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Research Article

RIVER BRAIDING MECHANISM -THE FLOW, MODE NUMBER, MORPHOLOGY AND STREAM POWER

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ABSTRACT
River braiding is characterized by channel division around alluvial islands. The growth of an island begins as the deposition of a central bar which results from sorting and deposition of the coarser fractions of the load which locally cannot be transported. For the geomorphologist, braided fluvial systems are abundant within upland and proglacial settings and are agents of considerable erosion and sediment transport. For engineers, the high rates of sediment transport, deposition and erosion combined with frequent channel shifting and rapid bank erosion may pose considerable design problems. For the ecologist, braided rivers form important agents of deposition that have been responsible for the accumulation of many sedimentary sequences that form valuable aquifers. Progress towards a much more understanding of the dynamics and deposits of braided rivers demands an interdisciplinary approach to a host of unresolved problems. Transport of sediment and sedimentary architecture of braided rivers many key issues remain to be addressed. Measurements of the adjustments of velocity, depth, width, and slope associated with the island development lead to the conclusion that braiding is one of the many patterns which can maintain quasi-equilibrium among discharge, load, and transporting ability with particle size which corresponding to the roughness and the dunes or other characteristics of bed configuration also the wavelength. The braided index and the specific stream power with 2D or quasi-3D flow will be discussed.

Keywords: *Braided Channel; Fluvial System; Specific Stream Power; Braided Index; Sedimentary Sequences*

INTRODUCTION
River braiding is characterized by channel division around alluvial islands and grows downstream in height by continued deposition on its surface, forcing the water into the flanking channels, which, to carry the flow, deepen and cut laterally into the original banks. In particular, several areas demand attention: the mechanisms of braid bar initiation. Zones of flow convergence and divergence, the influence of flow stage, channel hierarchies, grainsize influences upon braiding, braided channel morphology and scale, facies models of braided alluvium, aggradation and preservation, and the economic importance of braided rivers were discussed (Bristow & Best, 1993).
Braiding was observed in a small river in a laboratory. Measurements of the adjustments of velocity, depth, width, and slope associated with island development lead to the conclusion that braiding is one of the many patterns which can maintain quasi-equilibrium among discharge, load, and transporting ability. Channel width appears to be primarily a function of near-bankfull discharge, in conjunction with the inherent resistance of bed and bank to scour. Excessive width increases the shear on the bed at the expense of that on the bank and the reverse is true for very narrow width. Because at high stages width adjustment can take place rapidly and with the evacuation or deposition of relatively small volumes of debris, achievement of a relatively stable width at high flow is a primary adjustment to which the further inter-adjustments between depth, velocity, slope, and roughness tend to accommodate. Channel roughness, to the extent that it is determined by particle size, is an independent factor related to the drainage basin rather than to the channel. Roughness in streams carrying fine material, however, is also a function of the dunes or other characteristics

of bed configuration. Where roughness is independently determined as well as discharge and load, these studies indicate that a particular slope is associated with the roughness. At the width determined by the discharge, velocity and depth must be adjusted to satisfy quasi-equilibrium in accord with the particular slope. But if roughness also is variable, depending on the transitory configuration of the bed, then a number of combinations of velocity, depth, and slope will satisfy equilibrium.

BASIC METHODOLOGIES

At a given discharge, meanders occur at smaller values of slope than do' braids. Further, at the same slope braided channels are associated with higher bankfull discharges than are meanders. The changes in slope, roughness, and channel shape which accompany this division are in accord with quasi-equilibrium adjustments observed in the comparison of large and small rivers.

A braided river is one which flows in two or more anastomosing channels around alluvial islands. Braided reaches taken as a whole are steeper, wider, and shallower than undivided reaches carrying the same flow. The braided pattern developed after deposition of an initial central bar. The bar consisted of coarse particles, which could not be transported until local conditions existing in that reach, and of finer material trapped among these coarser particles. This coarse fraction became the nucleus of the bar which subsequently grew into an island. Braiding represents a particular combination, albeit a striking combination, of a set of variables in the continuum of river shapes and patterns (Leopold and Wolman, 1957 and 1963)

The wavelength of a meander is proportional to the square root of the "dominant discharge." One wavelength (a complete sine curve or 2πradians) encompasses twice the distance between successive points of inflection of the meander wave. It is well known that meandering channels characteristically are deep at the bend and shallow at the crossover or point of inflection. Thus, twice the distance between successive riffles in a straight reach appears analogous to the wavelength of a meander and should also be proportional to $Q^{0.5}$,

$\lambda=36Q^{0.5}$……………………………………………………………………………………………(1)

Since width is also proportional to the square root of discharge, wavelength is a linear function of stream width. The scatter of points in the width-wavelength relation is less than that in the. discharge wavelength relation. The relation is quite consistent though it includes straight channels as well as meanders. the relation is not a constant ratio but a power function having an exponent slightly larger than 1,

$\lambda=6.5w^{1.1}$ ………………………………………………………………………………………......(2).

