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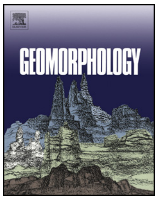

River pattern discriminant method based on resistance parameter and activity indicators

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ABSTRACT

A new river discriminant system is presented based on resistance law. A parameter characterizing river morphology and indicators reflecting activity of bed and bank are derived. They are defined as river morphology parameter and river activity indicators respectively. By relating river morphology to river activity through a comprehensive resistance factor, the discriminant curves characterizing river patterns, namely resistance thresholds, were derived, which make it possible to calculate the activity of bed and bank by just a few easy-obtaining hydraulic variables. In addition, the effect of riparian vegetation on riverbank strength is incorporated into this study. The discriminant method proposed in this paper has proved to be applicable in distinguishing river patterns by selected data sets of the model and natural rivers and in improving the understanding of patterning process.

1. Introduction

Alluvial rivers with different river patterns are subjected to quite different hydraulic resistance during the process of flowing. They tend to reach relative equilibrium states, as the parameters of channel section configuration and morphology will be changing as a result of adapting to varied flow and sediment conditions. Two main factors determine channel patterns: flow driving force and river activity. From the perspective of energy dissipation, flow resistance is a measurement of driving force and usually assumed to consist of grain resistance and form resistance. The former is caused by shear stress and the latter is attributed to the pressure difference in the presence of larger shape changes such as sand bars or even channel bifurcation in planform. What's more, riparian vegetation is also a significant source of resistance of river flow (Millar 2000; Tal and Paola 2010).

The characteristics of river morphology are the basis of studies on river evolution. A river's developmental process can be expressed using the time history of various characteristic parameters. The three major channel patterns classified by Leopold and Wolman (1957) are straight, meandering, and braided. A set of functions was derived to distinguish the three patterns through the empirical relationship between channel slope and bankfull discharge. Carson (1984) emphasized that median grain size of bed sediment is a factor affecting braided channel transformation. In order to obtain better agreement against measured discharge data and specific situations, some other conditions were introduced to correct the discriminant functions mentioned above, such as mean bed shear stress (Begin 1981). A variety of new discriminant methods has now been proposed, such as the stream power method (Petit et al. 2005; Van den Berg 1995) and logistic analysis (Bledsoe and Watson 2001). Lewin and Brewer (2001) argued that application of the stream power method should adapt to the specific study area, and associations revealed by logistic analysis do not necessarily imply causation. Bar theory (Ferguson 1987; Kleinhans 2010; Kleinhans and Van den Berg 2011) predicts the origin and modes of bars and provides partial explanations for pattern mechanisms. To investigate the formation mechanism and contributing factors of river morphologies, many theories have been developed, such as the stability theory (Fredsoe 1978; Parker 1976) and the nonlinear evolution model (Bai and Wang 2014). These models are based on objectively physical morphodynamic equations, which have met with success in providing an explanation for morphology processes. But they cannot be easily expressed as functions of variables such as discharge and water depth. Millar (2005) combined regime theory with a linear stability model and proposed bank stability analysis based on optimality theory. However, this extremal approach with good applicability still lacks an explanation for underlying causes.

With further research of river evolution mechanism, the discrimination of channels into straight, meandering, and braided has been modified. Anabranching and anastomosing with multiple channels are especially characteristic of many rivers. Nanson and Knighton (1996) treated anastomosing as a subset of anabranching, and anabranching remains to be identified as the term of nonbraided pattern of multithread rivers. Nanson and Huang proposed a mathematical model (Nanson and

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Huang 1999) and quantitative analysis (Huang and Nanson 2007) for exploring the physical causes for anabranching. Based on what is known about river morphodynamics, the agreement of treating anabranching as an additional pattern exists among investigators. Anabranching and braided are identified as two independent patterns of multithread in this paper. Eaton et al. (2010) used the rational regime approach to propose that no essential differences exist between straight and meandering channels, which are defined as single thread. We adopt the discriminant mode throughout this paper.

Methods for exploring the logical relationship between river characteristic parameters can be broadly summarized into three types. The first method is generally designed to describe rivers by equations from macro and micro perspectives. In this method, the linear and nonlinear relationships are established by deducing equations. For example, based on open channel flow equations, Ikeda et al. (1981) and Parker et al. (1982) proposed the linear and nonlinear models respectively to explain the development of channel. However, owing to the complexity of influence factors and the limitation of current knowledge, the mechanistic models have to make simplifications that will lead to the information losses and an unsatisfactory performance (Van den Berg and Bledsoe 2003). Therefore, the second method that a nonlinear relationship between characteristic parameters is founded on quantitative economics using experimental and measured data has become common. (e.g., Xu 2002; Xu and Cheng 2002). Yet the empirical relationship does little to identify the mechanism of pattern formation and is confined to the data selected. The third lies somewhere between the above two methods by offering correlations between various parameters based on existing equations and known laws. For example, Song and Bai (2015) proposed a discriminant method based on generalization of the famous Darcy-Weisbach equation. A parameter intuitively corresponding to the river shape can be used for pattern discrimination.

