Low Temperature Increases Sediment Transportation in Colorado River

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

Results of the observations are shown in Fig. 1, which gives the water discharge, water temperature, sediment concentration and sediment load at the Taylor's Ferry sediment sampling station (Fig. 2) on the Colorado River from 1943 to 1947, inclusive. These data were collected by the Office of River Control, U.S. Bureau of Reclamation, Boulder City, Nev., under the direction of C. P. Vetter, M. ASCE. 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 for indicating any effect temperature may have, as the number of variables that might effect the sediment load is much less than in most rivers.

Sampling Station Well Situated

The sampling station is located downstream from Lake Mead (behind Hoover Dam) and Lake Havasu (behind Parker Dam), in which the sediment coming down the Colorado is deposited, so that the discharge is clear. 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 Taylor's 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. The river is therefore much freer than most streams from great fluctuations in water discharge and in load of sediment brought into it by tributaries. Because of the relatively constant conditions, the effect of temperature is 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 for the sediment concentration and sediment discharge to become smaller with the passage of time. This tendency is due to the gradual coarsening of the river bed from which the load is picked up. Size analyses of the bed and suspended sediments show that they have gradually become coarser, and as the bed has become coarser, the water has been unable to pick up as large a load as before, but the particle size of the material which it does pick up is coarser. The principal changes in sediment load are therefore due to changes in amount of water discharge, coarsening of the bed, changes in water temperature and possibly some other unknown cause which fluctuates with the seasons and may be wholly or partly the effect of temperature.

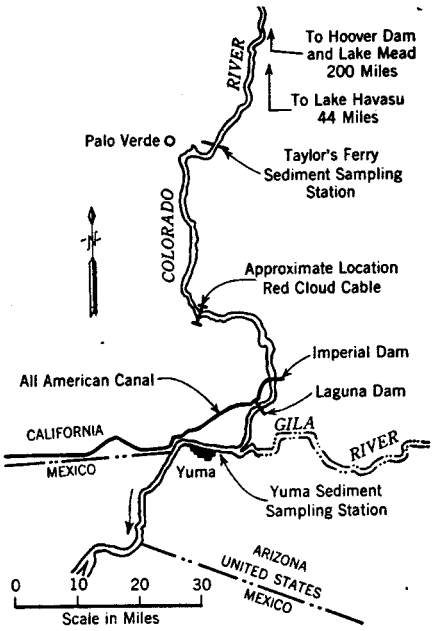

FIG. 2. LOCATION of Taylor's Ferry sediment sampling station on Colorado River is exceptionally favorable for showing effect of water temperature on amount of sediment carried in suspension. Sediment in reach is almost entirely picked up by river from its own streambed, as load from upstream has been settled out in Lakes Mead and Havasu. Regulation of upstream reservoirs gives constant flow and there is very little local inflow from tributaries.

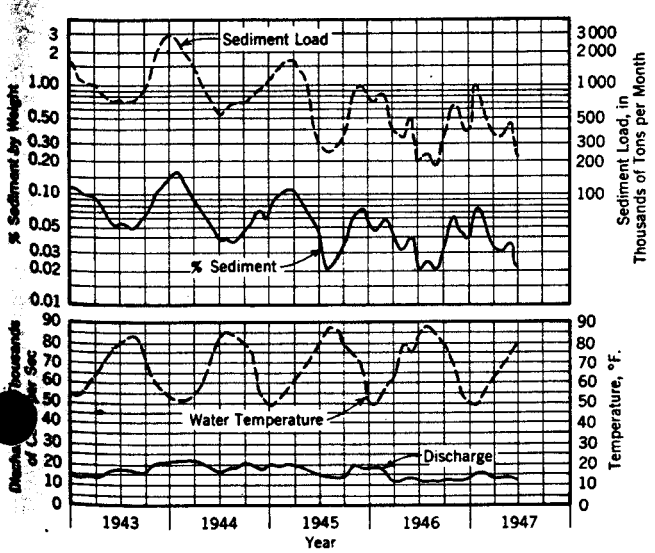

FIG. 1. Correlated and plotted measurements of sediment load, water temperature and river discharge at Taylor's Ferry Station on Colorado River show that sediment load increases as temperature of water falls. For a given discharge, sediment in suspension may be $2^1/_2$ times as great in winter as in summer.

