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Should River Restoration Be Based on Classification Schemes or Process Models? Insights from the History of Geomorphology

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ABSTRACT

River restoration design requires the application of fluvial geomorphic concepts, and should be expected to apply the techniques concurrent with contemporary thinking and research. Through a brief review of the history of geomorphology over the past century, striking parallels between geomorphic research and river restoration practice become apparent. Namely, restoration design has been, to date, dominated by classification schemes, which are the application of the historical geomorphology practiced by Davis. However, while geomorphology has progressed into its current paradigm of the physically-based process approach, river restoration is still dominated by historical geomorphic classification schemes. Reasons for this stagnation include (1) the ease of learning and applying classification schemes, and (2) public agencies' fully adopting classification schemes and holding suspect, or not even considering proposals or the findings of approaches which do not include reference to or use of a classification scheme. This is in spite of the validity of classification schemes in restoration design being criticized more often than supported in scientific literature. We suggest that dependence on, or requirement of, a specific design approach -- certainly one based on historical geomorphology -- precludes the ability of river restoration to develop as has geomorphology.

INTRODUCTION

Geomorphology involves describing and analyzing the features of the Earth's surface, and developing an understanding of the ways in which surface processes operate and control the development of landforms and landscapes. Rivers are a central area of study in geomorphology, and for this reason, principles of fluvial geomorphology have been used widely by those involved in river restoration. Designing a channel that will function 'naturally' to meet restoration goals is a complex process, and in addition to fluvial geomorphology involves application of knowledge and techniques from stream ecology, hydrology, and hydraulic engineering. In each of these areas one would expect that restoration designers employ methodologies consistent with contemporary thinking and research. However, it is interesting to note that some uses of fluvial geomorphology in stream restoration do not fit this model, rather they rely on geomorphic approaches that are not a major part of current research.

The two main approaches used in stream restoration do in fact represent two major schools of thought in geomorphology (historical versus process geomorphology). The aim of this paper is to illustrate the historical bases of these schools of thought by comparing and contrasting the methodologies of two key figures in geomorphology: William Morris Davis and Grove Karl Gilbert. By examining how approaches to geomorphic investigation have changed over the past

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50 years, it is possible to assess how river restoration design strategies fit within changing paradigms of geomorphic research and explanation. This assessment highlights the contrast between river classification schemes grounded in historical geomorphology, and physically based models consistent with modern process geomorphology. From this discussion it is apparent that there is a need to encourage more practitioners to develop and adopt design methods grounded in process geomorphology.

HISTORICAL PERSPECTIVE

William Morris Davis

The Davisian approach to geomorphology dominated the first half of the twentieth century. Davis approached geomorphology from the historical perspective; that is, he focused on the theory of the evolution of landscapes. Perhaps his most significant, or at least memorable, contribution to geomorphology was that of the 'geographical cycle' in which landscapes were considered in relative stages of youth, maturity, and old age. Davis was minimally, if at all, concerned with the mechanisms involved in the formation of landscapes, but rather, on their progression in an orderly sequence from one form to another.

While Davis promoted his theoretical model, and continued to refine it for many years (Thorn, 1988), it is worth noting what Davis considers the purpose of his model:

> *"[The geographical cycle's] value to the geographer is not simply in giving explanation to land-forms; its greater value is in enabling him to see what he looks at, and to say what he sees (Davis, 1899, p. 498)."*

Indeed, Davis promoted his model more as a communication tool than as a scientific one. In light of this, it is interesting to note Davis' view of geomorphology (geography) as a science:

> *"…geography, unlike all other sciences, should be developed by the use of only certain ones of the mental faculties, chiefly observation, description, and generalization (Davis, 1899, p. 483)."*

Grove Karl Gilbert

In contrast to Davis, Gilbert approached landscapes from a process, or physical perspective in which he used the scientific method (i.e., hypothesis testing) in order to identify and analyze the forces at work which caused a particular observed landscape. He often employed methods common in engineering dynamics such as free-body diagrams, and his focus on the processes involved in causing observed features is evident throughout his work. For example, in regards to meander migration, Gilbert observed the following:

> *"The first result of the wearing of the walls of a stream's channel is the formation of a flood-plain. As an effect of momentum the current is always swiftest along the outside of a curve of the channel, and it is there that the wearing is performed; while at the inner side of the curve the current is so slow that part of the load is deposited. In this way the*

> *width of the channel remains the same while its position is shifted…(Gilbert, 1877, p. 126)"*

Comparison

Perhaps the greatest comparison between the historical approach of Davis and the process approach of Gilbert can be summarized in the following quote by Davis:

> *"The forces by which structures and attitudes have been determined do not come within the scope of geographical inquiry, but the structures acquired by the action of the forces serve as the essential basis for the genetic classification of geographical forms. (Davis, 1899)"*

Though Gilbert and Davis were both widely respected geomorphologists, it was Davis' historic view of geomorphology that dominated geomorphic investigation for the first half of the twentieth century. Sack (1992) offers three possible reasons for why Davisian geomorphology became widely accepted:

1. the application of a life-cycle analogy from biology (i.e., Darwin) to other fields was fashionable at the time;
2. the non-quantitative nature of the geographical cycle made it understandable to a large sector of the population; and
3. Davis, being a professor at Harvard, taught his model to numerous students, many of whom subsequently taught their students.

