FLUVIAL CLASSIFICATION: NEANDERTHAL NECESSITY OR NEEDLESS NORMALCY

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ABSTRACT: Classification has and will continue to have an important role in science, particularly in fluvial geomorphology, which is solidly founded upon field studies and observation. This paper provides an overview of basic classification concepts and their application in river classification. Although the system of classification attributed to Aristotle has guided classification thinking for two millennia, new views regarding classification have recently emerged and are presented. Whether classification systems identify real categories or human abstractions is framed in the context of natural and nominal *kinds*. Classification systems devised by Leopold and Wolman (1957), Kellerhals et al. (1976), Nanson and Croke (1992), Whiting and Bradley (1993), Rosgen (1994), Miall (1996), Woolfe and Balzary (1996), and Montgomery and Buffington (1997) are briefly reviewed. Finally, 10 specific recommendations for improving the next generation of fluvial classification schemes, including a suggestion that classification be ignored in favor of other analytic methods, are provided.
KEY TERMS: Classification; fluvial geomorphology; philosophy.

SOME CLASSIFICATION BASICS

Why do people classify things? Psychologists theorize that in a universe of limitless numbers of objects and ideas, classifying things into groups is one of the brain's mechanisms for creating order out of chaos (Smith and Medin, 1981; Estes, 1994). Wired into our brains (and presumably the brains of others along our evolutionary branch) are mechanisms for consciously and unconsciously placing things into categories. Understanding how we classify is central to how we think and function, and to what makes us human (Lakoff, 1987).

Probably because categorizing things is a fundamental hominid trait, classification has become both part of our common sense knowledge and the subject of philosophers. From Aristotle through two millennia, much of our folk theory regarding classification has been adopted into technical theory of classification. The basic premise of such a classical view of classification is that things are placed into categories based upon their common properties. Categories are abstract summary representations of a class as a whole and are therefore not sets of descriptions of instances of the class (Smith and Medin, 1981). All entities having a given collection of common properties form a category; these properties are both necessary and sufficient to define the category. Categories may be divided into subcategories in which the defining category properties are nested. Properties can be characterized as either dimensions (quantitative) or features (qualitative). A feature property either exists or does not exist in a class definition, whereas dimensional properties are assessed by the magnitudes of their quantitative values. For example, a braided river is characterized by braid bar features that divide the river into multiple channels, whereas single thread rivers lack braid bars. Straight, sinuous, and meandering rivers have usually been delimited based upon the quantitative measure of sinuosity. Classical categorization ideas of necessary and sufficient conditions are easily adaptable to statistical techniques. Unsupervised classification techniques (such as cluster analysis) are used to define classes of objects based upon their properties. Supervised classification

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methods (discriminate analysis, pattern recognition) are used to define rules for selecting classes when one has objects of known class and properties that can be used to define rule-making training sets (Hand, 1997).

Although classical categorization has been with us for over 2,000 years, its perspective is probably a small part of a larger, more complex picture (Lakoff, 1987). Within the past several decades, two alternative viewpoints of classification theory have been advanced to eliminate shortcomings of the classical view. One of these, termed *probabilistic* or *prototype theory*, does not require all properties to be true of all class members (Smith and Medin, 1981). In the classical view where members are defined by common properties, no member should have special status or be more representative of the class. Probabilistic theory, on the other hand, suggests that there are members of a class that are more representative of the class than are its other members. Class members are assumed to vary in the degree both to which they share a property and to which they represent the class. Thus, class association is based upon individual location with respect to central tendencies (modal location) — not upon necessary and sufficient conditions of its properties (Smith and Medin, 1981). An individual is considered a member of a category if the sum of its weighted values exceeds some critical value. Thus, even though an individual has a relatively low feature sum, it can still be a member of a particular class, albeit less representative of the class. The best representatives of the class are those having weighted sum values closest to that of the abstract prototype.

The exemplar view is more extreme than the probabilistic view in that instead of some abstract summary prototype being most representative of a class, specific individuals or exemplars are used to define the class (Smith and Medin, 1981). The only basic assumption of the exemplar view is that the representation of a class consists of descriptions of its exemplars (Smith and Medin, 1981). An individual of unknown class is placed into a particular category if and only if it retrieves or compares well with a critical number of the exemplars of that class. The exemplar view is still an emerging one, but is quite similar to the way geologists identify geologic formations in a stratigraphic section. A definitive formation description is made at the type section locality from which the formation derives its name (e.g., Chugwater Formation for Chugwater Creek, Wyoming). Descriptions of the formation are made at other locations describing formation characteristics at those localities. These sets of descriptions then become exemplars for a geologist seeking to delineate a formation at yet another locality.

