EXPERIMENTS ON THE INFLUENCE OF TEMPERATURE ON THE SEDIMENT LOAD

By

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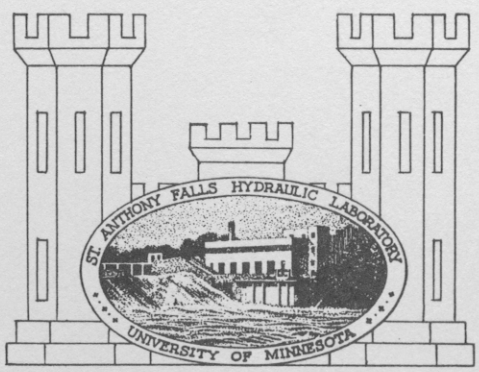

JANUARY 1958

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ST. ANTHONY FALLS HYDRAULIC LABORATORY
Minneapolis, Minnesota
in cooperation
with

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
OMAHA, NEBRASKA

M. R. D. Sediment Series No. 10

PREFACE

A study has been made under previous sponsorship of the Missouri River Division of the Corps of Engineers to determine transportation characteristics of Missouri River sediment (Contract DA-25-075-eng-437), the results of which were reported in April 1954 [1]*. This study was made at a time when the senior author was serving as a member of the Board of Consultants to the Division to investigate "Effects of Channel Stabilization and Navigation Projects upon Missouri River Water Levels." The physical data compiled in this Missouri River water-levels study seemed to present evidence of water temperature influence upon sediment transportation ability of the Missouri River. There was evidence of degradation of the stream bed during cold-water cycles, particularly when associated with high rates of stream flow. Some exploratory experimental studies were therefore undertaken to obtain qualitative information of the temperature effect upon the ability of flowing water to transport Missouri River sediment in suspension. These laboratory tests then reported [1] showed marked influence of the temperature upon suspended-sediment transportation.

Further studies were therefore undertaken with more particular reference to temperature influence and are here reported as agreed under Contract No. DA-25-075-eng-3876.

In the earlier exploratory studies no attempt was made to measure the total solid load transported by the flowing stream, while in the study now reported herein, provision was made to measure the total load of the stream as well as separately the suspended load. For these experiments, as in the earlier tests, the sediment used was obtained from the bed of the Missouri River near the site of the Garrison Dam and is typical of the bed material of the middle Missouri River. The tests were made in a recirculating channel particularly designed for this purpose. Water and sediment were recirculated through the system with the discharge held constant while the water temperature was varied over a range of 35 F to 85 F to correspond approximately to the usual annual temperature range of the Missouri River. The total sediment load and the suspended load were both measured for each

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*Numbers in brackets refer to corresponding numbers in the List of References on p. 15.

of the various temperature conditions. The results were in agreement with the earlier tests showing a wide range of suspended sediment load with changes in water temperature and supplied additional information by aid of the instrumentation introduced for measuring the total sediment load.

The experiments were performed at the St. Anthony Falls Hydraulic Laboratory under the supervision of Lorenz G. Straub, Director. Tests were performed by Gordon H. Flammer; Zal S. Tarapore assisted with analysis of the data; Alvin G. Anderson aided greatly in the analysis of the data and the preparation of this report. Others of the Laboratory staff also contributed to the study, the setting up of apparatus, and the production of this report.

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I. INTRODUCTION

The bed of the Missouri River consists primarily of fine sand with varying amounts of other sediment size grades of sand, silt, and some clay. The total sediment load is transported predominately by suspension in the turbulently flowing water. The mechanism whereby the sediment is dispersed throughout the flowing stream is much the same as in other diffusion processes; that is, for equilibrium conditions a balance exists between the factors that cause the dispersion and those that resist it. These factors are the turbulence of the flow tending to distribute the sediment uniformly throughout the depth of the stream and the force of gravity tending to settle out all suspended materials.

The influence of temperature upon the ability of the flow to transport sediment in suspension is evident from the following considerations. If for any reason either the pattern or intensity of turbulence is changed or the effect of gravity is changed, readjustment in the concentration of suspended sediment is to be anticipated. The most directly measurable index of the ability of the force of gravity to settle out a particle is the terminal velocity of fall of the particle in still water. In case the particle size normally found in the bed of the flowing stream is that of sand particles finer than about 1 mm, the fall velocity is a function of the viscosity of the water as well as of the shape, size, and density of the particle. The viscosity in turn is dependent upon the temperature of the water. At normal river water temperatures, particularly in the colder temperature range, a temperature change of the order of 20 F is associated with a viscosity change of the order of 20 per cent. Such a change in viscosity has a very strong influence upon the sedimentation rate of particles of sizes in the range of 1/16 to 1/2 mm diameter, a size range which predominates in the Missouri River bed.