Strahler and Subsequent Research

The approach to geomorphic investigation changed from historical to process dramatically in the middle of the twentieth century. This change was evidenced, ironically, at a symposium held in the honor of Davis. Specifically, A.N. Strahler attacked the historical approach as a "superficial cultural pursuit of geographers that is completely inadequate as a natural science" and that "those geomorphologists wishing to make substantial contributions to science must adopt a quantitative-dynamic approach to landform studies" (Sack, 1992). Strahler's focus was on the need to quantify the relationships between form and process, that is, to adopt the process approach introduced by Gilbert. He went on to point out that the process approach, or as he termed it, the quantitative-dynamic approach, was much more demanding than the historical approach due to its requiring thorough knowledge of geology, mechanics, thermodynamics, hydrology, mathematics, and statistics (Sack, 1992). He further argued that geomorphology should combine: (1) the empirical, where data are collected and analyzed using statistical techniques; and (2) the rational, where physical properties are accumulated into a mathematical model, and suggested that in time the two approaches would converge to reality (Strahler, 1952).

While geomorphologic research since Strahler has been dominated by process studies rather than historical, further review shows that the response of geomorphic investigation has been highly empirical. The majority of these empirical studies involve the statistical analysis of geomorphic parameters and surrogates for their controlling variables rather than the investigation of the physics of controlling mechanisms. Classic examples of the empirical approach from fluvial geomorphology are the relationships developed between channel cross section or planform and dominant discharge (Hey and Thorne, 1986; Williams, 1986). These developed relationships are most commonly power laws "in which the seductive quality of the trend may disguise order-of-magnitude local variability" (Lane and Richards, 1997). However, more recent research has been dominated by physically based process geomorphology. As numerical modeling via computers makes computationally based studies more viable, large amounts of research analyzing the physical processes at work is being done.

RIVER RESTORATION

River restoration is a relatively new science, in that it is just beginning to be recognized both scientifically and professionally. The development of standard restoration approaches has already become common (see example below), and the validity of these standards is important to consider. Conflicting viewpoints to restoration designs will continue to become significant given the high cost and public exposure of many restoration projects. Hence, in developing restoration approaches, it is worthwhile to note the similarities between geomorphic investigation methods of the past and current restoration approaches in order to, one hopes, predict and encourage appropriate directions for restoration design.

River Classification

In respect to river restoration, one must acknowledge the overwhelming influence of river classification schemes in channel design. The classification approach to channel design is intended to help a designer "predict a river's behavior from its appearance" (Rosgen, 1994), and that by assigning a reach of channel a classification (A2, C4, B6, etc), one can assess the channel's present stability, past conditions, and probable trend if left undisturbed. In many respects, this approach encourages the adoption of the historical approach to geomorphology. It is ironic that the dominant approach to river restoration, which is an applied form of fluvial geomorphology, has reverted back to the historic view of geomorphology (i.e., landscape evolution). This irony is even greater when one considers:

1. the process approach to geomorphology is the dominant approach of today, as discussed above;
2. the plethora of physical/process models available relating to fluvial geomorphology (e.g., hydraulic and sediment transport numerical models); and
3. the relative ease of process modeling since the development of the personal computer.

It is classification-based restoration design that has become the recommended procedure for many federally funded projects. For example, in contributing to project funding, the Natural Resources and Conservation District often requires designers to demonstrate in proposals "experience in the use and application of a stream classification system and its implementation" (MFWP, 1998). Similarly, classification schemes have been utilized in evaluation guides for riparian areas and U.S. Forest Service management plans even though geomorphologists have severely criticized the use of classification schemes due to their being based on criterion having little geomorphic significance (Miller and Ritter, 1996). Perhaps the greatest negative impact of classification schemes is related to public agencies' reliance on classification schemes for decision making. Professional geomorphologists and hydraulic engineers are often held suspect, or even thought incorrect, if their approach does not include reference to or use of a classification scheme.

Hence, it is worthwhile to investigate the possibilities of why restoration has reverted back to the historic approach. This can, perhaps, best be accomplished by noting the similarities between the reasons for the popularity of the Davisian approach to geomorphology during the first half of the 20th century and the reasons for the popularity of the classification approach to restoration today (Table 1).