In terms of the mechanical principles governing meander formation and the formation of pools and riffles, the wavelength is more directly dependent on width than on discharge. It is argued later in that in general, at a constant slope, channel width follows from discharge as a dependent variable. The new derivation relationship between channel width and discharge could be:

$w=4.74Q^{0.4545}$………………………………………………………………………………………(3)

The term "braid" is applied here to those reaches in which there are relatively stable alluvial islands, and hence two or more separate channels. For a given discharge, meanders, as one would expect, will occur on the smaller slopes. At the same slope a braided channel will have a higher discharge than a meandering one. In the rivers studied the braided channels are separated from the meanders by a line described by the equation:

$s=0.06Q^{-0.44}$…………………………………………………………………………………………..(4)

The Eq. (4) is with a slight difference of the one from Leopold and Wolman, (1957):

$s=0.013Q^{-0.44}$…………………………………………………………………………………………(4-1)

where Q is the bankfull discharge.

In natural channels specific variables often occur in association. For example, steep slopes are associated with coarse material. In a system which contains, as we have pointed out, a minimum of seven variables, a diagram which treats only two of these cannot be expected to describe either the mechanism of adjustment or all theoretically possible conditions. describe a set of conditions which are to be expected in many natural channels. Two ideas that will be explored more fully are inherent. First, at a given discharge various slopes are associated with varying channel shapes and patterns. Second, in considering an individual bifurcating channel, we are concerned with a division of discharge comparable to the comparison of downstream point with an upstream point in a river channel system. describe a set of conditions which are to be expected in many natural channels.

The relation of channel pattern to slope and discharge is of particular interest in connection with the reconstruction of the alluvial landscape from profiles of terrace remnants and from alluvial fills. Changes of climate might be accompanied by changes in precipitation md runoff. Such variations in streamflow might produce changes in the stream pattern without any accompanying change in the quantity or caliber of the load. An increase of flow could result in a meander becoming a braid; a decrease in discharge could make a braided channel a meandering one. Yet, a change in the character of the load, such as an increase in caliber which the presence of valley glacier might provide, could result in an increase in slope and a change from meandering to braiding without any change in the precipitation or discharge. The presence, then, of material of different sizes in successive valley fills suggests that at different periods in its history the river which occupied the valley may have had several distinctive patterns.

By Eqs. (3) and (4), here, we have derived an equation between width and slope:

$s=0.27\,w^{-0.968}$ ……………………………………………..…………………………….……………(5)

And the figure is expressed as following Fig. 1.

