RESPONSE OF THE LOWER MISSISSIPPI RIVER TO CHANGES IN VALLEY SLOPE, SINUOSITY AND WATER TEMPERATURE

BY

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INTRODUCTION

The problem of trying to maintain trouble-free alluvial waterways is very difficult. The use of our waterways either as floodways or navigation routes has been increasing at a rapid rate which has often resulted in an attempt to alter or control them. Thus, it is imperative to study the variables influencing the channel morphology in order to more effectively design and locate structures which will compliment instead of aggravate the channel form and process.

The Potamology Section, Vicksburg District, Corps of Engineers, has been studying the variables influencing the morphology of the Lower Mississippi River. Three of these variables are valley slope, sinuosity and water temperature.

VALLEY SLOPE AND SINUOSITY

Rivers have patterns which range from essentially straight to very meandering or even braided. The variations that are seen in different river systems can be partially attributed to the differences in the geologic history, discharge, hydrographs and sediment load. However, the changes in pattern that are seen along a river which is transporting a relatively constant sediment load at a given discharge are not as readily explained.

The variability of sinuosity along the same river is seldom mentioned. Sinuosity is the ratio of the river channel length to the length of the alluvial valley through which it flows. Recent studies (6, 10) of the dependence of sinuosity on the valley slope have shown that different sinuosities are developed at different slopes. Fig. 1, developed from model studies done at Colorado State University by Schumm and Khan, shows that a change in sinuosity can be expected with an abrupt change in valley slope. Fig. 2, developed from potamology studies, shows that the sinuosity of the Lower Mississippi River varies with valley slope in the manner predicted from Fig. 1.

Fig. 1 was based on data from sixteen experimental channels with the same discharge but very different sediment loads, whereas Fig. 2 shows the variation of sinuosity along one river. The data in Fig. 2 were obtained from the 1911-1915 survey of the Mississippi River between Cairo, Illinois, and Head of Passes, Louisiana, a river distance of 1,020 miles. This old survey was used because it provided information on the river before artificial cutoffs shortened the river by about 150 miles.

Laboratory or theoretical investigations seldom find confirmation from field investigations, but Figs. 1 and 2 demonstrate that such confirmation can occur.

Although the scatter in Fig. 2 is large, it can be seen that the lowest sinuosity occurs on the gentlest valley slopes which are characteristic of the lower 200 miles of the Mississippi. The low values of sinuosity at the steepest valley slopes occur where flows divide around large islands and middle bars. The flow in these steep valley areas has braiding tendencies.

Both Figs. 1 and 2 show that there is a threshold value of slope at which there is a major change in channel pattern from meandering to braided (or braiding tendencies). Up to this threshold value, sinuosity increases with slope.

It should be emphasized that along a given reach of a meandering river, meander loops are continually enlarging until they are naturally cut off. Thus, the sinuosity of a reach will vary about a mean with time (4), and hence much of the scatter on Fig. 2. For example, the very low point (slope of .00009%, sinuosity of 1.2) represents a reach north of Memphis, Tennessee, where several cutoffs occurred naturally during the late nineteenth century.

In the study of river systems, it is found that in many cases the river gradient varies only slightly while the slope of the valley surface varies significantly. That is, within a valley there are reaches of valley surface that are either steeper or gentler than the average river gradient. Variations of valley slope can be caused by slight uplift, depression or tilting of the valley or by a great difference in the sediment loads carried by tributaries and the principal channel. For example, below the junction of the Arkansas River with the Mississippi, the valley slope increases significantly because of the relatively high sediment discharges from the Arkansas River during recent geologic history (6). In order for a river to maintain a relatively constant gradient it must increase or decrease its sinuosity depending on the slope of the valley floor. Therefore, if other variables are eliminated, highly sinuous reaches should reflect a steeper valley slope while low sinuosity should reflect gentler valley slopes.

From the results of the experimental and field data, it is believed that variations of sinuosity and perhaps even extensive changes of pattern, for example, from meandering to braided, can reflect changes or differences in the slope of the surface on which a river flows.