Three methods of classifying have been presented above. But are classification schemes merely human constructions designed to aid understanding of complex phenomena? Or are classifications used for objectively "carving nature at the joints" (Hempel, 1965)? Categories of the former type that are defined for convenience or specific purpose are called *nominal kinds*, whereas those of the latter type based on natural systemization are termed *natural kinds*. More specifically, "something is a member of a natural kind if and only if it has real essence, an intrinsic property or set of properties that make it the kind of thing it is, irrespective of any system of classification we may find it convenient to adopt" (Wilkerson, 1986). Philosophical debate continues as to whether there really are natural kinds of things. If natural kinds do exist, they likely will be intimately intertwined with natural laws and an understanding of these kinds will help in explaining how nature functions (Collier, 1996). For science, perhaps the most important natural kinds are natural kinds of processes, which may be hierarchically structured with some processes more fundamental than are others (Ellis, 1996). Natural kinds therefore have an explanatory role, not just a descriptive one, in that they "signify certain clusters of causal powers, capacities and propensities which are naturally coinstantiated" (Ellis, 1996). Although seeking natural kinds of processes and causes is one of the basic goals of natural science (Ellis, 1996), some scientific endeavors may find that nominal kind classification systems based upon intended use will have more utility than classification based on natural categories (Dilworth, 1996).

Historically, most fields of science have gone through a classification phase. The classification phase usually occurs during the early stages of development of a scientific field as a means of ordering observations and descriptions. As a science advances, classification gives way to the development of empirically based laws and finally to theoretical understanding (Figure 1). Classifications may still be used in well-advanced sciences, but classes are descriptors based upon input from law and theory in the form of feedback. For example, the periodic table used in chemistry is a classification that has its underpinning in atomic-molecular theory. Because geomorphology is a relatively young field, classification continues to play an important role. Eventually, however, "classifications defined by reference to manifest, observable characteristics will tend to give way to systems based on theoretical concepts" (Hempel, 1965). In fact, because scientific usefulness is measured in part by an ability to predict, a "preoccupation with description could lead to decreasing usefulness because classification and description are usually insufficient bases for extrapolation and thus for prediction" (Leopold and Langbein, 1963).

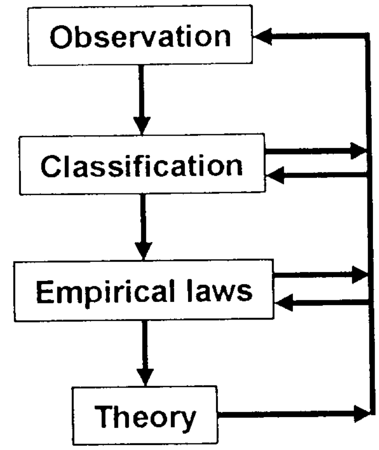

Figure 1. Evolutionary stages in the development of a field of science.

A VERY BRIEF REVIEW OF SOME FLUVIAL CLASSIFICATION SYSTEMS

Several recent reviews of fluvial classification systems have been published (Naiman et al., 1992; Downs, 1995; Thorne, 1997). For brevity, this section will evaluate only a few better known fluvial classification schemes. Additionally, I will limit my discussion to reach scale classification systems.

Form-based or morphological classification schemes implementing a classical view have been popular for river classification. Many of these have used the global property of river shape in plan form as the primary delimiter. The best known river classification of this type is the tripartite division of rivers into braided, meandering, and straight (Leopold and Wolman, 1957). Leopold and Wolman (1957) recognize that there is a continuum of river types reflecting various combinations of hydraulic factors; the braided, straight, and meandering patterns are associated with certain combinations of those factors. Kellerhals et al. (1976) have devised a system intended mainly "as an aid to summarizing descriptive field data" from map interpretation, aerial photography, and field inspection. The system rather exhaustively evaluates valley, valley flat, and stream characteristics, but primarily those that can be assessed as feature properties. Feeling that the plan form classification of Leopold and Wolman (1957) was unsatisfactory, Kellerhals et al. (1976) devised a system combining channel pattern, islands, channel bars, and major bedforms. Rosgen's (1994) classification of natural rivers places a heavy emphasis upon dimensional properties to define eight primary stream types. A hierarchical decision tree distinguishes types based upon the feature property of number of channel threads and the dimensional properties of entrenchment ratio, width-depth ratio, and sinuosity. Entrenchment ratio, sinuosity, and width-depth ratio have fuzzy decision rules that acknowledge the continuum of stream variability. Sediment size and channel slope are used to classify these types into subcategories.

