Discriminating Meandering and Braided Channel Patterns on the Basis of Discharge and Slope using a Physical Laboratory Model: the Emriver™ River Process Simulator

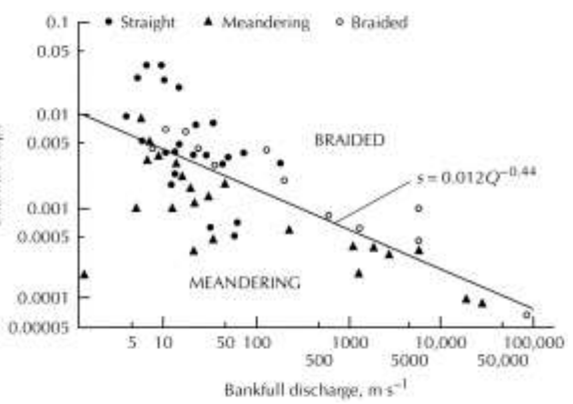
Michael J. Zaleha, Michael Flis, & Jeffrey Sherman

Department of Geology, Wittenberg University, Springfield, Ohio 45501-0720

mzaleha@wittenberg.edu

Introduction

River channel pattern is controlled primarily by sediment transport rate and stream power, with braided rivers characterized by relatively higher values than meandering rivers. ***Previous studies*** have shown that meandering and braided channel patterns can be discriminated on the basis of discharge and slope by virtue of their control on sediment transport rate and stream power. ***Discriminators of the form*** $S=aQ^{-b}$ have been used to demarcate the transition between these two channel patterns. ***The purpose*** of this study was to use a commercially available physical model, the Emriver™ River Process Simulator (a stream table), to investigate whether this relationship could be produced under laboratory conditions. **Right.** The classic plot of Leopold & Wolman (1957) discriminating natural meandering and braided channels on the basis of slope and discharge (from Bridge, 2003).



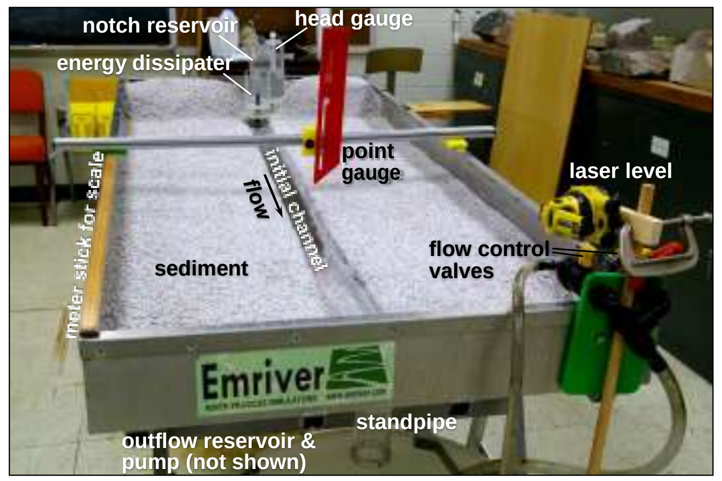
Abstract

River channel pattern is controlled primarily by sediment transport rate and stream power, which are largely a function of channel discharge (Q) and slope (S). Discriminators of the form $S=aQ^{-b}$ have been shown to quantitatively demarcate the transition between meandering and braided rivers. We used a commercially available physical model, the Emriver™ River Process Simulator (a stream table), to investigate whether this relationship could be produced under laboratory conditions.

