between fracture widening and flow. A breakthrough event occurs when the positive feedbacks between widening and flow lead to rapid widening along the entire length of the fracture. Breakthrough time is a function of the aperture size, hydraulic head and three chemical parameters (Dreybrodt and Gabrovsek, 2002). These represent the global factors—physical and chemical laws that would apply in any karst fracture at any time. However, Dreybrodt and Gabrovsek (2002) note that the same chemistry and physics produce different results under different boundary conditions; these different results are manifested not merely as quantitatively different passages, but as qualitatively different modes of cave formation. Because boundary conditions are local factors, each $p(L_i) < 1$, and the probability of any given mode of cave formation is less than one even under the simplified model, and the probability of any given passage geometry is even lower.

5. The pursuit of imperfection

The perfect landscape model shows that the more factors that are considered, the less likely is any particular landscape. In modelling language, the more variables and parameters included, or the more processes we attempt to model, the more singular the outcome. This suggests that the way to increase generality of models, explanations or conceptual frameworks is by reducing rather than increasing the number of explanatory factors.

Though motivated by different concerns, several approaches to this issue have emerged in recent years. In modeling landforms, Werner (1999) and Hergarten (2002) argue that the fundamental qualitative behavior of the system (a dune, river channel, beach, etc.) is more important than the quantitative details, and argue for what is fundamentally a phenomenological approach that captures essential relationships and behaviors. This method has had some success in modeling and explaining aeolian dunes, soil erosion, beaches, glaciers and fluvial systems, among others (Werner and Fink, 1994; Werner, 1995; Favis-Mortlock, 1998; Masselink, 1999; Bahr and Meier, 2000; DeBoer, 2001).

Qualitative modeling, based on the set of positive, negative or negligible interrelationships among the key components of a geomorphic system, has long been viewed as a fall-back option in the absence of the data or knowledge necessary to fully specify the quantitative relationships. However, Escultura (2001), Harrison (1999), Mendoza-Cabrales (1994), Phillips (1992, 1999a), Phillips and Walls (2004), Slingerland (1981) and Trofimov and Moskovkin (1984) have pointed out that qualitative models actually increase the generality of the results. The qualitative features of a phenomenon are often universal, while the quantitative features are quite variable (for example fully developed turbulence; Tsinober, 1998; Escultura, 2001; weathering and erosion; Phillips, 2005). For instance, while the specific quantitative relationships between vegetation cover and erosion resistance are highly variable in space and time, the qualitative link (more vegetation cover = greater resistance) applies everywhere and all the time. In the perfect landscape context, this can be viewed as model formulation to minimize *L* factors (parameterizations specific to places, times and situations) in favor of G factors (qualitative relationships that are universally or widely applicable). Qualitative stability models, as one example of qualitative models, have been successfully applied in coastal, fluvial, hillslope and soil geomorphology (Slingerland, 1981; Trofimov and Moskovkin, 1984; Phillips and Steila, 1984; Phillips, 1992; Mendoza-Cabrales, 1994; Phillips, 1999a, 2001) as well as in ecology and climatology.

In hydrology, the dominant processes concept (DPC) is a response to the recognition that there are difficulties in trying to model all potentially relevant hydrological processes, the field observation that often only a few processes dominate hydrological responses in any given watershed, and the experience of hydrologic modellers that simple models with a few dominant factors can capture the essential features of hydrologic response. The DPC therefore points to hydrological analysis based on simpler models and fewer processes, with the included processes based on observations within individual watersheds.

The DPC is primarily motivated by the goal of producing more efficient representations of hydrological response, but could also be viewed in light of the perfect landscape concept as using the local, contingent idiosyncrasies of a hydrologic system to prune the number of factors or variables considered. This conditioning of the global factors included in the model or analysis by the local factors in the system of interest could have the effect of increasing the generality of results—but in a synoptic context. In other words, the results of a DPC-based analysis could potentially be applied to other watersheds where the local, contingent conditions point to the same set of dominant processes.