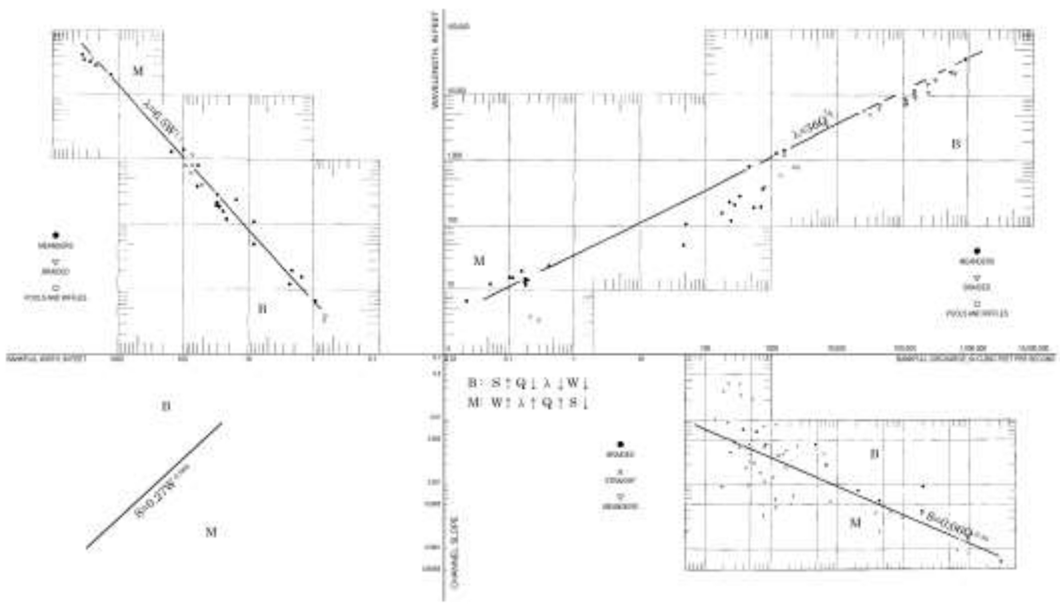

Figure 1: The relationship among channel slope, bankfull discharge, width and wavelength

In natural channels and in the flume that the wandering thalweg of a straight reach provides an additional mechanism for decreasing the width of the channel. Deposition of material on the insides of these thalweg bends tends to reduce the channel width.

These areas of deposition may also be associated with the loci of vegetation mentioned above. The width of a river is subject to constant readjustment if the banks are not well stabilized by vegetation. The magnitude of the readjustment depends on the nature of the banks and the amount and type of vegetation they support. If rivers from a great, diversity of geographic areas were considered, flood discharge would correlate more closely with river width than it would with any of the other channel factors such as depth, velocity, slope, or grain size, because the latter are apparently less directly controlled by discharge. There is, of course, considerable variation in width of streams having equal discharges of a similar frequency. Nevertheless, the variation between streams at a particular discharge is small relative to the change in width

with increasing discharge in the downstream direction. The difference in width between streams having equal discharge appears to be related to sediment concentration and to the composition of the bed and banks. One of the ways by which the hydrologic character of a basin affects river morphology is the size of the particles contributed to the debris load To relate this effect to the hydraulics, mechanisms by which the channel is adjusted, it is necessary to consider the interaction of grain size with other hydraulic factors.
In Fig. 1. we have the new finding information, that is
B: s↑ Q↓ λ↓ W↓ ……………………………………………………………………………………(6)
M: W↑ λ↑ Q↑ s↓ ……………………………………………………………………………………(7)
One of the ways by which the hydrologic character of a basin affects river morphology is the size of the particles contributed to the debris load To relate this effect to the hydraulics, mechanisms by which the channel is adjusted, it is necessary to consider the interaction of grain size with other hydraulic factors.
Engineers are familiar with the concept that at high Reynolds numbers the Darcy-Weisbach resistance coefficient,
$f \sim gRs/v^2$……………………………………………………………………………………(8)
or $1/\sqrt{f}=k(h/D_m)^{0.5}$……………………………………………………………………………(9)
is a function of relative roughness. Where the roughness is controlled by the grain size, relative roughness may be defined as the ratio of grain size to the depth of flow. The beds of natural rivers are often characterized by a wide range of particle size, particularly where the bed material is gravel. Because of both organized and random variation of grain size-distribution over the channel bed, the sampling problem is in itself important. Furthermore, even when an adequate sampling procedure is adopted, one must choose some representative size or some characteristic of the size distribution to typify the bed material. Thus far no completely satisfactory method has been developed for relating grain size in natural rivers to resistance.
River channel patterns are thought to form a morphological continuum. This continuum is two-dimensional, defined by plan features of which there are three (straight, meandering, branching), and structural levels of fluvial relief of which there are also three (floodplain, flood channel, low-water channel). Combinations of these three categories define the diversity of patterns. One of the most important factors in channel development is stream power, defined by water discharge and river slope. The greater the stream power, the stronger the branching tendency, but threshold values of stream power are different for the three different hierarchical levels of channel relief. The critical stream power values and hydrological regime together define the channel pattern, and analysis of the pattern type can be undertaken using effective discharge curves.
Stream power is the amount of energy the water in a river or stream is exerting on the sides and bottom of the river. There are many forms of the stream power formula with varying utilities such as comparing rivers of various widths or quantify the energy required to move sediment of a certain size. Stream power is closely related to various other criterion such as stream competency and shear stress. Stream power is a valuable measurement for hydrologists and geomorphologist tackling sediment transport issues as well as for civil engineers using it in the planning and construction of roads, bridges, dams, and culverts.
A major focus of recent research on channel patterns has been concerned with distinguishing a threshold between meandering and braided rivers, in terms of readily available data. These normally involve channel slope, a bankfull or some other representative discharge measure, and an index of bed material size. An alternative is to explore the patterning processes underlying the marked pattern scatter on bankfull stream power bed material size plots. Of the five sets of patterning processes, large-scale bed form development and stability is seen as especially important for meandering and braiding. For gravel-bed rivers, bed forms developed at around or above bankfull stage appear important for pattern generation, with braiding relating to higher excess shear stress and Froude number.
The first two may be combined as a measure of specific stream power (ω), defined as:
$\tau=\gamma hs=\rho ghs$ ……………………………………………………………………………………(10)
$\omega=\tau v=\rho ghvs=\rho gQs/w$……………………………………………………………………(11)