WATER TEMPERATURE

One of the factors that is often neglected in the design of waterways in alluvial rivers is the seasonal water temperature variation in relation to the effect it can have on the stage-discharge relationship and navigable depths. Investigations have shown that as the water temperature is lowered for a given stage, the discharge and sediment load increase and the bed roughness decreases. (1, 2, 3, 5, 9)

A comparison of data from the New Orleans District of the Mississippi River showed that the high point of a crossing was 20 feet lower at a water temperature of 55°F than it was a water temperature of 83°F. It was also found that a difference in temperature of 30 to 40°F can make as much as 10 to 20 percent difference in discharge at the same stage. (1)

Investigations on the Missouri River have shown that with a relatively constant discharge the stage lowers from 1 to 2 feet between the months of September and November. During this period there is approximately 30°F decrease in water temperature. Comparison of data also shows that during this period the average velocity of flow increases and Manning's roughness coefficient "n" decreases. (9)

Since rising stages often produce higher discharges than like falling stages, a further analysis has been made of temperature effects treating rising and falling stages separately to see if the discharge variations were caused by the rise and fall of stage rather than by temperature variations. This analysis, covering stations on the Mississippi and Missouri Rivers, showed that the cold water produced higher average discharges than the warm water for both rising and falling stages. (3)

The Potamology Section of the Vicksburg District, Corps of Engineers, is investigating the effect that water temperature has on the Mississippi River within their district. Figs. 3, 4 and 5 are typical plots from the above study which suggest that water temperature influences the flows in this portion of the Mississippi River. Each figure shows a comparison of data for only two temperatures. It would be desirable to have data points at intermediate temperatures but surveys taken at equal stages which also include sediment data are very limited; consequently, more data points were not available and thus the results are not conclusive.

Figs. 3, 4, and 5 are for approximately 11.5, 20.8, and 30.5-foot stages respectively. Each figure shows that as temperature is decreased the discharge, average velocity and suspended sand concentration increase. In addition, as temperature is decreased the percent sand increases in the suspended samples and decreases in the bed samples. This suggests that as temperatures decreases the finer sand particles are picked up from the bed and carried in suspension. The entrainment of sand from the bed is also indicated by the fact that the mean diameter (D_{50}) of the bed material increases with decreasing temperatures. It is suspected that other factors such as the seasonal variations in runoff and sediment supply may also play a role in the change in the D_{50} and the percent sand contained in the samples.

Fig. 3 shows that the area below ALWP (average low water plane) and the maximum depth below ALWP decrease with decreasing temperature, which is contrary to the findings of other investigators, while Figs. 4 and 5 show the opposite effect. The different responses can possibly be accounted for by the fact that Fig. 3 is for a falling stage in a crossing type section and Figs. 4 and 5 are for rising stages in a pool type section. Nevertheless, it can be seen from these figures that a change in water temperature of 30 to 40°F can be accompanied by as much as a 10-foot change in depths.

From the data for Figs. 3, 4 and 5, the following was found: for the same stage, a difference in water temperature of 30 to 40°F can be accompanied by a 9 to 19 percent difference in discharge, 2 to 19 percent difference in average velocity, 0.3 to 23 percent difference in maximum depth below ALWP, 2 to 13 percent difference in area below ALWP, 16 to 53 percent difference in percent sand in the suspended samples, 3 to 16 percent difference in percent sand in the bed samples, 37 to 63 percent difference in suspended sediment concentration, and 27 to 74 percent difference in the D_{50} of the bed material.

The different temperature effects that have been observed are suggestive of the complex interrelationship that exists between the hydraulic transport phenonema. Recent lab experiments (7, 8) have shown that the temperature effect on bed-load transport could be partially dependent on the flow conditions at the bed. However, these phenomena are not yet well understood for alluvial channels and thus cannot be clearly interpreted phenomenologically.