Table 1. Similarities between the historic approach to geomorphology (Sack, 1992) and the Classification approach to restoration

	Historical approach to geomorphology	*Classification approach to restoration design*
1	The application of a life-cycle analogy from biology (i.e., Darwin) to other fields was fashionable at the time.	Channel evolution models are generally accepted for the general description of landscapes and landscape evolution. Classification schemes are well used for communication purposes.
2	The non-quantitative nature of the geographical cycle made it understandable to a large sector of the population.	Application of the classification approach to restoration requires little understanding of geomorphology, hydraulic engineering or hydrology. Further, application of the approach requires no hydraulic or sediment transport modeling, which is needed for the majority of quantitative (engineering-type) approaches.
3	Davis, being a professor at Harvard, taught his model to numerous students, many of whom subsequently taught their students.	Classification approach to restoration has been taught to many federal and private practitioners via short courses. Ease of understanding and use results in rapid popularity.

As Table 1 indicates, there are similarities between the Davisian approach to geomorphology and the classification approach to restoration. However, there are two crucial differences between the two which should be noted:

1. While Davis' approach was scientifically accepted as a valid approach for almost fifty years, the classification approach to restoration design has been criticized since its first introduction to the scientific community (Kondolf, 1995; Miller and Ritter, 1996).
2. While Davis' approach to geomorphology represented a scientific (academic) pursuit limited mainly to landscape descriptions, river restoration affects waterways and thus has significant economic and safety implications.

Process Geomorphology in River Restoration

The historical approach to geomorphology is valid, and certainly has its place in current geomorphic investigation. Likewise, classification approaches in restoration have a certain degree of value: for initial education and communication, they are indeed valuable. However, their limitations must be noted. It is the use of classification beyond initial characterization and communication that must be avoided. That is, their use in the actual design of channels should be limited, if not excluded. There are several reasons for limiting the use of classification schemes in restoration design.

1. Classification schemes tend to oversimplify the complexity of the fluvial system and tempt unqualified persons to attempt restoration design without proper knowledge or experience. To have a minimal understanding of a fluvial system, even at the river reach scale, one must be

capable of applying hydraulics, geology, geotechnical slope stability, sediment transport, stream ecology, and hydrology at a minimum. Kondolf (1995) notes that classification schemes have a seductive quality to non-geomorphologists in that they tempt one to consider the river 'known' once it has been classified. The geomorphologists recognizes that the classification is only the beginning of the analysis process.

2. The scientific basis for extending classification schemes beyond simple stratification of channel forms has been criticized more often than substantiated (Kondolf, 1995; Miller and Ritter, 1996). If one follows the adage of Schumm (1972) that "the foundation of a science is its published literature," then using classification for restoration design is not based on a strong foundation.
3. It is not entirely clear that classification schemes are needed or are not misleading, as typical geomorphic analysis is sufficient to provide necessary information (Ashmore, 1999). For example, Figure 1 uses data from braided and single channel rivers in New Zealand as given by Church and Rood (1983) which would fall into Rosgen class D and C channels, respectively. When analyzing channel width as a function of discharge, a classification approach suggests that the variation in width is the result of a change in stream type. However, if the data are treated *continuously* via stream power, the width discrepancy can be seen as the combined effect of slope and discharge. By not being tempted to stratify data by channel types, one can analyze or design channels using appropriate continuous variables to represent channel morphology.

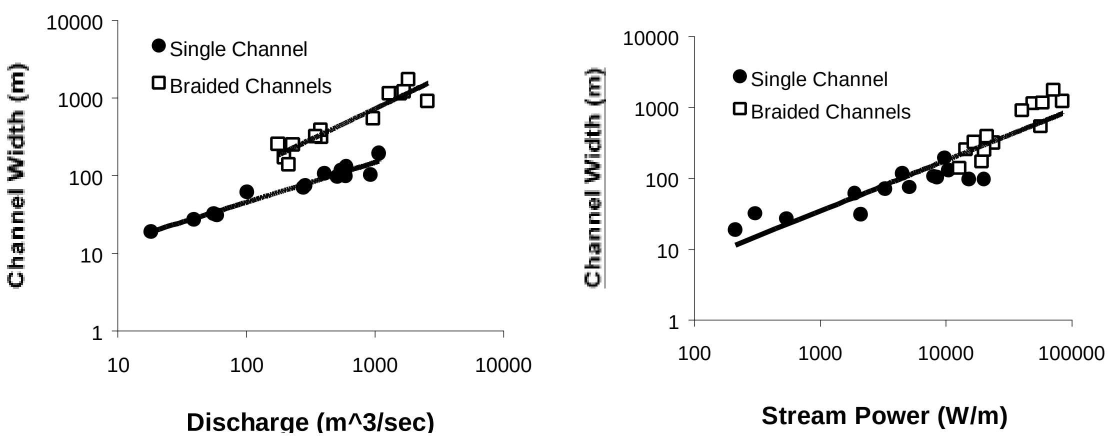

Figure 1. Relationships between channel width and discharge and channel width and stream power (adapted from Ashmore (1999)).