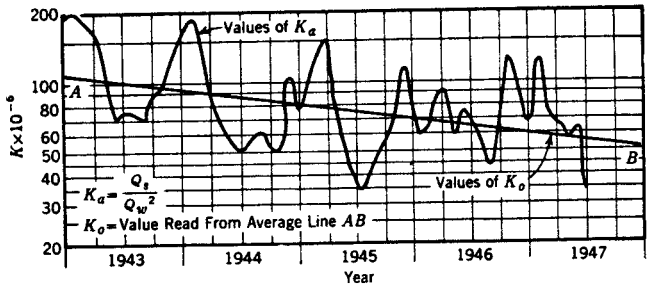

FIG. 3. RELATIVE MAGNITUDE of sediment load had discharge been uniform is shown by plotting values of constant K_a (found for all sediment observations) against calendar time. Slope of line is due to coarsening of bed with passage of time.

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 fact is expressed by the equation $Q_s = K_a Q_w^2$, in which Q_s is the sed ment load in tons per day, K_a is a constant, and Q_w is the water discharge in cubic feet per second. The values of K_a were found for all the sediment observations and plotted against calendar time. The resulting graph, Fig. 3, shows approximately what the relative magnitude of the sediment load would have been had the discharge been uniform.

An average line, AB, 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 goes on. The ratio of the values of K_a (as computed from the observed data) to the value of K_0 (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_0 value of the average line was plotted against the water temperature at the time of observation, with the result given in Fig. 4. This figure 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 in Fig. 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 0.589 mm. The load in each size range was analyzed in the same way as previously described for the total load. For sizes from 0.044 mm to 0.295 mm the temperature effect seemed very close to that shown in Fig. 4. For the size 0.295 mm to 0.589 mm, the change with temperature was negligible.

This analysis shows that the change in load due to temperature change occurred almost entirely in sediment of sizes smaller than 0.3 mm.

The results shown by the 1943 to 1947 data were confirmed by the records collected at Red Cloud Cable, Taylor's 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. This curve showed practically the same fluctuation of sediment load with temperature as obtained for the 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.

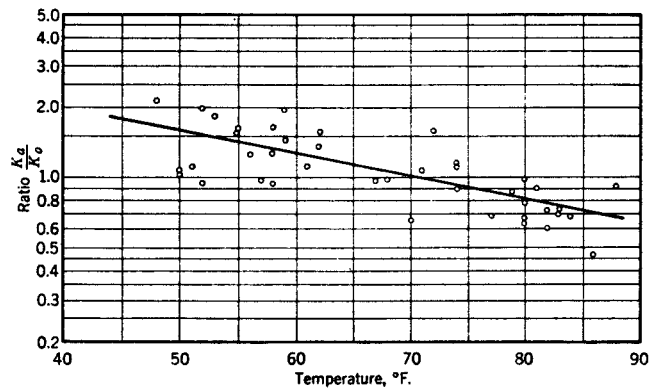

FIG. 4. SUSPENDED LOAD carried by Colorado River varies inversely with temperature of water, according to data collected at Taylor's Ferry sampling station during period 1943–1947. Graph was prepared by plotting ratio K_a/K_0 from Fig. 3 against water temperature as determined at time of observation.

Problem in Movement of Suspended Load

Since most of the sediment load of the Lower Colorado River is carried in suspension, the results should be analyzed as a problem in the movement of suspended load. 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 turbulence, 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, but the magnitude of these effects is much less than of 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 rate of picking up of material from the streambed.

The sediment study here described 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, M. ASCE, head of the Bureau of Reclamation's Hydraulic Laboratories, Research and Geology Division, Branch of Design and Construction, in Denver, Colo. R. F. Blanks, M. ASCE, is head of the Division, and L. N. McClellan, M. ASCE, is chief engineer of the Bureau of Reclamation and Director of the Branch of Design and Construction.