Two rather interesting process-based classical view classifications have been recently proposed. A distinctive process-oriented approach to channel classification is taken by Woolfe and Balzary (1996) who "define and predict sedimentation and erosion regimes across the entire spectrum of channel styles." Eight categories (fields of channel style) are defined with each category representing a spectral segment relating rates of channel to floodplain aggradation/degradation. There are two dimensional process properties used in the classification: rate of change of channel elevation and rate of change of floodplain elevation. This classification system is entirely independent of channel morphology and applicable to all sedimentary systems involving channelized flow. Unlike Woolfe and Balzary's (1996) form-independent classification scheme, Whiting and Bradley (1993) utilize dimensional measures of fluvial form in their process-based classification system for headwater streams. Forty-two stream classes are defined on the basis of domains in three two-dimensional phase space 'panels' where the domains represent different and distinct physical processes and their relative rates (Whiting and Bradley, 1993). The domains are process interpretations based upon dimensional properties of morphological features, which include channel gradient, channel width, valley width, and median sediment size.

Although none of the existing fluvial classifications can be considered to implement the probabilistic view of classification, two systems come closer than others do. Montgomery and Buffington (1997) and Nanson and Croke (1992) have devised classification systems that, to some degree, implement prototypes. Nanson and Croke's (1992) genetic classification of floodplains describes 15 floodplain types that are grouped into suborders, orders, and classes based upon similarity of sediment cohesiveness and specific stream power. Descriptive characteristics include both process and form features and dimensions. In their classification system, Montgomery and Buffington (1997) define seven channel types based upon overall qualitative morphological character. Seven fuzzy, mainly feature characteristics are used to define whether or not a stream is of a given type. Although neither of these two classification schemes implements weighted sums to decide whether an individual falls into a class, other characteristics are similar to probabilistic view classes. Montgomery and Buffington's (1997) use of adjective feature descriptors of *typical* and *dominant* illustrate that these are desirable features but not absolutely necessary for describing a type. Both systems use illustrations of their abstract conceptualizations of their types, and Nanson and Croke (1992) provide best examples of types from the literature.

Miall (1996) approaches stream classification from a fluvial sedimentologist's perspective. More significant is that his approach is closer to the exemplar view (Smith and Medin, 1981) than are those of other classification systems. As Miall (1996) describes, each class "is a summary of a particular environment, in which local details have been distilled away, leaving the 'pure essence' of the environment... the resulting summary acts as a norm for purposes of comparison, and as a framework and guide for future observation." Sixteen specific fluvial *styles* are grouped into three major classes — gravel-dominated, sand-dominated high-sinuosity, and sand-dominated low sinuosity. Styles represent identifiable depositional environments and may be identified by sinuosity, braiding parameter, sediment type, and characteristic architectural elements. Styles are named based upon predominant characteristics (e.g., flashy, ephemeral, sheetflood, sand-bed river). However, in exemplar fashion, Miall (1996) attaches some styles with names based upon exemplar streams (e.g., Platte type, Bijou Creek type).

IMPROVING FLUVIAL CLASSIFICATION SYSTEMS

Within this section I offer 10 recommendations for developers of future fluvial classification systems to improve their products. This list is by no means exhaustive. It does present thoughts obtained by examining existing fluvial classification schemes.

Recommendation 1: Base Classifications on Natural Kinds

Assuming there are natural kinds of rivers, these kinds should be intimately linked with natural laws of river development. Thus, classification systems based on natural kinds should have utility in explaining and predicting river conditions. The goal for the classifier is to determine what those natural kinds are. Because river types appear to exist along a continuum, it seems logical that natural kinds of rivers would be spectral kinds (Ellis, 1996) distinguished by continuously varying formative process or controlling factors.