CONCLUSIONS

The similarity of the curves in Figs. 1 and 2 and the agreement between the field and laboratory investigations support the contention that among other variables, the slope of the valley floor upon which a river flows strongly influences its pattern.

The investigations that have been made on the effects that the seasonal water temperature variation has on the stage-discharge relationship, sediment transport and bed roughness exemplify the importance of recognizing the close interrelationship that exists between the various parameters. This interaction of variables could be of extreme practical significance in rivers where it is necessary to not only predict the sediment transport, but also to predict the unobstructed depths available for navigation.

REFERENCES

1. Burke, P.P., "Effect of Water Temperature on Discharge and Bed Configuration, Mississippi River at Red River Landing, Louisiana," Technical Report No. 3, Committee on Channel Stabilization, Corps of Engineers, U. S. Army, Aug., 1966.

2. Carey, W. C., "Effect of Temperature on Riverbed Configuration: Its Possible Stage-Discharge Implications," Proceedings of the Federal Inter-Agency Sedimentation Conference, Agriculture Research Service, USDA, Misc. Publication No. 970, 1963, pp. 237-272.

3. Fenwick, G. B., "Water-Temperature Effects on Stage-Discharge Relations in Large Alluvial Rivers," Techinical Report No. 6, Committee on Channel Stabilization, Corps of Engineers, U. S. Army, Sept., 1969.

4. Fisk, H. N., "Geological Investiation of the Alluvial Valley of the Lower Mississippi River," Mississippi River Commission, Vicksburg, Mississippi, Dec. 1944.

5. Lane, E. W., Carlson, E. J., and Hanson, O. S., "Low Temperature Increases Sediment Load in Colorado River," Civil Engineering, Sept. 1949, pp. 45-46.

6. Schumm, S. A., et al., "Variability of River Patterns," Nature, Physical Science, Vol. 237, No. 74, May 29, 1972, pp. 75-76.

7. Taylor, B. D., and Vanoni, V. A., "Temperature Effects in Low-Transport, Flat-Bed Flows," Journal of the Hydraulics Division, ASCE, Vol. 98, No. HY8, Proc. Paper 9105, Aug., 1972, pp. 1427-1445.

8. Taylor, B. D., and Vanoni, V. A., "Temperature Effects in High-Transport, Flat-Bed Flows," Journal of the Hydraulics Division, ASCE, Vol. 98, No. HY12, Proc. Paper 9456, Dec., 1972, pp. 2191-2206.

9. U. S. Army Corps of Engineers, "Missouri River Channel Regime Studies," U. S. Army Corps of Engineers, Missouri River Division Sediment Series No. 13B, 1969.

10. Winkley, B. R. and Robbins, L. G., "Geometric Stability Analysis of an Alluvial River," Proceedings of the Mississippi Water Resources Conference, Jackson, Mississippi, 1970