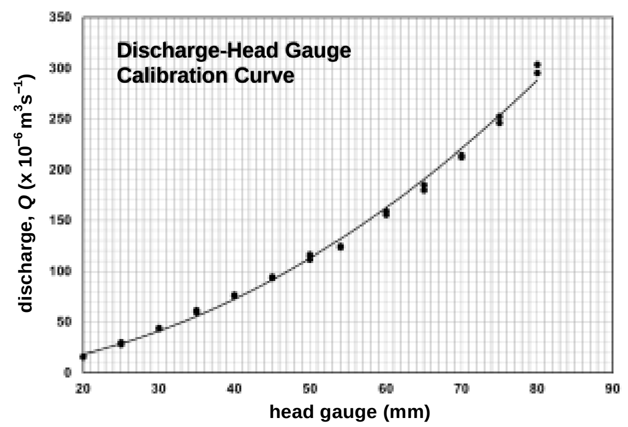
The model is a metal box 2.13 m long, 0.91 m wide, and 0.15 m deep. The sediment is well sorted, ground plastic with a D_{50} of 1.15 mm and a density of ~1.4 g/cm^3. Prior to each experimental run, sediment was graded to a thickness of 2-4 cm, and an 8 cm-wide straight channel was excavated. Discharge was calibrated to a head gauge within the upstream inflow reservoir. Outflow was through a standpipe which could be adjusted vertically to effect channel slope. After each run, channel slope was measured with a laser level and point gauge. Thirty-three runs were conducted under various conditions of discharge and standpipe elevations. During each run, the channel was allowed to aggraded and evolve until it reached a state of dynamic equilibrium. Run times were typically 15-50 minutes.

Data were plotted on a log-log graph of dimensionless slope versus discharge. The data form two clearly defined fields of meandering and braided channels. The line demarcating the fields is defined by the equation $S=2\times10^{-9}Q^{-1.70}$, a form comparable to data for natural rivers. However, coefficient a and exponent $-b$ are both markedly less than those for natural rivers, which are typically 10^{-2}-10^{-4} and -0.25 to -0.44, respectively. These results indicate that the transition in channel pattern under our experimental conditions occurs at a lower slope for a given discharge and/or at a lower discharge for a given slope than for natural systems. This may be due to the lower density of the experimental sediment relative to natural sediment, or due to the effects of the relatively high experimental slopes on the force balance on grains (i.e., mobility). Despite the limited size and simplicity of the experiments, results are comparable to data for rivers, which speak to the "unreasonable effectiveness" of physical laboratory models and encourage their use to study processes of natural systems.

Experimental Setup & Procedure

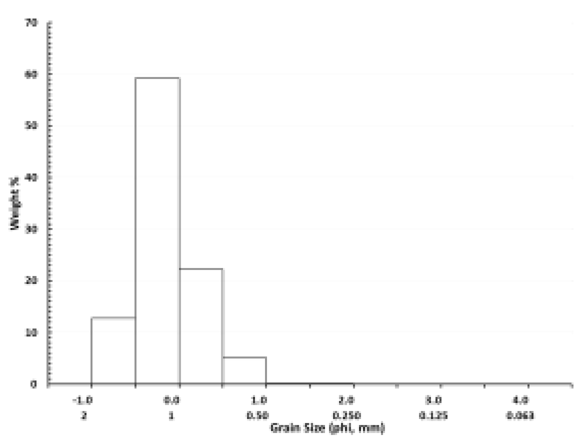


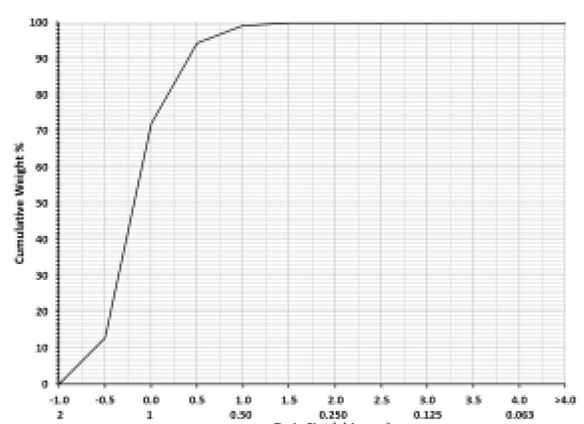
The physical model is the commercially available Emriver™ River Process Simulator (a stream table) manufactured and distributed by Little River Research & Design. The model is a metal box 2.13 m long, 0.91 m wide, and 0.15 m deep. Upstream inflow was through a notch reservoir and energy dissipater. The reservoir has a head gauge which measures the water elevation within the reservoir that varies with discharge. Discharge was regulated with a valve and determined using the discharge–head gauge calibration curve shown to the right. Downstream outflow was through a standpipe which could be adjusted vertically to effect channel slope. Prior to each experimental run, sediment was graded to a thickness of 2-4 cm, and an 8 cm-wide straight channel was excavated. After each run, channel slope was measured with a laser level and point gauge.