Recommendation 2: Base Classifications upon Processes or Controlling Factors

Many fluvial classification schemes have been based wholly or in part upon characteristics of channel form. Channel forms, although readily measurable, are the end products of complex, dynamic systems (Figure 2). These end products may be non-unique manifestations of underlying controlling factors and processes. Form-process feedbacks (Lane and Richards, 1997) and geomorphic *convergence* (when different processes can produce similar outcomes) (Schumm, 1984) suggest that many fluvial forms may not be natural kinds. Braided rivers, for example, may be indicative of aggrading, degrading, or equilibrium conditions (Germanoski and Schumm, 1993). Braid bars can result from any one of five mechanisms: central bar deposition, transverse bar conversion, chute cutoff, multiple dissection of lobes, and avulsion (Ferguson, 1993). This lack of a one-to-one correspondence between geomorphic process and form suggests that measurement of fluvial processes or controlling factors, albeit difficult, may be a better pathway to discovering natural kinds of rivers.

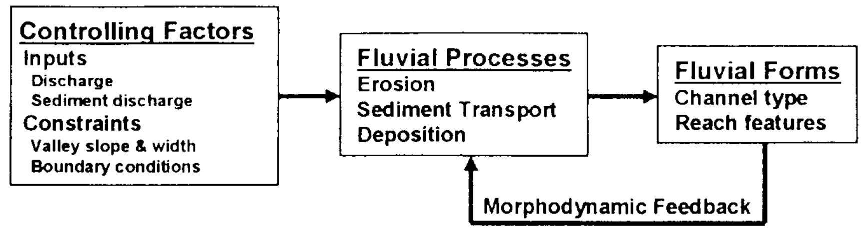

Figure 2. Simple conceptualization of relationships among controlling factors, fluvial processes, and fluvial forms. Most classification systems have concentrated on fluvial forms, which are the output products of a complex, dynamic system.

Recommendation 3: Base Classifications upon Temporal Change and Thresholds

It might prove worthwhile to extend the process-based idea presented in recommendation 2 to longer temporal spans wherein rivers are truly perceived not as "things in space" but as "processes through time" (Pinet, 1997). The classification scheme devised by Nanson and Croke (1992) is an example of a system that inherently recognizes temporal stability with respect to equilibrium by organizing floodplain types into disequilibrium and dynamic equilibrium classes. Another change-based approach to fluvial classification (although not identified as a classification system by its author) is Trimble's (1995) organization of five conceptual models of valley storage fluxes. His five models include a quasi steady state class and four classes showing various departures from a steady state. Extensions to the ideas presented by these two classifications could incorporate parameters such as reaction time versus relaxation time (Bull, 1991) or threshold ratio parameters such as stream power to critical power (Bull, 1979).

Recommendation 4: Base Classifications on Theory

Many fields of science begin with an observation-based classification stage and then advance to law-forming and theory development stages. After some period of growth in a scientific field, all of these stages occur simultaneously, with feedbacks from more advanced levels of knowledge guiding less advanced levels (Figure 1). Thus, at some evolutionary point, even observations are based upon theory and not just upon mindless collection of data. With time, classification should become less dependent upon purely observational input and more dependent upon geomorphological theory.

Recommendation 5: Base Classifications on a Probabilistic View

Most classification systems in geomorphology and other scientific fields have been based upon the classical view of classification. The development of new concepts of classification theory in the past several decades allows us to begin assessing the applicability of these concepts to systems of fluvial classification. Probabilistic classification concepts appear to hold much promise, particularly since necessary and sufficient conditions of the classical view are replaced by central tendency conditions, which provide more flexibility for the complex continuum of the fluvial system.

Recommendation 6: Calibrate and Verify Classifications for Prediction

Recommendations 1, 2, 3, and 4 intertwine classification with scientific understanding and explanation of fluvial conditions. If the goal of using a classification system is to make management predictions (as opposed to increasing understanding), then a purely empirical rather than rationale approach to classification can be taken. The empirical approach may be of limited value to understanding landform genesis (Strahler, 1952). However, if strong interrelationships are discovered between measurables and outcomes, then a classification based on this approach could be useful for some management applications. I suggest treating empirical classification systems similarly to black box models, which are developed without any consideration of physical processes (Refsgaard, 1996). In particular, the black box classifications should have many of the same limitations as black-box simulation models, including problems of extrapolation. If empirical predictive classification schemes are to be developed and used, then they should be calibrated, verified, and updated as more outcome data become available.

