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Discussion

A classification of natural rivers: reply to the comments by J.R. Miller and J.B. Ritter

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The writer thanks Drs. Miller and Ritter for their detailed discussion of his paper on the classification of natural rivers (Rosgen, 1994). Their points are worthy of consideration and will be discussed here.

A primary purpose of my proposed river classification is to make more specific and easier the communication among workers. Without such a system, relating the major characteristics of a given reach to fellow workers requires considerable explanation and specific data. To give a general picture of the reach in a few letters or numbers is advantageous.

Beyond such a purpose, however, Miller and Ritter (1996) state that "criteria upon which the classification is based (must have) geomorphic significance." I am not certain of what specifically was meant by this statement, however, the criteria used for delineation of stream types are slope, width/depth ratio, dominant particle size of channel materials, entrenchment (vertical containment of the river which determines the presence and or extent of a floodprone area adjacent to the bankfull channel), single versus multiple thread channels, and sinuosity (ratio of stream length to valley distance or ratio of valley slope to channel slope). These criteria are geomorphologically significant when describing the morphology and functioning of streams at a broad level. These delineative variables were selected to describe the morphological character of streams as measured in the field. They describe the dimensions, pattern, profile and materials of the river. Since these are directly observed and measured variables, it would be reasonable to assume that they are geomorphologically significant in describing streams of similar morphology. These morphological variables provided an initial basis for an integrative stratification to separate one stream type from another. For example, as gradient increases, width/depth ratio and sinuosity decrease in alluvial channels. Streams which become very steep (> 0.04) are associated with a step/pool morphology, do not have developed floodplains (entrenchment ratio < 1.4), have a very low sinuosity (1.2 or less) and width/depth ratios predominantly lower than 12. These are

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described as "A" stream types. These variables are significant when comparing hydraulic and sedimentological relations of various stream types which vary considerably in their dimensions (width/depth ratio and entrenchment ratio), pattern (sinuosity), profile (slope), and materials of the stream channel.

The variability that exists between stream types as identified using the selected delineative criteria provides a partial basis for many interpretations unique to a stream type. For example, single thread, alluvial streams that have slopes less than 0.02 have bed features associated with a riffle/pool morphology and gradients greater than this in the 0.02–0.04 range are associated with rapids dominated bed features (Grant et al., 1990). In the river classification presented (Rosgen, 1994), there is a slope delineation break at the 0.02 or less for riffle/pool stream types (C, E and F), and a slope break at the 0.02–0.04 range for B and G stream types. Whether these breaks or the criteria are "geomorphologically significant" as questioned by Miller and Ritter (1996) can still be up for discussion, however, the criteria and these ranges reflect on distribution of energy and resultant bed features. These relations provide fish habitat interpretations, recreational boating difficulty classes, sediment routing relations, etc.

The use of gradient combined with width/depth ratio, entrenchment ratio (quantitative index of vertical containment), sinuosity, and channel materials is very significant in providing a basis of sorting and interpreting streams of like character.

I have selected these particular integrative river variables in the proposed classification methodology due to their sensitivity, measurability (quantitative), consistency and importance on the channel form (morphology) and function. There are additional stream influence variables, however which refine the management interpretations beyond the initial stream delineation variables. These variables are listed in Table 1 (level III stream inventory) in the river classification paper (Rosgen, 1994).

In the discussion by Miller and Ritter (1996), the ability to predict a rivers behavior using the stream classification system was questioned. It is appropriate to question any prediction methodology or interpretations dealing with the complex nature of river process. In retrospect, use of terms such as "implying" river behavior may have been a better choice. However, an example of how this system has been used in prediction for management applications is shown in Figs. 8 and 9 of the river classification paper (Rosgen, 1994). Observations of the adjustment of channels to imposed change that results in a morphological change in stream type is depicted in these figures. For example, the high sensitivity to disturbance of "E" stream types, the high bank erodibility potential, and high vegetation controlling influence (on the morphological variables), (Table 3, Rosgen, 1994) indicates the high probability of channel adjustment caused from direct disturbance of poor grazing practices. These poor grazing practices may be associated with use at the wrong season, high plant utilization, and/or shearing of banks from animal concentrations. Regardless, the prediction of the channel adjustments associated with these "E" stream types generally results in an **increase** in (1) bank erosion, (2) width/depth ratio, (3) stream gradient and (4) sediment supply and sediment deposition. Additionally, the prediction of such impacts to this "E" stream type would also result in a **decrease** in (1) sinuosity, (2) meander width ratio and (3) sediment transport capacity. The magnitude of these channel adjustments is often such that the stream types shifts from one type to another as depicted in Figs. 8 and 9

(Rosgen, 1994). This is not only a probable situation, but has been observed by this author over 31 years of field observations. The method of applying stream classification to depicting such adjustments may help in displaying complex interactions of the channel leading to a shift in morphology and function.

