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EFFECT OF TEMPERATURE ON SEDIMENT TRANSPORTATION

by

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Considerable evidence has accumulated indicating that temperature exerts a material effect on the transportation of sediment by flowing water. Perhaps the most striking indication is in the record of sediment discharge above the Imperial Dam, a Bureau of Reclamation structure on the Lower Colorado River, which was called to the writers' attention by Roy E. Goss, Hydrographer, United States Bureau of Reclamation, Yuma, Arizona. These data indicate that a much larger load of sediment is carried by the river during the winter than during the summer for approximately the same flow. Since the only apparent explanation for the quantitative difference of sediment discharge at these two periods of the year is the variation of temperature of the water, this phenomenon initiated a general inquiry into the probable effect of temperature on the transportation of sediment in flowing streams.

The results of the sediment observations are shown on Figure 1, which gives the water discharge, water temperature, sediment concentration and sediment load at the Taylors Ferry sediment sampling station on the Colorado River from 1943 to 1947, inclusive. These data were collected by the Office of River Control, United States Bureau of Reclamation, Boulder City, Nevada, under the direction of C. P. Vetter. It will be noted that for a given discharge, the sediment load may be as much as 2-1/2 times as great in winter as in summer. The conditions in this reach of the Lower Colorado

River are exceptionally favorable to indicating any effect temperature may have, as the number of variables which might affect the sediment load is much less than in most rivers. This station is located downstream from Lake Meade and Lake Havasu, in which the sediment coming down the Colorado is deposited, and clear water is discharged from them. Because of the regulating effect of these two reservoirs, the flow of the river is unusually uniform. There is very little local inflow between Lake Havasu and Taylors Ferry and the sediment carried by the river is almost entirely picked up from the streambed. Approximately 70 percent of this load is composed of fine and very fine sand. This stream is therefore much freer than most streams from great fluctuations of water discharge and of load of sediment brought into it by tributaries. Because of the relatively constant conditions, the effect of temperature would be much more apparent than in an ordinary stream.

It will be noticed that although the sediment concentration fluctuates, being generally larger in winter than in summer, there is distinct tendency of the sediment concentration and sediment discharge to become smaller with the passage of time. This is due to the gradual coarsening of the riverbed from which the load is picked up. Size analysis of the bed and suspended sediments showed that they gradually became coarser, as shown on Figures 2 and 3, respectively. As the bed became coarser, the water was not able to pick up as large a load as before, but the particle size of the material that it did pick up was coarser. The principal changes in sediment load were therefore due to the changes of water discharge, the coarsening of the bed, the changes of temperature of the water, and possibly some other unknown cause which fluctuates with the seasons and may be wholly or partly the effect of temperature.

An attempt was made to compute the magnitude of the fluctuations assumed to be due to temperature, by eliminating the effect of the variation of water flow and streambed coarsening. The first step was to eliminate the effect of water discharge. From many observations it has been found that the sediment load in natural streams varies roughly as the square of the discharge. This was expressed by an equation $Q_s = K_a Q_w^2$, where Q_s is the sediment load in tons per day, K_a is a constant and Q_w is the water discharge in second-feet. The values of K_a were found for all the sediment observations and plotted against calendar time as indicated on Figure 4. This shows approximately what the relative magnitude of the sediment load would have been had the discharge been uniform. An average line A-B was then drawn through the values of K_a, sloping gradually downward to indicate the approximate variation which the value of K_a would have had if temperature fluctuations had not been present. The slope of the line and the lower values of K_a represented by it, are due to the coarsening of the bed as time went on. The ratio of the values of K_a as computed from the observed data to the value of K_o obtained from this average line should give a comparison of the magnitude of the fluctuations due to temperature. The magnitude of the ratio of the fluctuating K_a value to the gradually changing K_o value of the average line was plotted against the water temperature at the time of observation, with the result given on Figure 4. This shows that the ratio decreased with increasing temperature at a rate sufficient to make the average load at the time of lowest temperature about 2-1/2 times the average load at the time of highest temperature.

It will thus be seen that whether or not this fluctuation is due to temperature, it is of so large a magnitude that its cause must be determined if accurate analyses are to be made of many sediment actions in the Lower Colorado River, and other similar streams. The sediment load shown on Figure 1 is the total load carried by the stream. Computations were carried out to determine whether the effect of this cause was the same on particles of different sizes. The total load was broken into four parts, each part composed of particles of a small size range, the four parts covering the entire range of sizes carried, which was from 0.044 mm to 0.589mm. The load in each size range was analyzed in the same way as previously described for the total load. For sizes from 0.044mm to 0.295mm the temperature effect seemed to be very close to that shown on Figure 4. For the size 0.295mm to 0.589mm the change with temperature was negligible.

The results shown by the 1943 to 1947 data were confirmed by the records collected at Red Cloud Cable, Taylors Ferry and Imperial Damsite for the years 1935 to 1942, inclusive. During 1935-1942 the sediment load and water discharge were determined by measurement, but the water temperature was not recorded. In preparing these data, a curve of the fluctuation of temperature throughout the year was drawn up by averaging the temperature curves as determined for the years 1943 to 1947. Using the temperature from the average curve for the date on which each measurement was taken, Figure 5 was plotted, in the same manner as used in securing Figure 4. This shows practically the same fluctuation of sediment load with temperature as obtained for years 1943 to 1947, but the scatter of the points was greater, probably because the actual temperatures varied somewhat from the values obtained from the average temperature curve.