Michael Walls and I (Phillips and Walls, 2004) essentially took this approach (but without specific reference to the DPC or the perfection of landscapes) in our study of divergent evolution of fluviokarst landscapes in central Kentucky. We used a model of flow partitioning between surface and subsurface, and between concentrated and diffuse, flow to attempt to explain the tendency of the most highly eroded portions of the study area to diverge into either highly karstified zones with little or no surface flow or fluvial erosion, or fluvially dissected zones with few or no solutional landforms. Our qualitative model is highly general in that it does not depend on specific, necessarily local, parameterizations. On the other hand, some of the links in the model are not universal, and we chose the sign of those links based on conditions and field observations within our study area. The model is thus not applicable to all fluviokarst landscapes, but is potentially relevant to those where the positive and negative links in the flow partitioning model are the same as in the inner Bluegrass region of Kentucky.

There is a wide potential for expanding a DPC approach in geomorphology based on synoptic typologies. Dreybrodt and Gabrovsek (2002), for instance, present a review of modeling of karst evolution based on universally applicable chemical and physical laws, but note that different local factors (boundary conditions) may result in different modes of cave formation. By developing a catalog of sets of boundary conditions associated with particular modes of cave formation (ideally both in the model context and in field-based reconstructions of cave development), prediction and generalization could potentially move forward in a synoptic context. Note that a traditional, reductionist approach to this problem would typically involve introducing more variables, a more complex model and a more detailed representation of dissolution kinetics. The synoptic framework, by contrast, emphasizes more attention to local case studies to provide a basis for applicability of the simpler, more general process model.

6. Worldviews

The perfect landscape concept circumscribes a geomorphological worldview that may be compared and contrasted with existing, more familiar worldviews.

6.1. Equilibrium

While equilibrium is variously and often poorly defined in geomorphology, the most common frameworks are based on a concept of a steady-state resulting in a dynamic balance between force and resistance. As they have evolved over the years, worldviews derived from this notion are based on the ideas that:

- Landforms and geomorphic systems move toward, and given enough time achieve, a steady-state that is characteristic of or adjusted to environmental constraints and boundary conditions; for instance, the equilibrium river channel or hillslope.
- Equilibrium states are steady-states that are stable and can maintain themselves in response to small disturbances, such as post-storm recovery of equilibrium beach profiles or post-dam achievement of a new equilibrium river channel.
- Similar boundary conditions will produce similar outcomes.
- History matters most in the initial stages of landscape evolution or soon after a disturbance, and increasingly less so thereafter.
- Landscape evolution is mainly convergent, with initial variations or the effects of disturbances gradually reduced in a progression toward a steady-state adjustment to environmental conditions.

6.2. Historical

Historical approaches in geology and geomorphology, and traditional regional geography, are often characterized as being concerned primarily with the particulars of place and history, and as viewing landforms and landscapes as singularities, with little regard for general principles except as they apply to specific situations. While this is a caricature that is both oversimplified and sometimes unfair (as is the equilibrium worldview described above), it serves here to outline an alternative worldview, based on the ideas that:

- Landforms and geomorphic systems are local products of specific chains of historical events.
- Equilibrium states are relevant only in the short term, pending the next leg of the historical journey.
- In theory, similar boundary conditions will produce similar outcomes, but only in the unlikely event of history repeating itself.
- History is the predominant explanatory factor in landscape evolution.
- Landscape evolution may be convergent or divergent, depending on whether or not certain cyclical theories of landscape evolution are subscribed to.

6.3. Nonequilibrium

Yet a third worldview is often characterized as “nonequilibrium” to contrast it with traditional equilibrium worldviews, even though this perspective typically recognizes the presence of steady-state equilibria—just not that equilibrium is necessarily more common or important than nonequilibrium. Arising chiefly out of nonlinear dynamical systems approaches to geomorphology and related fields, the nonequilibrium worldview is based on the ideas that:

- There are multiple possible equilibrium states for many geomorphic systems.