Recommendation 7: Incorporate Size Factors into Classification Systems

With the notable exception of Church (1992), nearly all existing fluvial classification schemes ignore size and scale aspects in their derivation. Although size measurements may be made to derive classification parameters, these measurements are usually converted into dimensionless shape or pattern indicators (e.g., width-depth ratio and sinuosity). Scale issues, however, are significant both in absolute and in relative ways. The absolute effects of size can be related to flow discharge. For example, as downstream river size increases with discharge, width increases more rapidly than depth, as is indicated by the exponents in the downstream hydraulic geometry equations (Leopold and Maddock, 1953). Thus, with all other conditions being equal (e.g., bed and bank materials), larger rivers should be wider relative to their depth than are smaller streams. Relative size effects include those influenced by relationships between the channel and its boundary features. For example, channel characteristics may be influenced by bank vegetation factors, and these are dependent upon the size of the channel in relation to size of the surrounding vegetation. Fluvial classification systems that effectively incorporate relative and absolute size factors may prove especially beneficial for restoration purposes.

Recommendation 8: Use Nomenclature that Improves Communication

The fluvial environment is being examined by professionals from many disciplines who are undertaking watershed analyses, the NEPA process, engineering projects, and environmental restorations. For individuals from multiple disciplines to effectively describe and communicate the aspects of a complex natural system, a classification system that 'creates order out of chaos' is beneficial. Classifications devised to aid communication need not be based upon natural kinds, for the purpose is merely to allow individuals to develop mental pictures of rivers. For this reason, form-based classification systems are most useful, for forms are more intuitive and understandable to humans than are geomorphic processes or causes. A key aspect of a classification scheme of this type should be its composition of a readily understandable nomenclature. Hill (1963) provides an excellent set of eight rules for classifying geological faults, which, I believe, could improve the nomenclature of future fluvial classification systems. I present Hill's (1963) rules herein in abridged form:

1. A name should be widely understood and used.
2. A name should be descriptive or explanatory.
3. A name should be a common word, if possible.
4. A name should be rationale and appropriate to the science involved.
5. A foreign name should be used when appropriate, but in untranslated form.
6. Symbolic and/or mnemonic terms may be used if they are more practical than descriptive terms.
7. The same thing should not be given two different names nor different things given the same name.
8. A name should represent a group of things, processes, or concepts, and if possible, should also be part of a greater group.

Recommendation 9: Treat Classifications as Hypotheses — Not as Paradigms

In some respects, classification schemes can be treated similarly to hypotheses in that their development is undertaken to seek to explain regularities in nature. If classification systems are viewed as hypotheses with respect to their use, then each additional use becomes a test either verifying or nullifying their explanatory capability. For example, as evidence amasses regarding a classification scheme's explanatory or predictive capability, modifications can be made. If necessary, it can be discarded in favor of a new system. Unfortunately, a particular theory, or perhaps classification scheme, can become the only way that a field of science evaluates a particular class of problems. The philosopher of science Thomas Kuhn (1962) identified this situation as *normal science* to which he attached the now overused word *paradigm*. Kuhn contends most scientists operate within the bounds of scientific norms seeking to refine theories devised by others, rather than exploring beyond them. As Kuhn (1963) states, given a paradigm "and the requisite confidence in it, the scientist largely ceases to be an explorer at all, or at least to be an explorer of the unknown." However, enough paradoxes or anomalies eventually arise that the paradigm can not explain, so it is cast off in a scientific revolution (Kuhn, 1962). I believe that the tripartite division of the river continuum into braided, meandering, and straight patterns (Leopold and Wolman, 1957) functioned as a classification paradigm that for several decades directed geomorphic thinking about rivers. The paradigmatic nature of this classification scheme possibly delayed understanding of anomalies such as anastomosing (Knighton and Nanson, 1993) and wandering (Church, 1983) river types, and even today it remains a dominant influence upon river classification.

Recommendation 10: Ignore Classification

Much of the desire to classify rivers may derive from fluvial geomorphology's composite heritage from geology and geography — fields where observation, description, and classification have played major roles. In other disciplines, classification plays little or no part. Generally, hydrologists have followed an engineering heritage of being analytical rather than classificatory. For example, in the design of a water supply project, one doesn't unnecessarily worry about the hydrologic classification of a stream. Instead, the concern is about the volume and timing of flow, which is analyzed through a modeling approach. As geomorphological theory advances, conceptual and mathematical geomorphological models will undoubtedly provide capabilities not inherent in classification systems.

CONCLUSION

Classification has and will continue to have an important role in science, particularly for fluvial geomorphology, which is solidly founded upon field studies and observation. A fuller understanding of the principles behind classification system development should improve the design of future classification systems. However, classification should be considered only one part of a much larger scientific puzzle that also incorporates observation, laws, hypotheses, theories, and models.

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