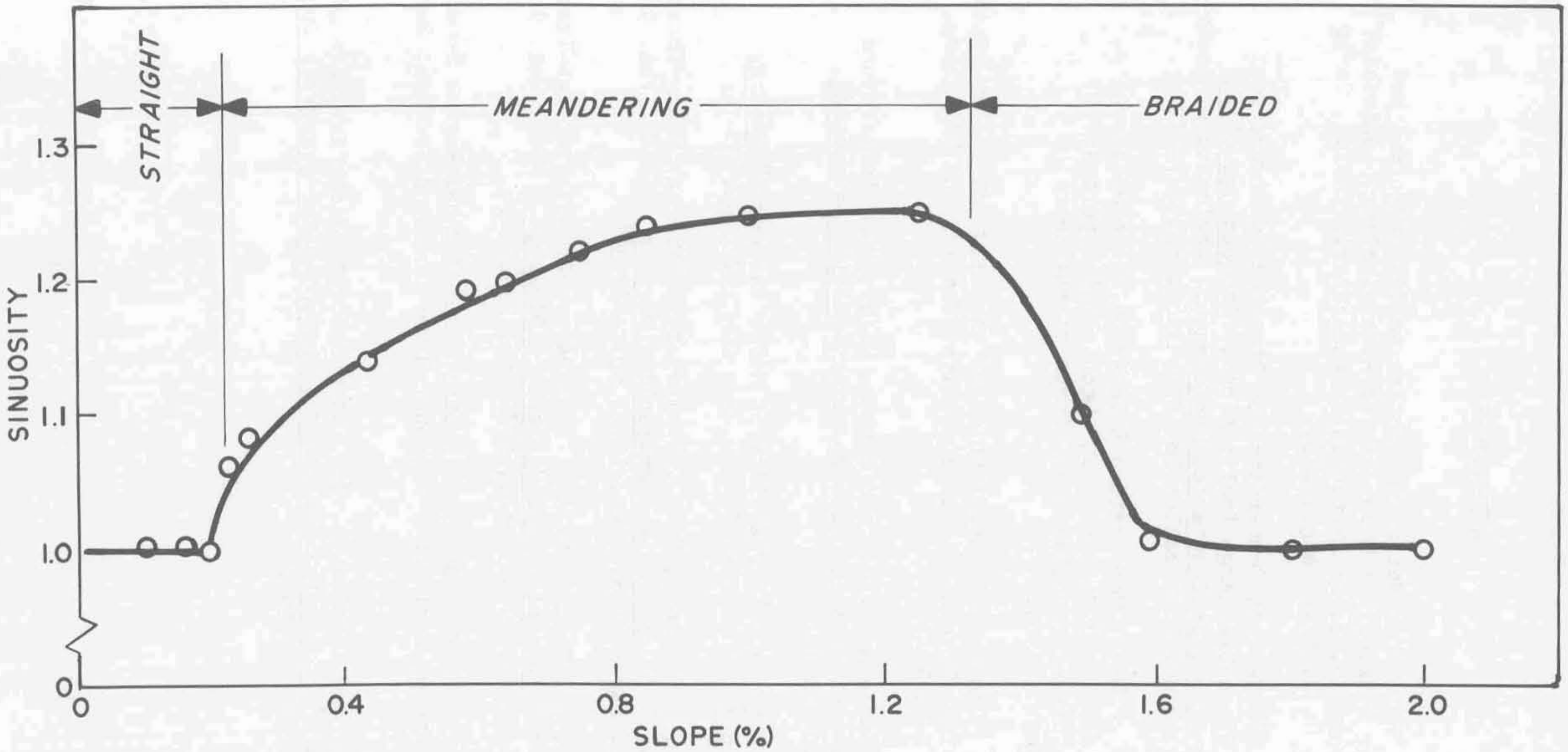


FIG. 1 RELATION BETWEEN VALLEY SLOPE AND SINUOSITY (RATIO OF CHANNEL LENGTH TO VALLEY LENGTH OR RATIO OF VALLEY SLOPE TO STREAM GRADIENT). FROM EXPERIMENTAL STUDIES DONE AT COLORADO STATE UNIVERSITY BY SCHUMM AND KHAN, 1971

