Reports

Meander Wavelength of Alluvial Rivers

Abstract. *Data on river channel and sediment characteristics were collected at 36 cross sections of stable alluvial river channels in Australia and western United States. These data demonstrate that the meander wavelength of a river is dependent not only on water discharge, but also on the type of sediment load moved through the channel. The meander wavelength of rivers that are transporting a high proportion of their total sediment load as both sand and gravel will be greater than the meander wavelengths of channels of similar discharge which are transporting mainly fine sediment loads.*

The form characteristics of graded or stable alluvial river channels are a function of both geologic and hydrologic characteristics of the watershed. Although other factors can be locally important, the average characteristics of a river channel are established predominantly by the quantities and the character of runoff and sediment delivered from the drainage system (*1*). For example, channel width and depth and the dimensions of the meander pattern have been related to discharge (*2, 3*); and channel dimensions also have been related to quantity and size of sediment load (*4*). Channel shape, expressed as a width-depth ratio, and channel pattern or sinuosity have been related to the percentage of silt and clay exposed in the channel cross section (*5*).

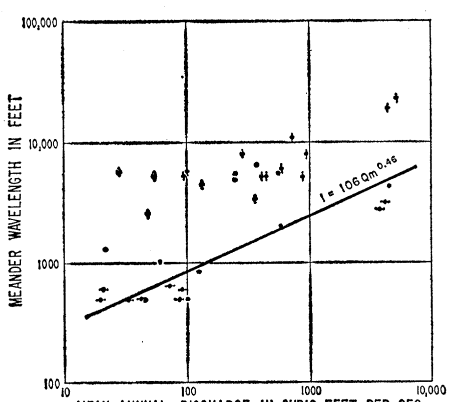

Fig. 1. Relation between meander wavelength (l) and mean annual discharge (Qm). The regression line is that obtained by Carlston (*3*). Classes of channels are designated as follows: bedload channels by dots with vertical bars, mixed-load channels by dots, suspended-load channels by dots with horizontal bars.

In discussions of the controls of river morphology, discharge has appeared as the most significant variable. Less attention has been devoted to sediment load because data on the total sediment load are not easily collected, and they are rarely available. Nevertheless, a significant change of either discharge or sediment load, or both, will cause an adjustment of river channel dimensions in a manner which will compensate for the hydrologic change (*6*). I have previously suggested that the percentage of silt and clay (sediment smaller than 0.074 mm) that is exposed in the perimeter of stable alluvial channels is an index (M) of the proportion of the total sediment load that is transported in suspension (*5*). Support for this hypothesis has been obtained from five channels on the Great Plains, for which data on the total sediment load have been collected (*7*). Channels with more than 20 percent silt and clay exposed in their perimeters were designated suspended-load channels, and these transport only about 3 percent or less of sand and gravel. Channels containing less than 5 percent silt-clay in their perimeters were designated bedload channels, and these transport more than 11 percent of their total load as sand and gravel. An intermediate class was designated as mixed-load channels (*5, 7*).

Data have been collected on the morphologic, hydrologic, and sediment characteristics of 36 stable channel cross sections for which discharge records are available for periods in excess of 10 years. Thirty-three sets of data were obtained near gaging stations on the Great Plains of western United States, and three sets of data were obtained near gaging stations on the Murrumbidgee River of New South Wales, Australia (*7*). None of the channels contain significant quantities of sediment coarser than sand, but the data include a large range of sediment and channel characteristics. Meander wavelength was obtained by measuring the distance between every systematic river bend along one side of a valley over a 5- to 10-mile (8 to 16 km) section near a gaging station. Information concerning mean annual discharge (Qm) and mean annual flood (Qma) was obtained from discharge records collected at the gaging stations. The percentage of silt and clay in the perimeter of each channel (M) was obtained by grain size analysis of a composite sample of the upper six inches (15 cm) of bed and bank sediments (*5, 7*).