The "geomorphic significance" of the application of these variables which describe stream types is evident in the example shown in Fig. 9 (Rosgen, 1994) when an E4 stream type is converted to a G4 (gully) in a meadow, the entrenchment ratio (floodprone area width/bankfull width) converts from greater than 2.2 to less than 1.4. This is the quantitative index that documents the condition of a stream that has lost its floodplain and is now vertically contained. All floods in the future will now be contained in a narrow and very deep channel causing accelerated bank erosion and high sediment supply. My interpretation of such an application of these delineative criteria for stream classification leading to the abandonment of a rivers floodplain would have "geomorphic significance".

The conversion from a meandering "C" stream type to a braided "D" stream type (Fig. 8, Rosgen, 1994) involves the change from a sinuosity of 2.5 to that of 1.1 due to disturbance of streambank vegetation. In their discussion Miller and Ritter (1996) questions the "geomorphic significance" of sinuosity as well as the applications for management of the stream classification. This particular example may provide some interpretations regarding "geomorphic significance" and applications. When the sinuosity decreases, there is a corresponding increase in width/depth ratio and meander width ratio. As the process of channel adjustment continues depicted in Fig. 8 (Rosgen, 1994), there is a reduction in sediment transport capacity and an increase in sediment supply. Deposition from both introduced sediment generated from bank erosion and upstream supply occurs, forming bars and multiple channels. Bed features are associated with a series of convergence and divergence transport processes which produce local scour and deposition. The corresponding morphology of the stream changes from a meandering (C) to a braided (D), with major changes in slope, width/depth ratio and sinuosity. These variables that depict this change are significant, or else they would not have been observed and subsequently measured as altered, despite this major shift in stream morphology. This author has observed many rivers that have shifted from meandering to braided due to an increase in width/depth ratio from streambank erosion acceleration.

A additional comment of Miller and Ritter (1996) is that there were no definitions of terms such as "channel stability", "streambank erosion potential", "vegetation controlling influence" and "recovery potential". Definitions were not presented in my paper, but will be presented here to add clarification: (1) *channel stability* is the ability of a stream, over time, to maintain its dimension (width and width/depth ratio, floodprone area width, etc.), pattern (plan view geometry) and profile (slope and bed features) in such a manner that it transports the erosional debris and stream flow of its watershed without neither aggrading nor degrading; (2) *streambank erosion potential* is associated with characteristics of the streambank to resist the various agents of erosion and the distribution of the energy which influences erosional processes. The nature of the streambank materials, bank heights, rooting depths and densities, bank angles, and other criteria are used to assess streambank erodibility; (3) *vegetation controlling influence* is the ability of vegetation through rooting shear strength, depth and density, surface protection from flow forces to maintain the bank stability, width/depth ratio, sinuosity, and other morphological variables which maintain a given stream type. Some stream types are influenced by vegetation more for these variables than other stream types (see Table 3, Rosgen, 1994).

Miller and Ritter (1996) "fail to see the process significance" between channels having different values of sinuosity. Sinuosity as defined and as used in my classification system is the index of the ratio of valley slope to channel slope as an adjustment mechanism of the channel. For example, when an alluvial channel with a sinuosity of 2 is straightened in a meadow, which then has a sinuosity of 1 and doubles the channel slope, the stream characteristically degrades and abandons its floodplain. It then becomes entrenched (deeply incised) and accelerates bank erosion as the channel strives to increase its sinuosity. This process is shown in Fig. 9 in the manuscript and describes evolutionary stages of channel adjustment where sinuosity, slope, width/depth ratio, entrenchment ratio and stream type are changed. These are all integrative variables which act simultaneously resulting in a morphological state. Sinuosity is one of the integrative variables which I selected to help describe channel morphology. Sinuosity as a delineative criteria also is used to assist in delineation of stream types from aerial photographs.

Miller and Ritter (1996) imply that the differences in hydraulic geometry relations among different stream types cannot be understood nor be trusted unless basic data are presented from which the geometry were developed. They are correct that it would be useful to have every point plotted and every piece of data available in tabular form so that any graph can be reproduced by the reader. In fact, the author is grateful to the editors of Catena to permit such a long manuscript to be published in full even though tabulated basic data are not included. Even though this information describes flows of one cross-section example for a similar frequency, these specific relations are not intended to become used for "universal extrapolation" as suggested by the reviewers. These relations were presented as a *method* of further stratifying hydraulic geometry influenced greatly by differences in morphological character (such as width/depth ratios). Any use for extrapolation would need to involve the development of dimensionless ratios of these values to account for streams of various sizes as well as differences in stream morphology.

Miller and Ritter (1996) requested additional information on the definition of particle d_i as used in the example of the critical dimensionless shear stress computation. As used here, it is the value equivalent to the 50th percentile, which was consistent with Andrews (1984) as referenced. In response to the question about the critical dimensionless shear stress values of the B3 versus the B4 stream type, ratio of pavement to sub-pavement particle sizes, which are different for these stream types, would explain at least part of the differences. The author stated in the paper, p. 193, "Stream types and their morphologic/hydraulic characteristics *do not substitute* for detailed on-site investigations as described by Andrews ..." and that this method "has potential" for estimating purposes, thus, the reviewers comment that the author asserts "knowing stream type one can predict critical dimensionless shear stress values ..." is a misleading conclusion.