The only record of experiments found which dealt with the effect of temperature on the movement of sediment were those of Ho[9], who experimented with the movement of coarse material in a glass-walled flume in Germany. He used water with temperatures ranging from 2° to 45° C, and found very much greater movement of material at the higher temperatures. This effect is just the opposite of that found in the Lower Colorado River, where the movement was greater at lower temperatures. In his analysis of his results, Ho does not allow for the resistance of the sides of his flume. Ho's experiments have been analyzed by Einstein, who found that when this resistance was taken into account, allowing for the effect of temperature on its magnitude, the movement of sediment was practically the same at all temperatures for the same shear on the streambed.

In his studies of the meandering of alluvial rivers, J. F. Friedkin[12] observed that in his models, when the temperature fell below about 60°F, with the coarse sand which he used, riffles tended to form and reduce the amount of sediment transported. If bed load movement is found to increase with temperature while the suspended load decreases with temperature, determination of the quantities of sediment transportation in a natural stream is likely to be very complex.

A study was also made of the effect of temperature on the transportation of sediment as indicated by the various formulae which have been proposed for computing the amount of sediment which would be transported by a stream of flowing water. The formulas of Schoklitsch[5] and Straub[10] do not consider any temperature effects. The bed (material) load formula of Einstein[11]

9/ Numbers refer to references at end of report.

shows a small effect, the load decreasing with decreasing temperature. The magnitude of this effect decreases as the particle size of the material carried increases. The Lane-Kalinski[3] relations for suspended load consider no effect of the temperature on the pickup of material from the bed, but show decreasing transport of the material in suspension, with increasing temperature. This difference is a function of the change of settling rate of the sediment particles with temperature, due to the change of the viscosity of the water. The Kalinski[4] bed-load formula shows a very slight effect of temperature, due to the change of density of the water with temperature.

Since the load of the Lower Colorado River was carried in suspension, the results should be analyzed as a problem in suspended load movement. The fluid mechanics of this phenomenon is now fairly well understood as regards the transportation of the sediment particles after they have been raised from the bed into suspension by the effect of the turbulence of the water, but a satisfactory analysis of the raising of the particles from the bed to combine with this transportation in suspension has not yet been worked out. The effect of temperature on the transportation of sediment already in suspension is due to its effect on particle settling rate, as mentioned above, but the magnitude of these effects are much less than those indicated by the Lower Colorado River observations. Since the temperature effects on transportation of sediment already in suspension are of lesser magnitude, it follows that most of the effect of temperature observed in the Colorado River observations is due to the picking up of the material from the streambed.

The study described herein was part of an investigation of the control of sediment in the Middle Rio Grande, initiated by the Sedimentation Subcommittee of the Federal Interagency River Basin Committee. The study was carried out under the direction of J. E. Warnock, head of the Bureau of Reclamation's hydraulic laboratories, Research and Geology Division, Branch of Design and Construction, in Denver, Colorado. L. N. McClellan and R. F. Blanks are heads of the branch and division, respectively.

REFERENCES

1. Bureau of Reclamation, Report No. 5-15.1-2, "Plan for Development, Middle Rio Grande Project, Rio Grande Basin, New Mexico."

2. E. W. Lane, Report of the Subcommittee on Sediment Terminology, Transactions, American Geophysical Union, December 1947, p. 936.

3. E. W. Lane and A. A. Kalinski, "The Relation of Suspended to Bed Material in Rivers," Transactions, American Geophysical Union, pp. 637-41, 1939, and E. W. Lane and A. A. Kalinski, "Engineering Calculations of Suspended Sediment," Transactions, American Geophysical Union, pp. 603-607, 1941.

4. A. A. Kalinski, "Movement of Sediment as Bed Load in Rivers," Transactions, American Geophysical Union, pp. 615-620, 1947.

5. Samuel Shultis and W. E. Corfitzen, "Bed Load Transportation and the Stable Channel Problem," Transactions, American Geophysical Union, p. 457, 1937.

6. Stafford C. Happ, "Sediments in the Middle Rio Grande Valley, New Mexico," Geologist Soil Conservation Service.

7. J. R. Freeman, "Flood Problems in China," Transactions, A.S.C.E., Vol. 85, 1922, pp. 1435-1441.

8. F. E. Holmquist, "Behavior of Debris--Carrying Rivers in Flood,"

9. Ho, Pang-Yung, Abhengigheit der Geschiebebewegung von der Kornform und der Temperature, Mitteilungen der Preubischen Versuchsanstalt fur Wasser, Erd-und Schiffbau, Berlin, 1939

10. L. G. Straub, "Hydraulic and Sedimentary Characteristics of Rivers," Transactions, American Geophysical Union, p. 375-382, 1932.

11. H. A. Einstein, "Formulas for the Transportation of Bed Load," Transactions, A.S.C.E., 1942, p. 561-597.

12. J. F. Friedkin, "A Laboratory Study of the Meandering of Alluvial Rivers," U. S. Waterways Experiment Station, Vicksburg, Miss. p. 28.