where w is river width, γ is water density, g is the acceleration due to gravity, h is average depth (～hydraulic radius),. v is water velocity, s is channel slope and Q is a representative measure of discharge, usually bankfull discharge Q_{bf}, and bed material size.

The total amount of energy $(\Sigma\Omega)=(\Sigma\omega wt) = \int \omega w\ dt = \int(\gamma QS)dt$……………………………………(12)

where, t is time in sec, Ω in J/s.

Romashin (1968) constructed a Q–s diagram using valley slope and median flood discharge for freely developing channels. Analyzing Romashin's diagram, Antropovskiy (1972) suggested considering stream power per unit of flow length $\Omega=\rho gQs$ [W/m]. He found some Ω thresholds between free meandering, incomplete meandering and multi-branching patterns.

After re-examination of data in terms of a modern classification (Albyan and Chalov 1998), the field of the diagram may be divided into three parts:

1. area of meandering (below dotted line), $\Omega<4$kW/m;
2. area of meandering and branching (braided), $4<\Omega<15$kW/m;
3. area of branching (braided, above solid line), $\Omega>15$kW/m;

Use of Ω values instead of specific power seems to be appropriate for free channels because width itself depends on Q and s values in unconfined conditions.

Every flow that transports sediment affects channel form. The product of sediment discharge and its frequency may be considered as an index of the channel-forming rate. Data analyses in the form of gradient–discharge charts constructed for channel forms of different order define a number of Q–s transition criteria, which reflect stream power per unit flow length. Using such criteria, the main problem is to choose a representative discharge value. To shift from the use of solitary values (mean, extreme, bankfull) to the continuous discharge spectrum, an effective discharge curve, EDC (an integral characteristic of hydrological and sediment regime and reflects the main features of the channel pattern, may be used for channel pattern analysis), is constructed. This allows interpretation of multilevel channel planforms in relation to both channel and bar-scale threshold criteria.

The flow regime and the sediment supply of the river have been considerably altered by hydroelectric dams, flow diversions and gravel mining. In addition, river dynamics have been affected by the construction of streambank protection structures. To document these changes, a historical analysis was performed using maps and aerial photographs. Morphological features that were examined included planform configuration, channel width, braiding index and bed elevation. There are three indices for estimation of the braiding intensity of a braided river, viz. braiding index (BI) by Brice [1960, 1964], braiding parameter (Bo) by Rust [1978] and braid-channel length ratio (B) by Friend and Sinha [1993]. In the present study, the braiding intensity is estimated by using the braiding index (BI) following Brice [1964] using the relation:

Braiding index = 2 (Li)/L ……………………………………………………….…………....………….…(13)

where Li = sum of the length of the braid bars and islands in a particular segment of the river, and L = length of the course of the river in that particular segment. A river is called braided when its braiding index is more than 1.5, and the river is a braided one.

The results indicate that as a consequence of decreases in the flows and sediment supply, remarkable channel changes have occurred in the river during this century, especially during recent decades. The recent history of river provides a clear example of how river engineering and natural resource development practices can induce dramatic alterations in river morphology through changing the flow regime, sediment supply and channel boundary characteristics. Analysis of historical maps and aerial photographs has documented decreases in width, braiding intensity and bed elevation, coupled to a planform change from braided to wandering. The magnitude of morphological response was very high. The channel has undergone a general narrowing with a decrease in average width to 35％ of its initial value, while the braiding index has decreased from about 3 to 1.5. In several reaches the planform pattern has changed from braided to wandering. The magnitude of these changes results from the additive effects of some human interventions and the natural propensity of braided rivers for rapid morphological adjustment. Improved river management and water resource strategies should take account of the styles and magnitudes of channel change identified and consider steps to avoid or mitigate the adverse aspects of morphological response to future human activities. Specifically, morphological response may affect, to a greater or lesser degree, flood conveyance, channel stability, sediment supply to downstream reaches and the coast, aquifer recharge and aquatic and riparian ecology. Due account must be taken to conserve and protect these important river functions and natural resources and improved understanding of morphological response is a key step towards achieving those goals of river basin management. The observed trends of channel change suggest that the river has not yet reached a new equilibrium condition and it may, therefore, be predicted that reductions in width and braiding intensity are likely to continue in the immediate future. (Nicola Surian, 1999).