Prior to conducting the experiments, discharge was measured by collecting water from the standpipe for a given amount of time. Discharge was measured under various flow settings and head gauge elevations to calibrate discharge with the head gauge reading.

The sediment used in the model is well sorted, ground melamine plastic. Two grain size analyses were conducted by sieving using standard procedures. The sediment has a ***mean grain size of 1.09 mm***, a ***median grain size, D_{50}, of 1.15 mm***, and a ***density of 1.3-1.5 g/cm^3***. Accounting for density differences between the plastic and quartz, these grain sizes equate hydraulically to quartz grain sizes of: mean=0.33 mm and D_{50}=0.35 mm.





$$\textbf{quartz equivalent grain size} = \frac{(\text{sediment density}_{model} - \text{fluid density})\ (\text{grain size}_{model})}{\text{sediment density}_{quartz} - \text{fluid density}}$$

Thirty-three experimental runs were conducted under various conditions of discharge and standpipe elevations. Standpipe elevation, to a degree, effects channel slope, the higher the standpipe, the lower the slope. During each run, the channel aggraded with sediment supplied from lateral bank erosion and also sediment manually fed into the upstream portion of the channel. Channels were allow to aggrade and evolve until they reached a state of dynamic equilibrium, i.e., the established channel pattern did not change even though the channel (or channels in the case of braided patterns) continued to migrate, eroding and depositing sediment. Resultant channel slopes were a function of standpipe elevation and aggradation, which was, in turn, a function of discharge. Run times were typically on the order of 15 to 50 minutes.

Meandering Channel

Example of a meandering channel developed in the model. Discharge was 50 x 10^{-6} m^{3}s^{-1} and the slope was 0.034. Run time was 30 min. Arrows indicate the active channel. Scale is the same as in the photo to the right.

Braided Channel

Example of a braided channel developed in the model. Discharge was 88 x 10^{-6} m^{3}s^{-1} and the slope was 0.030. Run time was 15 min. Arrows indicate some of the active channels.

Yamuna River

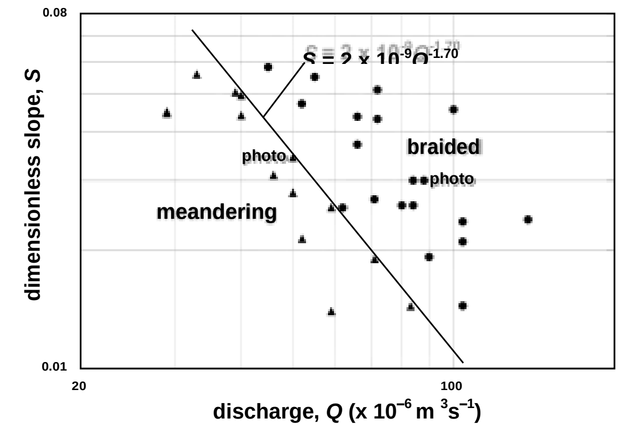
Yamuna River, India, exhibiting a meandering channel pattern comparable to that developed in the model above. Image from Google Earth.

Brahmaputra River

Brahmaputra River, Bangladesh, exhibiting a braided channel pattern comparable to that developed in the model above. Image from Google Earth.

Results

Data were plotted on a log-log graph of dimensionless slope versus discharge. The data form two clearly defined fields of meandering and braided channels. The line demarcating the fields is defined by the equation $S=2\times10^{-9}Q^{-1.70}$, a form comparable to data for natural rivers.



Discussion & Conclusions

In the equation for the line demarcating the meandering and braided fields, coefficient a and exponent $-b$ are both markedly less than those for natural rivers, which are typically 10^{-2}-10^{-4} and -0.25 to -0.44, respectively (see table below). These results indicate that the transition in channel pattern under our experimental conditions occurs at a lower slope for a given discharge and/or at a lower discharge for a given slope than for natural systems. This may be due to the lower density of the experimental sediment relative to natural sediment, or due to the effects of the relatively high experimental slopes on the force balance on grains (i.e., mobility). Despite the limited size and simplicity of the experiments, the resultant trend is comparable to data for rivers. Hence, under relaxed scaling rules, laboratory experiments can reproduce processes and phenomena of natural systems, a concept referred to as "unreasonable effectiveness" by Paola et al. (2009; also see Kleinhans et al., 2014). Further, the results suggest that the processes governing channel pattern are scale-independent. Such results encourage the use of physical laboratory models to study processes of natural systems.