The author has personally collected bedload data on over 120 streams involving a wide range of stream types. Portions of this data involving measured bedload, suspended sediment, bed material size distribution, bedload size distribution, hydraulic data (velocity, slope, width, depth, cross-sectional area and discharge) are included in Williams and Rosgen (1989). The number of channel reaches inspected in the field in the course of developing this classification scheme has been well over eight hundred.

It is on the basis of this large amount of data collected during field work over many years that the delineative criteria and projected sequences from one channel type to another were gradually established. These data encompass a great variety of climatic regimes in many parts of North America.

Miller and Ritter (1996) comment about a ''serious problem'' involving a mis-quote from Grant et al. (1990), the author states as shown in the sentence at the top of p. 175, ''... Using their bed form descriptions the above described stream types were plotted against the corresponding slope ranges reported by Grant et al. (1990)''. The author used their graph to plot stream type data by general slope class to show similarity of groupings of slope class and corresponding bed features, independent of the data set used in the development of the stream classification system. The author personally communicated about this relation with Dr. Gordon Grant. Miller and Ritter (1996) state that the work of Grant et al. (1990) collected data from ''steep boulder bed mountain channels''. The riffle/pool streams with slopes from 0.003 to 0.013 as shown in the Grant et al. (1990) paper, as referenced in Fig. 2, p. 175, are not the slopes nor bed morphology which typifies ''steep boulder-bed mountain channels''.

Miller and Ritter (1996) made a statement that ''we doubt that stream type boundaries as defined by entrenchment ratio have any geomorphic significance''. The author directs them to Dunne and Leopold (1978) (p. 647), on the relation of the dimensionless ratio of depth/bankfull depth and corresponding ratio of their discharges. d/d_{bkf} values associated with a 50 year flood averaged 1.8 (1.8 times bankfull depth in floodprone areas). The use of 2.0 was selected on the inspection of 460 cross-sections which varied from streams with no floodprone area to streams with a well developed floodplain and low terrace (often both the active floodplain and the low terrace were included in the floodprone area). Entrenchment as described by Galay et al. (1973) is the vertical containment of the river. No quantitative description has been offered, thus, the author attempted to develop a quantitative method which would help describe the nature of the landform outside of the bankfull channel. This is significant, as it determines the hydraulic condition for flows that exceed the bankfull discharge. For streams that are slightly entrenched (2.2 ratio or greater) the flood waters are dispersed at depths proportionate to the width of the floodprone area and magnitude of the flood. Contrast this with the entrenched channel (1.4 ratio or less) where flood waters cannot be dispersed onto a floodprone area, but rather increase in depth at a faster rate than width with increasing discharge above bankfull. Hydraulics, sediment transport, shear stress, stream power, velocity distribution, bank erosion rates, and channel adjustments occur quite differently in entrenched streams from those that are slightly entrenched (well developed floodprone areas). This is ''significant'' when evaluating physical processes of river adjustment.

Miller and Ritter (1996) stated in reference to flood flows that ''many arid-climate rivers do not rise above bankfull'' The author has seen many arid ''C'' stream types in

Colorado, New Mexico, Texas and Arizona that occupy their floodplain when flows exceed the bankfull stage. There are entrenched rivers, however, in arid climates such as the A, G and F stream types that do not have floodprone areas and are contained within their banks. These banks are generally terraces, and are not overtopped with floods in the modern climate. The D or braided rivers, however, often increase their channel cross-section dimensions and position during floods which would agree with the statement by Miller and Ritter (1996). In this example, the use of a stream classification system would help clarify a particular generalization more specific to a group of stream types to prevent misinterpretations.

The author takes exception to the statement offered by Miller and Ritter (1996) that ''the classification system cannot be utilized for the management purposes put forth in Table 3''. The author collected data over many years to develop this system specifically for water resource management applications. This classification system has been implemented for water resource and fishery management applications by hundreds of individuals and many agencies since the first publication (Rosgen, 1985). The hierarchy of river inventories describes 4 discrete levels as shown in Table 1, page 172 (Rosgen, 1994). Level II describes the existing morphology of river channels, interpreting river characteristics and implying behavior, while level III describes the ''state'' or ''condition'' of the stream using site specific studies of stream types to determine departures, instability, potential vs existing conditions and many more variables that influence the existing channel. This level is where we predict river behavior. The information obtained at the Level IV inventory validates the previous levels that imply or predict river behavior. The data collected at this level quantifies rates of aggradation/degradation, lateral extension, sediment transport, and many other conditions measured by stream type. These levels promote responsible management applications from prediction of potential impacts to validation using this stream classification system.

Miller and Ritter (1996) refer to this system as a ''painless cookbook''. No description of a river reach is painless, for it requires field data often difficult to obtain. If one looks at the data required in the field to make a place for a reach of channel in one of the categories in this classification system, it is obvious that the procedure is not painless, nor should we expect it to be. The data needed are quantitative, requiring actual measurement.

Since no classification scheme is ever perfect, they are never complete. I can merely suggest that this one is at least a beginning, and as it is used in the field by a large number of various observers that are gathering data, I am sure it can and will be improved.

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