Schumm (1977) and Petts (1979) have proposed conceptual models to predict the morphological response of channels to changes in the driving variables of water flow and sediment supply. The authors proposed the following relationships:

$Q^-, Q_{sb}^- \rightarrow w^-,\ d^{\pm},\ (\frac{w}{d})^-,\ \lambda^-, p^+,\ S^{\pm}$ (Schumm; 1977)……………………….……………………..…(14)

$Q^-, Q_{sb}^- \rightarrow w^-,\ d^{\pm},\ (\frac{w}{d})^-,\ A_b^-, p^+,\ S^{\pm}$ (Petts; 1979)………………………….…………………..…..(15)

where Q = discharge, Q_{sb}= bed load, w = width, d = mean depth, λ = meander wavelength, A_b= channel capacity, p = channel sinuosity and S = channel gradient. The results of this historical analysis demonstrate that the Piave River has exhibited a decrease in the width, w^-, a decrease in the channel capacity, A_b^- and an increase in the sinuosity, p^+. While the available data do not allow an accurate estimate of the changes in the mean depth and in the channel gradient, these findings are generally consistent with the morphological response to decreases in flow and bed load expected from theory. The braided Piave River has also experienced a marked decrease in braiding intensity, $\boldsymbol{BI^-}$, which might be considered as equivalent to a decrease in meander wavelength in a meandering river.

The instability of rivers has been investigated theoretically by several authors. A two-dimensional flow model, assuming that the direction of the local sediment transport is parallel to the local velocity vector and that the sediment transport rate is uniquely related to the bed shear stress. Extending the analysis by introducing a three-dimensional flow model which takes account of the helical motion induced because of the non-uniform vertical velocity distribution in the basic flow, an effect neglected in the previous approaches. Further, the introduction of the effect of a transverse bed slope on the transportation of the sediment was mentioned and found that this effect is of great significance, because the theory predicts that the river will braid into an infinite number of branches if it is not included. This suggests that an accurate knowledge of the interaction of fluid flow and sediment motion is necessary in order to develop an adequate description of the river instability. The total amount of sediment is transported partly as bed load and partly in suspension. The fact that at large flow rates a greater part of the sediment load will be carried in suspension implies that there can be no unique relationship between the transport rate and the bed shear stress. To account for this, it is necessary to introduce a supplementary equation of continuity for the suspended sediment, and to be able to estimate the transport rates of the bed load and the suspension separately.

ANALYSIS AND RESULTS

River improvement often involves changes in channel width, such as constriction to improve navigability and widening to reduce flooding risk. In all these cases the morphology of the river is likely to change further, at all spatial scales. At the cross-sectional scale, river widening may lead to the formation of alternate or multiple bars, river narrowing to their disappearance. The ecological condition of a river depends partly on the morphological state. One of the important quantitative indicators of the river morphological state is the number of bars that form in the cross section. The classical approach to determine the number of bars in a channel cross section defines a separator between ranges in which river planform styles with certain numbers of bars are linearly stable or unstable. The number of bars, primarily a function of the channel width-to-depth ratio, that form in an alluvial channel cross section can be determined from a physics-based linear model for alluvial bed topography. The classical approach defines separators between ranges in which river planform styles with certain numbers of bars are linearly stable and linearly unstable. The method directly estimates the most likely number of bars and gives fair results when using the Engelund and Hansen sediment transport formula irrespective of bed sediment when distinguishing between sand bed rivers and gravel bed rivers. The results are good for width-to-depth ratios up to 100 but deteriorate for higher width-to-depth ratios. This is ascribed to the neglect of non-linear effects by which the number of bars decreases through coalescence as bars grow to a finite amplitude. In particular, it correctly predicts the absence of free bars (only point bars: m<1, m=transverse perturbation mode or number of bars in a cross section, dimensionless) as well as the presence of alternate bars (m=1), central bars (m=2) or multiple bars (2<m<5). As a consequence, the method appears to be a good predictor for the transition between meandering and braiding and the method can be used as a reliable predictor for whether reducing or enlarging the width of a river will lead to a meandering, transition, or braided planform (Alessandra Crosato and Erik Mosselman, 2009).