A final note concerning teaching, Zaleha has effectively used this commercially available model and the S vs Q plot in his *Sedimentology* course. Not only does the exercise demonstrate controls on channel pattern, but provides students the opportunity to explore the usefulness, variance, and limitations of physical modeling.

Discriminators of channel pattern based on discharge, slope, and sediment size (from Bridge, 2003).

Equation	Comments	Author
$S=0.0007Q_m^{-0.15}$ $S=0.0041Q_m^{-0.15}$	Meandering sand-bed rivers Braided sand-bed rivers	Lane (1957)
$S=0.0125Q_{bf}^{-0.44}$	Meandering to braided transition	Leopold & Wolman (1957)
$S=0.000196Q_{bf}^{-0.44}D^{1.14}$	Meandering to braided transition	Henderson (1961, 1966)
$S=0.0009Q_m^{-0.33}$ $S=0.0041Q_m^{-0.33}$	Meandering sand-bed rivers in Kansas Braided sand-bed rivers in Kansas	Osterkamp (1978)
$S=0.0016Q_m^{-0.33}$	Meandering to braided transition	Begin (1981)
$S=0.042Q^{-0.49}D_{50}^{0.09}$ $S=0.042Q^{-0.49}D_{90}^{0.27}$	Meandering to braided transition for gravel-bed rivers	Ferguson (1984, 1987)
$S=aQ^{-0.5}D^{0.5}$	Meandering to braided transition	Chang (1985)

S, channel slope; Q, discharge in m^3/s; subscripts m and bf, mean annual and bankfull, respectively; D is diameter of bed sediment in mm; subscripts 50 and 90, 50% and 90% percentiles of grain size distribution.

References Cited

Begin, Z.B., 1981, The relationship between flow-shear stress and stream pattern: Journal of Hydrology, v. 52, p. 307-319.

Bridge, J.S., 2003, Rivers and floodplains: forms, processes, and sedimentary record: Blackwell, Oxford, 491p.

Chang, H.H., 1985, River morphology and thresholds: Journal of the Hydraulics Division, ASCE, v. 111, p. 503-519.

Ferguson, R.I., 1984, The threshold between meandering and braiding, *in* Smith, K.V.H., ed., Proceedings of the First International Conference on Hydraulic Design: Springer, New York, p. 6.15-6.29.

Ferguson, R.I., 1987, Hydraulic and sedimentary controls of channel pattern, *in* Richards, K.S., ed., River channels: environment and processes: Blackwell, Oxford, p. 125-158.

Henderson, F.M., 1961, Stability of alluvial channels: Journal of the Hydraulics Division, ASCE, v. 87, p. 109-138.

Henderson, F.M., 1966, Open channel flow: Macmillan, New York.

Kleinhans, M.G., van Kijk, W.M., van de Lageweg, W.I., Hoyal, D.C.J.D., Markies, H., van Maarseveen, M., Roosendaal, C., van Weesep, W., van Breemen, D., Hoendervoogt, R., and Cheshier, N., 2014, Quantifiable effectiveness of experimental scaling of river– and delta morphodynamics and stratigraphy: Earth-Science Reviews, v. 133, p. 43-61.

Lane, E.W., 1957, A study of the shape of channels formed by natural streams flowing in erodible material: Missouri River Division Sediment Series, no. 9, US Army Engineer Division, Missouri River, Corps of Engineers, Omaha, Nebraska.

Leopold, L.B., and Wolman, M.G., 1957, River channel patterns: braided, meandering and straight: US Geological Survey Professional Paper 282-B, p. 39-85.

Osterkamp, W.R., 1978, Gradient, discharge, and particle size relations of alluvial channels in Kansas, with observations on braiding: American Journal of Science, v. 278, p. 1253-1268.

Paola, C., Straub, K., Mohrig, D., and Reinhardt, L., 2009, The "unreasonable effectiveness" of stratigraphic and geomorphic experiments: Earth-Science Reviews, v. 97, p. 1-43.