Typical of the foregoing effect in the case of sediment transportation in suspension by the Missouri River is the evidence from the following tabulation compiled in a previous report [2] and extracted here. The temperature influences described have also been summarized elsewhere [3].

TYPICAL GRADES OF SEDIMENT TRANSPORTED IN SUSPENSION
BY THE MISSOURI RIVER PAST KANSAS CITY

Season & Date	Water Discharge cfs	Total Suspended Sediment Content in Water	Total Silt & Clay < 1/16 mm		Total Sand > 1/16 mm	
			Content in ppm	% of total	Content in ppm	% of total
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Winter						
Jan. 3, 1930	22,200	1240	396	31.9	844	68.1
Feb. 11, 1930	34,800	2630	1690	64.2	940	35.8
Late Spring						
Apr. 15, 1930	67,200	4270	3660	85.7	610	14.3
Apr. 22, 1930	50,500	2690	2020	74.9	670	25.1

It will be noted that despite lower water discharges (with consequent lower velocities and lower turbulence) in the winter than in the late spring, the concentration of coarse materials transported in suspension is appreciably greater in the winter than in the spring. For example, note the higher sand content (Column 6 in tabulation) in suspension in winter as compared to late spring. This shows the influence of the lower temperature and higher viscosity upon raising the sediment transportation ability of the river during cold-water flows. The high amounts of fine material of silt and clay categories in the late spring (Column 4) is due to the contribution of silt and clay in water from surface runoff from the tributary drainage area.

The effect of temperature upon character and amount of suspended load has also been noted by the senior author in connection with the review of data from extensive observations on the Missouri River. For example, other things being equal, it appears that during prolonged periods of cold-water flow, there is a strong tendency toward degradation of the stream bed. Conversely, aggradation tendency is evident when the mean temperature over a long period of time is higher than normal. These effects, of course, are not immediately observable but require long periods to be measurable and are difficult to segregate sharply from other influences upon the river regimen. The temperature influence has also been called to attention qualitatively by others, reported more specifically for the Colorado River [4].

The experiments described in the present report were directed toward an investigation of the effect of temperature on the sediment load under conditions

of constant discharge and a temperature range between the limits of 35 F and 85 F. The apparatus was so mechanized that the sediment and water could be recirculated at predetermined, controlled temperatures in such a way that the total load transported could be related to the temperature.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

A. Experimental Apparatus

1. Recirculating Channel

The channel used for these tests was 60 ft long by 1 ft wide and was equipped with a pump and a 4-in. return pipe to form a recirculating system (Figs. 1 and 2). The sides were of painted steel except for a 5-ft glass section from Station 38 to 43 which permitted observation of sediment motion and character of the bed (Fig. 3). The bed material had an average depth of 0.5 ft of Missouri River sediment which was originally obtained from the river bed near the Garrison Dam. Figure 4 shows the size distribution of this sand. A Venturi meter in the return line was fitted to indicate the rate of discharge. Temperature control was effected by thermostatically controlled refrigeration coils in the head and tailwater boxes (Fig. 5). The temperature could be maintained at any temperature from 34.5 F to 90 F to within ±2 F. A carriage, mounted on horizontal rails, straddled the channel and served as a datum for point-gage measurements of the water surface as well as bed-elevation measurements by a disk gage (Fig. 6). The gage verniers could be read to the nearest 0.001 ft. Water-surface elevations at each 5-ft station were also indicated by a piezometer bank mounted on the side of the channel.

2. Suspended-Load Measurement Equipment

The suspended-load measuring apparatus was mounted on the carriage (Fig. 6). It consisted of a 1/4-in. diameter siphon withdrawal tube having a Venturi meter in the line for measurement and control of the withdrawal rate. On either side of the sample tube a static- and stagnation-pressure tube was mounted (Fig. 7). These were used to measure the velocity in the immediate vicinity of the sample tube tip. After measuring the velocity, the flow rate through the tip was adjusted so the entrance velocity equaled the stream velocity—this being a necessary requisite for obtaining an