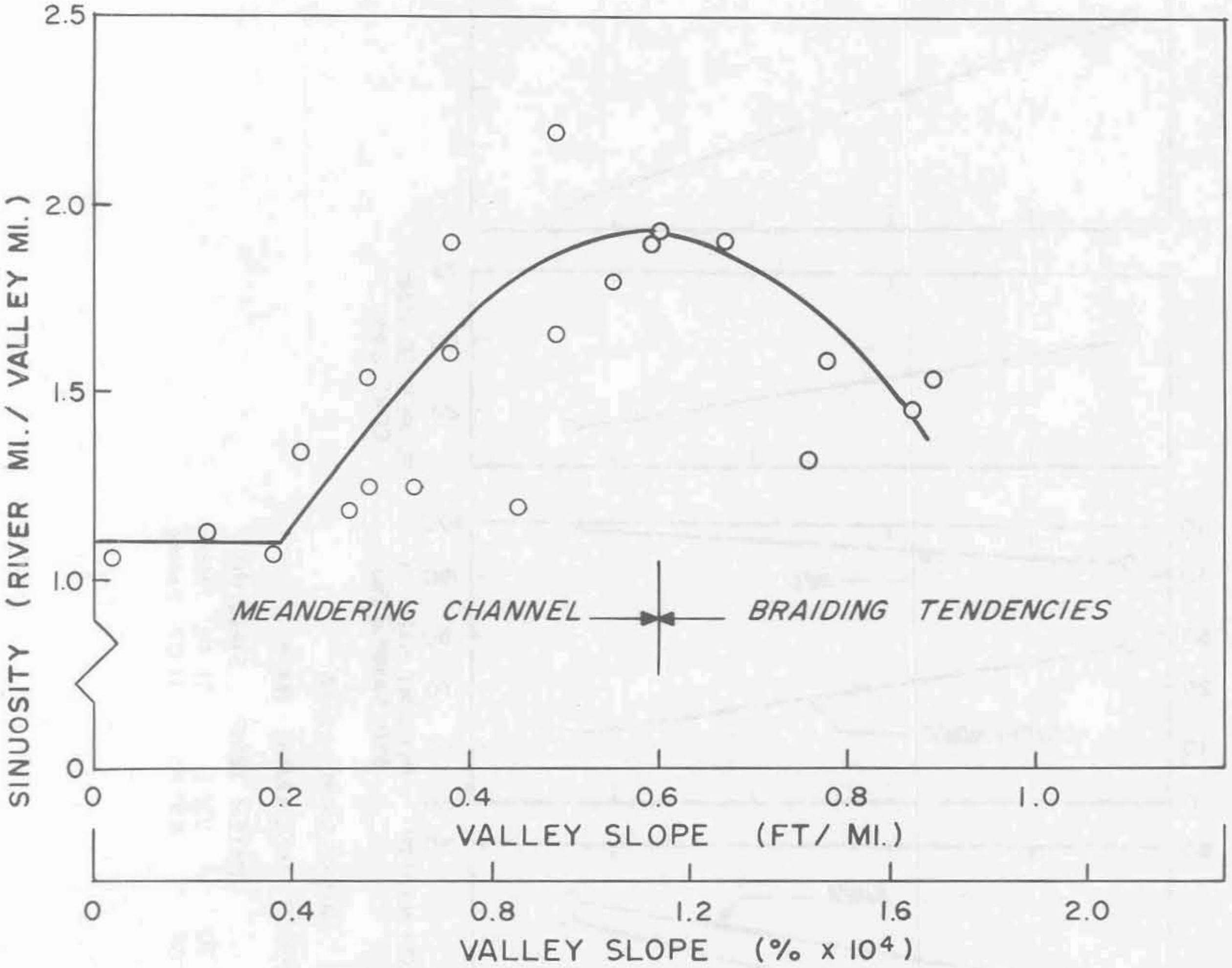