The linear equations describe the longitudinal variation of the near-bank deviations of flow velocity and bed topography from the normal flow conditions as a result of upstream disturbances. They are obtained from the steady state 2-D depth-averaged continuity and momentum equations for water motion, a sediment balance equation, a sediment transport formula and an equation for the direction of sediment transport. After linearization of the momentum and continuity equations for perturbation, the equation for the longitudinal profile of the near-bank velocity excess becomes:

$$\frac{\partial U}{\partial s} + \frac{U}{\lambda_W} = \left(\frac{1}{2\lambda_W}\frac{u_0}{h_0}\right)H \qquad (16)$$

where U and H are the near-bank values of the main flow velocity and water depth perturbations as a function of the downstream distance; h0 reach-averaged water depth, in m, u0 reach-averaged flow velocity, in m/s, and λ_w streamwise adaptation length needed for the decay of perturbation in the transverse distribution of streamwise flow velocity, in m.

$$\lambda_W = \frac{h_0}{2C_f} \qquad (17)$$

and C_f= g/C^2 with C =Chezy =$\frac{u_0}{\sqrt{Rs}} =$ coefficient for hydraulic resistance.λ_s streamwise adaptation length of cross-sectional bed topography (or water depth profile), in m,

$$\lambda_s = \frac{1}{(m\pi)^2} h_0 \left(\frac{B}{h_0}\right)^2 f(\theta_0) \qquad (18)$$

$$f(\theta_0) = \frac{0.85}{E}\sqrt{\theta_0} \qquad (19)$$

with E a calibration coefficient, B (or w) the channel width, and θ_0 the reach averaged value of the Shields parameter.

$$\frac{2\pi}{L_P} = \frac{1}{2\lambda_W}\left[(b+1)\frac{\lambda_W}{\lambda_S} - \left(\frac{\lambda_W}{\lambda_S}\right)^2 - \frac{(b-3)^2}{4}\right]^{1/2} \qquad (20)$$

$$\frac{1}{L_D} = \frac{1}{2\lambda_W}\left[\frac{\lambda_W}{\lambda_S} - \frac{(b-3)}{2}\right] \qquad (21)$$

here LD downstream damping length, in m, and LP streamwise wavelength, in m. Withα= λ_s/λ_w and β=B/h_0 (or w/h_0) and

$$\alpha = \frac{2}{\pi^2}\frac{\beta^2}{m^2}C_f f(\theta_0) = F\left(\frac{\beta}{m}\right)^2 \qquad (22)$$

Therefore Eq.(21) becomes:.

$$\frac{1}{L_D} = \frac{1}{4\lambda_W}\left[\frac{\pi^2}{C_f f(\theta_0)}\left(\frac{m}{\beta}\right)^2 - (b-3)\right] \qquad (23)$$

with b: degree of nonlinearity of sediment transport versus depth-averaged flow velocity (q_{bed}=f(u_0^b), dimensionless). For a classical bed load transport predictor such as Meyer-Peter and Müller, n = 3 for high Shields numbers and increases to infinity towards the critical Shields number for sediment motion. We choose n = 4 for sand-bed rivers and for gravel-bed rivers n = 10 (following Crosato and Mosselman, 2009) as gravel is closer to the threshold of motion, so that the nonlinearity is stronger. For every bar mode, the point of zero damping (λ_w/LD =0) always falls within the harmonic range, then it can be taken to be representative for the formation of m mode incipient bars. In this case,

$$\alpha = \frac{2}{(b-3)} \qquad (24)$$

and

$$IP_{ue} = \alpha m^2 \qquad (25)$$

Let Eq.(22)=Eq.(24), then

$$m = \frac{\beta}{\pi}\sqrt{(b-3)f(\theta_0)C_f} \qquad (26)$$

In Eq.(19) with E=0.5 and C_f= g/C^2, θ_0=$u_0^2/(C^2\Delta D_{50})$, and Δ=（ρ_s-ρ）/ρ= relative sediment density under water and D50 = sediment median grain size, u_0 =C$\sqrt{h_0 i}$ with i (or s) being the longitudinal gradient and Q_w=B$u_0 h_0$, by rewriting Eq. (25),

$$m^2 = 0.17g\frac{(b-3)}{\sqrt{\Delta D_{50}}}\frac{B^3 i}{CQ_W} \qquad (27)$$

where the relation between BI and the mode, m, could be shown as:

BI=1+(m-1)/2 ……(28)

Herein, a river is considered single-thread for BI less or equal to 1.5, moderately braided for 1.5<BI<3 or braided for BI equal or greater than 3, where Bi = number of active channels across the river width W during channel-forming discharge. For the Meyer-Peter and Mu¨ller transport formula this results in the following expression:

$$\mu = (C/C_{90})^{3/2} \qquad (29)$$

$$b = \frac{3\mu\theta_0}{\mu\theta_0 - 0.047} \qquad (30)$$

Substituting Eq. (30) into Eq. (27), the mode m is obtained. In Eq. (26), β is a sensitive parameter of geometry on channel patterns, while $Q_{wi} \rightarrow Q_s D_m$ could be the effects of specific stream power with sediment of the flow. In Eq. (25), a river is predicted to braid if the actual IP for higher modes is above this threshold. For a given mode, m, and sediment characteristics which corresponding the flow characters to presenting the strengths of the channel bed and banks, the β could be obtained. Inversely, mode m can be solved with known β and flow characters with the corresponding sediment characteristics. The channel patterns can be altered by changing β, m, or sediment characteristics (or flow situations).

Comparing an empirical stream power-based classification and a physics-based bar pattern predictor by careful selection of data from the literature containing rivers with discharge and median bed particle size ranging over several orders of magnitude of various channel patterns and bar types without obvious eroding or aggrading tendency is analyzed. Empirically a continuum is found for increasing specific stream power, here calculated with pattern-independent variables: mean annual flood, valley gradient and channel width predicted with a hydraulic geometry relation. 'Thresholds', above which certain patterns emerge, were identified as a function of bed sediment size. The most important variables are actual width–depth ratio and nonlinearity of bed sediment transport. and the bank strength is indirectly included in the empirical prediction. In combination, empirical and theoretical prediction provide partial explanations for bar and channel patterns. Increasing potential-specific stream power implies more energy to erode banks and indeed correlates to channels with high width–depth ratio. Bar theory predicts that such rivers develop more bars across the width (higher Bi). At the transition from meandering to braiding, weakly braided rivers and meandering rivers with chutes are found. Bar and channel patterns can well be discriminated and predicted with channel particle size and specific potential stream power calculated from mean annual flood discharge, valley gradient and width predicted with a hydraulic geometry relation. Empirical power functions of channel particle size are given as lower thresholds for meandering rivers with scroll bars, for meandering rivers with chutes or weakly braided rivers, and for braided rivers. Bar pattern is reasonably well predicted by forced-bar theory, particularly the transition from single-thread (straight and meandering) to multi-thread (chute cutoffs and braided). Bar theory demonstrates the importance of actual channel width–depth ratio and channel gradient. Kleinhans and Berg (2010) presented some useful information as following,

$\omega=\tau v=\rho g h v s=\rho g Q s/w$…………………………………………..……………………..…..……….(11)

is a parameter for the potential maximum of the available flow energy corresponding to a minimum sinuosity.

$\omega_{bm}=900D_{50}^{0.42}$…………………………………………………………………………….…..….(31)

where subscript bm indicates braided meandering;

$\omega_{ia}=90D_{50}^{0.42}$……………………………………………………………………………..……….….(32)

where subscript ia refers to the discrimination between inactive channels and active channels with scroll bars;

$\omega_{sc}=285D_{50}^{0.42}$……………………………………………………………………..…….…….….(33)

where the subscript sc indicates the discrimination between scrolls and chutes.

To assess the nonlinearity of sediment transport, we also plot the criteria for bed load and suspension (Soulsby, 1997). These must be converted from non-dimensional shear stress (Shields number) to stream power. From their definitions and the law of Chézy, it can be derived that

$$\omega=\frac{\tau^{1.5}C}{\sqrt{\rho g}}=\theta^{1.5}C\frac{[(\rho_s-\rho)gD_{50}]^{1.5}}{\sqrt{\rho g}} \quad \text{……………………………………………………………...…..……(34)}$$

To represent the position of rivers relative to the empirical discriminators on one axis, the trend of increasing stream power with particle size is removed by normalization: the unit potential valley-related stream power of all individual rivers is divided by the stream power at the braiding threshold for the same particle size as ω equal to or greater than ω_b. The mode is straightforwardly interpreted as active braiding index. Braided rivers are reasonably

separated at BI = 3 from moderately braided rivers or meandering rivers with chute cutoffs. Equation (31) is reinterpreted as a lower ‘threshold’ for highly braided systems.