In this paper, we use the third method to develop new dimensionless thresholds. Flow resistance, which makes the stress condition clear, is thought to comprise bed resistance, bank resistance, and morphology resistance. Based on appropriate assumptions, river activity indicators (bed and bank activity indicators) are first introduced. Defined indicators are designed to describe the range of activity for distinct patterns in detail. A river morphology indicator (the river pattern control parameter) is proposed that relates the activity to morphology. It provides insight into channel discrimination using thresholds based on variables describing the property of the system. Riparian vegetation has been proved to have significant influence on the hydraulic geometry and evolution of alluvial rivers (Hey and Thorne 1986; Millar 2000; Murray and Paola 2003; Julian and Torres, 2006; Tal and Paola 2010). A set of new practical river pattern thresholds is established taking the effect of riparian vegetation into account. These results are then analyzed against the results of data sources and related studies. Compared with previous pattern discriminant methods, the new method has a more explicit mechanical meaning, and it can be expressed as functions of variables easily obtained for basic inputs.

2. River resistance and activity indicator

2.1. River resistance

As shown in Fig. 1A and B, the resistance of flow in the river is called river resistance, which includes air resistance on the surface, bed and bank friction (grain resistance), and morphology resistance (form resistance caused by cross-section, in-channel features, and flow separation or expansion losses of bend and branch sections; resistance caused by riparian vegetation).

Air resistance on the surface generally is negligible except during typhoons and tornadoes. Bed resistance comprises bed friction and bed morphology resistance. Bed morphology resistance mainly comes from ripples if the riverbed is sandy ($d_{50} < 2$ mm); however, it mainly comes from gravel resistance structure (Chang, 1988) for gravel ($d_{50} > 2$ mm). The bank resistance mainly comprises bank friction and the resistance caused by riparian vegetation. Notably, rivers with especially small or large median grain size of bed material, such as muddy and bedrock-controlled rivers, are not included in this study.

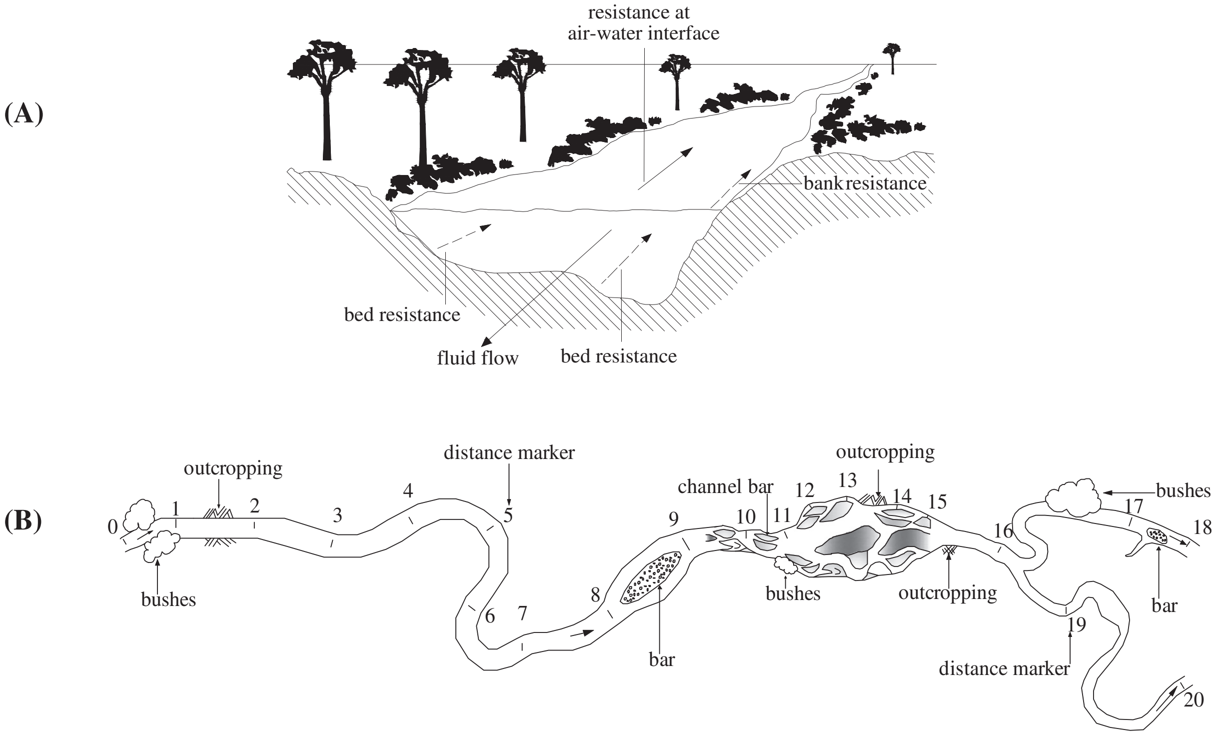

Fig. 1. Flow resistance in channels. (A) Boundary resistance in open channel flow. (B) Hypothetical planview of a river channel.