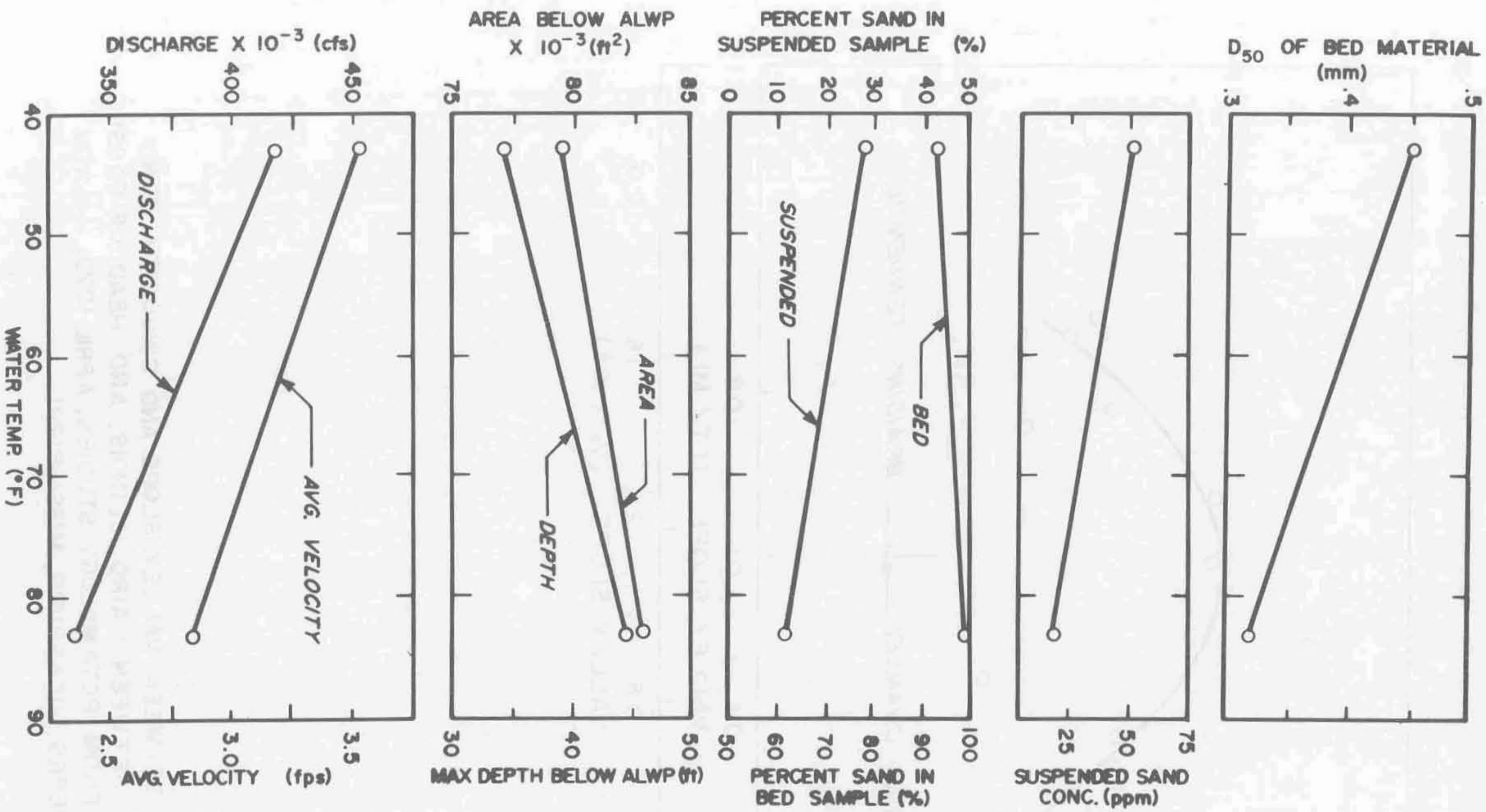