Substituting Eq. (3) and Eq. (4) into Eq. (11) and letting it equal to Eq. (34), we have the new relation result:

$68Q^{1.66}[\theta(\rho_s-\rho)D_{50}/\ h_0\ ]^{1.5}=1$……………………………………………………………...….(35)

with Q= $h_0 u_0$w and u_0 =C$\sqrt{h_0 i}$ with i (or s), and Eq. (3), then C=$Q^{0.7655}/1.161h_0^{1.5}$.

Combining Eq. (11) and Eq. (31) with ρ=1,000kg/m^3 and g=9.81 m/s^2, we obtain:

$Q^{0.1055}>7.255D_{50}^{0.42}$……………..…Braiding

$Q^{0.1055}\leqq 7.255D_{50}^{0.42}$……………..…Meandering…………………………………………………….(36)

Comparing Eqs. (6) and (7) with Eqs. (14) and (15), the results are quite agreeable.

DISCUSSION AND CONCLUSIONS

Braided rivers have complicated and dynamic bar patterns, which are challenging to fully understand and to predict both qualitatively and quantitatively. Linear theory ignores nonlinear processes that dominate fully developed bars, whereas natural river patterns are determined by the combined effects of boundary conditions, initial conditions such as planimetric forcing by fixed banks and the physical processes. To reproduce morphology and dynamics characteristic of braided rivers and determine the model sensitivity to generally used constitutive relations for flow and sediment transport, we use the 2-D depth-averaged morpho-dynamic model. We analyze bar and channel shapes and dynamics quantified, the results show that the chosen set of boundary conditions and physics in the numerical model is sufficient to produce many morphological characteristics and dynamics of a braided river but insufficient for long-term modeling because long-term modeling may result in a reduction of bar and channel dynamics and formation of exaggerated bar height and length. Formation and dynamics of idealized braided rivers in a physics-based nonlinear 2-D numerical model and assessed model sensitivity to choices of initial and boundary conditions and constitutive relations for flow resistance and sediment transport on sloping beds are studied. To exclude forcing on bar patterns by initial and boundary conditions, we kept these as simple as possible. Morphological model results are very sensitive to the constitutive relation for bed slope effects and also to the type and parameter values of the constitutive relations for flow resistance and sediment transport.

3-D data of the mean and turbulent structure of flow collected at a natural confluence of rivers with discordant beds to (1) describe the three-dimensional flow field of a natural junction of channels; (2) assess the role of changes in bed morphology occurring during transport-effective events on the structure of flow at a confluence; and (3) examine how the three-dimensional structure of flow varies with changes in the ratio of momentum flux between the two confluent streams is presented.

The mean field of flow is characterized by (1) the acceleration of flow in the downstream portion of the post-confluence channel, but by lower velocities upstream in the mixing layer area; (2) a stagnation zone at the apex of the junction; (3) a zone of flow deviation, and strong fluid upwelling, close to the avalanche face and at the margin of the tributary mouth bar; and (4) reduced velocities over the depositional bar at the downstream junction corner. The position and extent of these zones vary with changes in the ratio of momentum flux. Very high intensity of turbulence peaks up to 50% and turbulent kinetic energy were observed in the mixing layer region. Distortion of the mixing layer, characteristic of flow where bed discordance is present between the two tributary channels, was evident from mean and turbulent flow data. This field study suggests that the effects of bed discordance on flow, sediment transport, and the resultant bed morphology must be incorporated into conceptual and numeric models of these sites of complex flow. How the major features of mean and turbulent structure of the flow at a river junction vary in relation with changes in bed morphology and fluctuations in the ratio of momentum flux between the confluent rivers. The results show that bed morphology exerts a feedback on the structure of flow, and that the relative differential of depth between the two streams, together with the pro-gradation and regression of the tributary avalanche face with changing momentum flux Mr, are particularly important. Very high turbulent kinetic energy and intensities of turbulence in the mixing layer zone suggest that vortices in this region are the dominant features of flow in terms of the impact on sediment transport and bed morphology. These results suggest that models of the structure of the flow at river junctions must take into account various bed morphologies that can occur at these sites. More detailed three-dimensional field studies are needed to generalize these findings, particularly concerning the remarkably high levels of turbulence recorded. Future research should concentrate on mean and turbulence data.

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