- Equilibria may be unstable, and thus sensitive to small disturbances, as well as stable.
- Geomorphic systems are overwhelmingly nonlinear, raising the possibility of complex nonlinear dynamics—particularly associated with dynamical instability.
- Due to dynamical instability (equivalent to deterministic chaos), similar boundary conditions may produce different results.
- History matters, because unstable geomorphic systems may be path-dependent.
- Landscape evolution may be divergent, with progressive differentiation over time, as well as convergent.

6.4. Perfect landscapes

Can we articulate a worldview tied to the perfect landscape concept? Such a perspective should have some affinity to the nonequilibrium view, with its emphasis on the possibility of instabilities. There are also affinities with the historical worldview, as landscape perfection emphasizes the role of historical contingency. The basic tenets of the perfect landscape concept are that:

- Landscapes are strongly influenced by laws, principles, relationships and rules that are independent of place and time, and that operate within their domains everywhere and always (global factors).
- Landscapes are strongly influenced by historically and geographically contingent factors that are particular to place and time and thus idiosyncratic (local factors).
- The probability of encountering any specific set of applicable global and local factors is extremely low; thus, landscapes have elements of uniqueness.
- The key to increasing the generality of models, concepts and research results is to reduce the number of variables and factors considered.

These lead to a worldview based on the notions that

- Landscapes are circumstantial, contingent outcomes of deterministic laws operating in a specific environmental and historical context.
- A landscape is only one possible outcome of a given set of processes and boundary conditions, which is determined by a specific, perhaps irreproducible set of contingencies. However, the possible outcomes are strongly constrained by the applicable laws.
- While it is legitimate and useful to conduct research focussed on either global laws or local contingencies, the ultimate goal of explaining landscape evolution requires the integration of global and local approaches.

7. Concluding remarks

In a review of sandstone weathering research, Turkington and Paradise (2005) identified seven factors contributing to scale issues in stone durability studies. These are geographical and temporal variability of external forcings and controls, heterogeneity of internal properties, inheritance, inconsistent responses, the episodic nature of weathering processes and responses, singularity and inherent complexity arising from processes and interactions emerging at larger scales that are not derivable from smaller scales. These seven factors can be applied to geomorphology as a whole and make a convenient framework for summarizing the perfect landscape concept.

The multiplicity and variability of external forcings in space and time, heterogeneity of internal conditions and episodicity of landform change indicate that even when applicable global laws and principles are known and can be confidently applied, the boundary conditions are irreducibly variable. This reinforces the notion that global laws should be applied with due attention to local conditions and constraints. Inheritance, along with variability in external and internal conditions, points to important influences of historical contingency. The dynamical instability in many geomorphic systems is responsible, in many cases, for the inconsistent responses and inherent complexity (Turkington and Paradise, 2005).

With respect to singularity, the explanation given by Turkington and Paradise (2005, Table 2) is remarkably consistent with the perfect landscape concept: “Each weathering system displays particular combinations of conditions at instances in space and time; specific, or contingent, properties may be regarded as unique, or unpredictable.”

The perfection of landscape is inextricably entwined with dynamical instability. It is the (possibility of) disproportionate responses to initial variations and to disturbances that makes many geomorphic systems path-dependent and historically and spatially contingent. It is the exaggeration of differences, divergent evolution, that dictates that local differences matter so much.

A perfect landscape worldview challenges traditional reductionism and equilibrium as a normative concept (as opposed to a reference condition and/or a possible rather than inevitable outcome). On the other hand, the perfect landscape notion embraces an attempt to meld several different geomorphic traditions—including process-mechanical and historical approaches. Landscapes are indeed shaped and controlled by deterministic, global laws, but the operation of these laws in specific geographical and historical contexts means that landforms and landscapes are often circumstantial, contingent outcomes, not derivable from global laws alone. Rather, the perfect landscape is only one possible outcome–albeit strongly constrained by applicable laws–of a given set of processes and boundary conditions, which is determined by a specific, perhaps irreproducible set of contingencies.

Perfection of landscapes implies many complications and uncertainties for geomorphologists, but also innumerable wondrous possibilities and a reenchantment with landforms. To quote the writer Alan Moore (1987): "To distill so specific a form from that chaos of improbability, like turning air to gold, that is the crowning unlikelihood. The thermodynamic miracle."

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