Need for Progression through Statistics

Just as the science of geomorphology advanced through the use of statistics, so river restoration design has progressed into the use of statistical relations developed for natural, stable channels. However, their extensive use tends to be a hallmark of channel designers with little geomorphologic knowledge or experience. To illustrate the inherent problem: a geomorphology student is not in classes long before learning of the relationship between pool/riffle sequences and '5 to 7 channel widths.' This relationship exemplifies the simple quantification of a fluvial feature. Unfortunately, this characteristic, derived for a given data set at a given period in time, has long been accepted as a design feature in many restoration projects, regardless of the specific project's geomorphologic or hydraulic characteristics. This significance is obvious when considering the recent work of Rinaldi and Johnson (1997), which showed that the 5 to 7 channel widths is more likely to be 1.2 to 4.3 in urban conditions. Similarly, Doyle et al. (1999) showed large discrepancies between assumed relationships of dominant discharge (bankfull vs. effective) in several streams, relationships which are used extensively in classification based approaches to river restoration (Rosgen, 1994). In the case of an unstable channel in Nevada, if the common assumption that bankfull discharge was equivalent to effective discharge was used, a discharge almost four times too large would have been used for design, requiring excessive amounts of earth-work, and most-likely resulting in large degrees of aggradation. These are just several of many examples illustrating the fact that empirical models are representations of a specific location in time and space which are not universally applicable. While providing a starting point, their applicability to a given site can only be verified through process/physically based analysis.

Hence, just as Strahler emphasized the need to couple empirical models with process ones in order to arrive at reality, we emphasize the need to move beyond both classification and empirical models to physically based process models for channel design. While more robust physically based process models of channels are still in the development stage (e.g., CONCEPTS), partial models of hydraulics (HEC-2, HEC-RAS, SAM), sediment transport (HEC-6, SAM) and bank stability (Darby, 1998) are available and fairly easy to use. Dependence on classification schemes, coupled with only a vague familiarity of fluvial geomorphology and empirical equations may indicate an inadequate basis of expertise from which to attempt a river restoration project.

DISCUSSION

The conflicting approaches to river management discussed above are not new. Well before river restoration became a prominent subject, Schumm (1972) acknowledged a continuing problem:

> *" …the description and classification of rivers by geomorphologists has not provided the engineer with useful information that can be applied to river control problems. On the other hand, the concern of the engineer with the relatively rapid response of a river to the influence of structures has caused him to lose sight of the fact that the river has a history… (Schumm, 1972, p. 2)"*

Schumm goes on to point out the conflicting views being categorized as quantitative for engineers, but qualitative for geomorphologists, and that both views must be brought together to proceed successfully in river related research. It is this coupling that is noticeably absent in the majority of today's restoration design, particularly that based on classification schemes.

Most river restoration designers will acknowledge an inherent 'art' of river restoration, although this might be more a function of knowing when and how to impart variability about a geomorphic mean, or how to incorporate habitat, in order to create systemic diversity. However, there is also the need to acknowledge that this 'art' is not static, in that it is not merely on display. Rather, restoration designs must prove functional hydraulically, geomorphically and biologically. As well, restored rivers affect the general public from both an economic (e.g., public funding) and a safety (e.g., instability or flooding) standpoint. These aspects of restoration should push designs past art and into applied science, and thus require restoration as a science to keep up with contemporary geomorphic science. This progression will only be accomplished when restoration practitioners move past the days of historic geomorphology and into the current state of the science of geomorphology, namely physically based process geomorphology.

CONCLUSIONS AND RECOMMENDATIONS

The goal of this paper is not to criticize the developers of the differing approaches to geomorphology or restoration, for it is the accumulation and progression of ideas in science that is inherent to its value. Rather, the intent is to point out the strengths and appropriateness of each method, and to encourage the further development of ideas and practice of river restoration as a science.

The science of restoration cannot continue to develop, that is to bring together the quantitative and qualitative aspects of river management, when limitations are placed upon the methods from which designers can choose (recall the requirements of the MFWP). Indeed, work in both stable and severely altered environments (such as urbanized systems with altered hydrology and sediment transport regimes) requires careful application of analog, empirical, and analytical restoration approaches in order to approximate appropriate channel conditions. While preliminary insight can be gained through the application of classification schemes, adequate analysis for quantitative restoration design requires analysis well beyond their current scope. Thus, it is the opinion of these authors that the dependence on, or requirement of, a specific design approach -- certainly one based on historical geomorphology -- precludes the ability of river restoration to develop as has geomorphology.

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