FIG. 2 RELATION BETWEEN VALLEY SLOPE AND SINUOSITY FOR MISSISSIPPI RIVER BETWEEN CAIRO, ILLINOIS, AND HEAD OF PASSES, LOUISIANA. DATA FROM POTAMOLOGY STUDIES, APRIL 1970, U.S. ARMY CORPS OF ENGINEERS, VICKSBURG, MISSISSIPPI



MISSISSIPPI RIVER

CHICOT DISCHARGE RANGE

DATE	WATER TEMP	STAGE (ft)
13 JULY 70	83° F	11.48 Falling
20 DEC 68	43° F	11.87 Falling

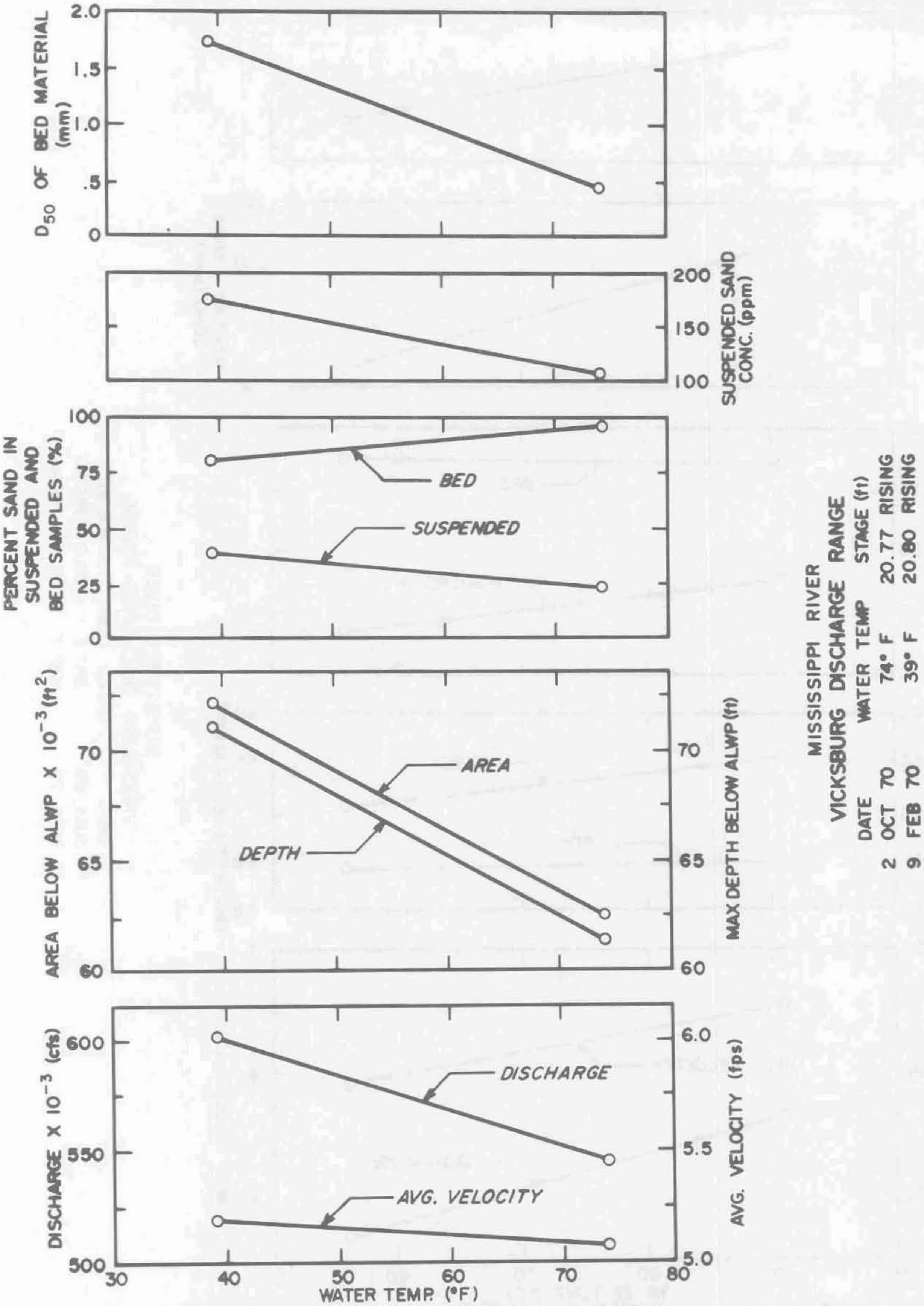


FIG. 4 WATER TEMPERATURE EFFECTS ON THE LOWER MISSISSIPPI RIVER, VICKSBURG DISTRICT

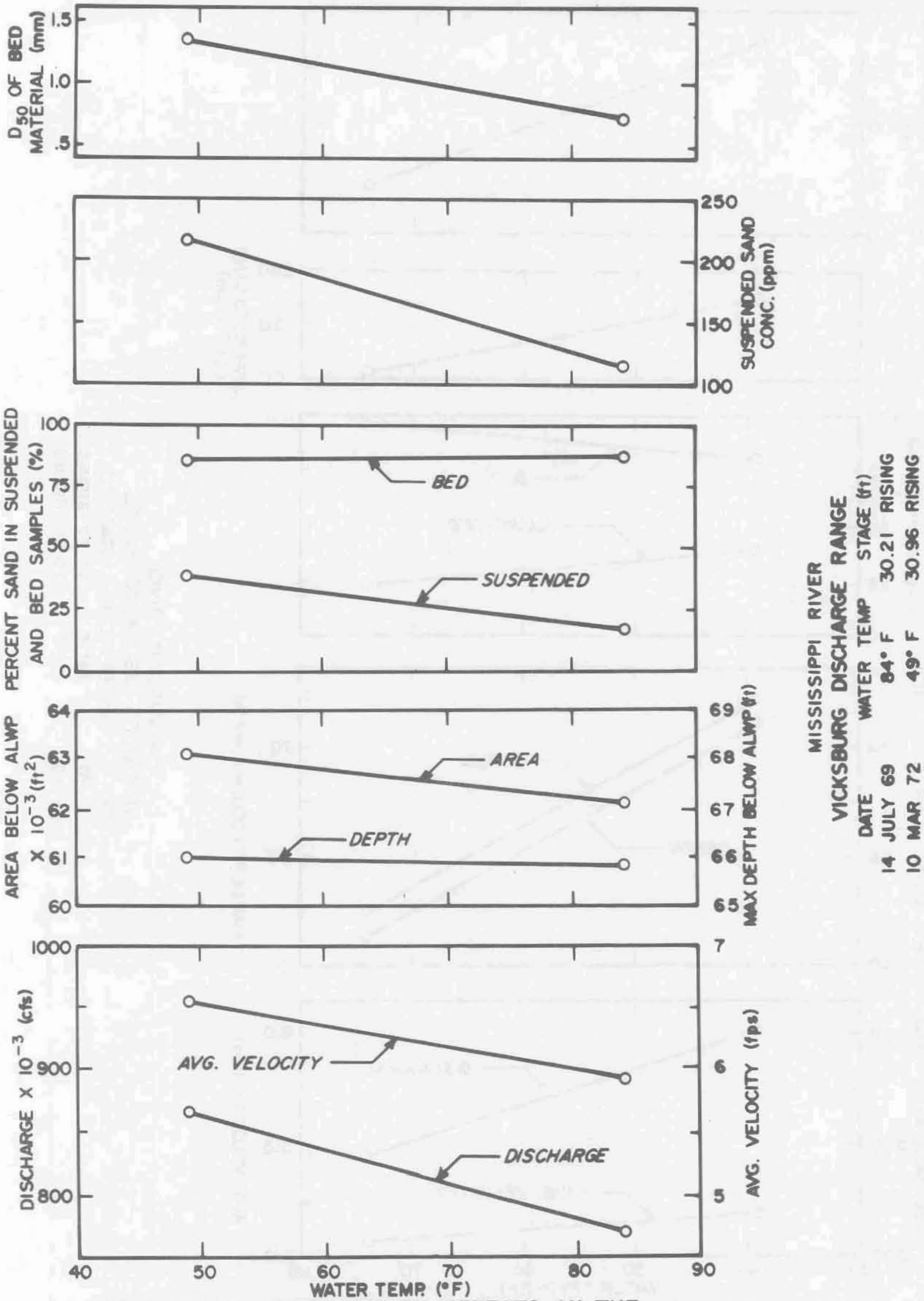


FIG. 5 WATER TEMPERATURE EFFECTS ON THE LOWER MISSISSIPPI RIVER, VICKSBURG DISTRICT