Meander wavelength has been discussed (*3, 8, 9*), and there appears to be more uncertainty concerning the independent variables which influence meander wavelength and meandering in general than any other river characteristic. For example, meander wavelength dimensions have been attributed to water discharge alone (*9*), to channel width (*8*), and to gradient (*3, 10*).

The data on the relation between meander wavelength (l) and mean annual discharge (Qm) scatter over a full log cycle in contrast to the very good relation shown by Carlston for 14 rivers of eastern United States (*3*). For Carl-

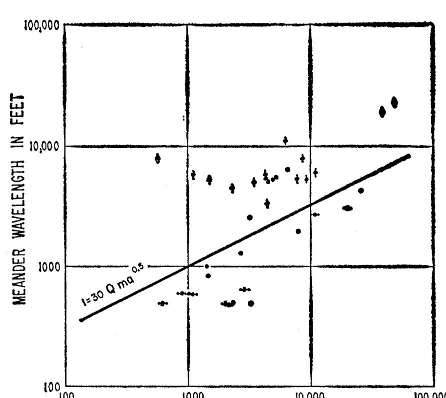

Fig. 2. Relation between meander wavelength (l) and mean annual flood (Qma). Regression line is that obtained by Dury (*9*). Classes of channels are designated as follows: bedload channels by dots with vertical bars, mixed-load channels by dots, suspended load channels by dots with horizontal bars.

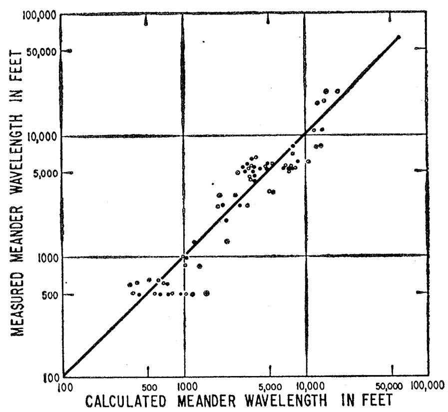

Fig. 3. Relation between measured and calculated meander wavelength from Eq. 1 (data plotted as dots) and Eq. 2 (data plotted as open circles).

ston's data about 98 percent of the variation of the meander wavelength from the mean is explained by mean annual discharge alone, whereas, for the data used here, only 43 percent of the variation of wavelength from the mean is explained by discharge. A possible explanation of this large difference in the coefficient of determination might be that Carlston's data were collected from one type of river, whereas my data were collected from a range of channel types including both bedload and suspended load channels as defined above. The distribution of points on Fig. 1 supports this assumption. The points representative of suspended-load channels, that is, those containing a high percentage of silt and clay (M), fall about the regression line, whereas the points representative of bedload channels, those containing a low percentage of silt and clay, plot well above the regression line.

A multiple regression analysis yielded the following equation:

$$l = 1890\, Qm^{0.34}/M^{0.74} \qquad (1)$$

In this equation mean annual discharge (Qm) and the percentage of silt-clay in the perimeter of the channels (M) explains 89 percent of the variation of wavelength (l) from the mean (correlation coefficient = .95; standard error = 0.16 log units), which is a significant improvement over the relation between wavelength and discharge alone and which indicates the influence of the type of sediment load on the meander wavelength.

Meander wavelength is related to the bankfull discharge of many rivers (*8, 9*) or to a discharge of the order of magnitude of the mean annual flood (Qma). Dury's (*9*) regression line relating meander wavelength to bankfull discharge passes through the scatter of points resulting from the plotting of meander wavelength against mean annual flood (Fig. 2). On Fig. 2 the low silt-clay channels plot above his regression line, whereas the high silt-clay channels plot below his regression line.

A multiple regression analysis yields the following equation:

$$l = 234\, Qma^{0.48}/M^{0.74} \qquad (2)$$

In this relation, 86 percent of the variation of meander wavelength from the mean is explained (correlation coefficient = .93; standard error = 0.19 log units), but only 40 percent of the variation is explained by the use of mean annual flood alone.

Significant improvement of the estimation of meander wavelength occurs when a factor representative of type of sediment load is used (Fig. 3), and it is concluded that differences in meander wavelengths between rivers or changes of meander wavelength along a river cannot be attributed to changes of water discharge alone. Instead, a tenfold range in meander wavelength at a given discharge can be attributed to variations in type of sediment load (Figs. 1 and 2).

It has been suggested that the dimensions of meanders are related to channel gradient (*3, 10*) and width (*8*). However, a simple correlation of stream gradient against meander wavelength is not significant. It is true that the simple correlation of meander wavelength with channel width will be very good, but both are closely related to discharge and type of sediment load (*7*). Therefore, although many river characteristics are interrelated, as are width and meander wavelength, the independent variables that determine both channel width and meander dimensions are discharge and type of sediment load.

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References and Notes

1. S. A. Schumm and R. W. Lichty, *Amer. J. Sci.* **263**, 110 (1965).
2. L. B. Leopold and T. Maddock, Jr., *U.S. Geol. Surv. Prof. Paper* **252** (1953).
3. C. W. Carlston, *Amer. J. Sci.* **263**, 864 (1965).
4. S. Leliavsky, *An Introduction to Fluvial Hydraulics* (Constable, London, 1955), p. 231.
5. S. A. Schumm, *U.S. Geol. Surv. Circular* **477** (1963).
6. E. W. Lane, *Amer. Soc. Civil Eng. Proc.* **81**, paper No. 745 (1955).
7. S. A. Schumm, *U.S. Geol. Surv. Prof. Paper*, in press.
8. L. B. Leopold and M. G. Wolman, *ibid.* **282-B**, 39 (1957).
9. G. H. Dury, *ibid.* **452-C** (1965).
10. J. F. Friedkin, *U.S. Waterways Expt. Sta., Vicksburg* (1945).
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Mercury: Observations of the 3.4-Millimeter Radio Emission

Abstract. *Observations of the 3.4-millimeter radio emission from Mercury during 1965 and 1966 yielded the following relationship between average brightness temperature* T_B *of the disk and the planetocentric phase angle* i:

$$T_B = 277\ (\pm 12) + 97\ (\pm 17) \cos\ [i + 29 \text{ deg } (\pm 10 \text{ deg})]\ {}^\circ K$$

The errors are statistical standard; the phase shift corresponds to a phase lag —that is, the maximum and minimum of insolation lag the maximum and minimum of planetary radiation.

Observations of Mercury made in 1965 at 3.4 mm (88 Ghz) indicated the absence of any significant difference between the average brightness temperature, T_B, over the disk on the day and night sides (*1*). That is, there was no variation of T_B with phase angle i. This unexpected result led us to make much more extensive observations in 1966. The resulting data clearly show a T_B variation with phase angle.

We made observations at 3.4 mm for a total of 410 hours of integration time on 102 days from 5 April through 23 October 1966 with the 15-foot (4.57-m), 2.8-arc-min-beamwidth antenna of the Space Radio Systems Facility of Aerospace Corporation. We used computer-controlled dual-beam observing, data reduction, and calibration procedures identical to those used in 1965 (*1*). As in 1965, no data were taken when Mercury was within 3 arc degrees of the sun. From three to 14 observing cycles, each 26 minutes long, were obtained every day. The daily average antenna temperatures recorded in 1966 ranged from −0.02 ± 0.05 (standard error) °K to +0.38 ± 0.04 °K. Correction factors for atmospheric attenuation ranged from 1.13 to 1.67, the average value being 1.36.

The daily values of T_B for both 1965 and 1966 are shown in Fig. 1. The values represent unequal amounts of integration time. We have not normalized the observed T_B values to Mercury's mean heliocentric distance; if