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SUSPENDED SEDIMENT EFFECT ON FLOW RESISTANCE

by

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Canada

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ABSTRACT

A general velocity distribution consisting of a logarithmic profile plus a wake function has been used to investigate the effect of suspended sediment on flow resistance. From the experimental evidence that the wake constant increases when sediment is in suspension, it is shown that flow resistance must be reduced.

RÉSUMÉ

On s'est basé sur une distribution générale des vitesses composée d'un profil logarithmique et d'une fonction de sillage pour étudier l'effet des sédiments en suspension sur la résistance à l'écoulement. A partir de la preuve expérimentale de l'augmentation de la constante de sillage en présence de sédiments en suspension, on montre que la résistance à l'écoulement doit diminuer.

MANAGEMENT PERSPECTIVE

Flow in natural channels is often subject to changes in sediment load.

Understanding and modelling flows in sediment laden rivers is greatly improved if the resistance to flow is established. In addition, river slopes are influenced by sediment loading which may be critical during high flows with respect to flood levels.

This report analyses the available theories and data and concludes that flow resistance is reduced by sediment in suspension. Experiments are required to establish quantitative relationships.

T. Milne Dick
Chief, Hydraulics Division
April 1, 1982

PERSPECTIVE DE GESTION

L'écoulement dans les canaux naturels est souvent soumis à des variations de la charge sédimentaire.

La compréhension des écoulements dans les rivières chargées de sédiments et leur modélisation sont grandement facilitées lorsque la résistance à l'écoulement est établie. De plus, les pentes des rivières varient en fonction de la charge sédimentaire qui peut être critique pour les niveaux de crue pendant les périodes de débit élevé.

Le présent rapport étudie les théories et données existantes, et conclut que la résistance à l'écoulement est réduite par les sédiments en suspension. Des expériences sont requises pour établir des relations quantitatives.

Chef, Division de l'Hydraulique

T. Milne Dick

1er avril 1982

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SUSPENDED SEDIMENT EFFECT ON FLOW RESISTANCE

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INTRODUCTION

In studies of flow with suspended sediment, the two issues which are often raised are the effects of the suspended sediment on the velocity distribution and the flow resistance. Based on the experimental results of Vanoni (10), Einstein and Chien (3) and Elata and Ippen(4), researchers have generally accepted the view that, as the sediment concentration increases, the von Karman constant, κ, becomes progressively smaller than the clear water value of 0.4. However, this view is not universally endorsed. Imamoto et al. (7) found κ to increase with sediment concentration in his experiments while Fukuoka (5) and Itakura and Kishi (9) suggested that the value of κ does not change. The question of flow resistance is also not completely resolved. Some researchers (9, 11) found that the friction factor was reduced by the presence of suspended sediment while others (7, 8) advocated the opposite effect.

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In a recent article, Coleman (1) analyzed his own data and reexamined the data from earlier experiments to show that the change in κ which was found in earlier investigations was caused by the incorrect application of the logarithmic velocity distribution - to the region where the log law is really not valid. By applying the log law only to the region close to the wall, Coleman found that the presence of suspended sediment had no effect on the value of κ. The velocity distributions were found to conform with the law of the wake which was introduced by Coles (2) for boundary-layer flows.

It appears that Coleman has presented the most convincing argument to date on the effects of suspended sediments on the velocity distribution in open channels. The general velocity profile, given by the logarithmic law plus a wake function, seems to be valid for all of the flow depth outside of the viscous sublayer. In this article, it will be shown how this general velocity distribution leads to certain conclusions regarding the effect of suspended sediment on the flow resistance.

THE VELOCITY DISTRIBUTION

Even though the logarithmic velocity distribution is normally assumed to apply for the whole flow it is, strictly speaking, valid only for the constant stress layer which is a rather thin region close to the wall. Experimental data show that the velocity in boundary layers starts to deviate from the logarithmic distribution at a shear Reynolds number U_*y/ν, between 500 to 1000 (6). U_* is the shear velocity; y is the distance from the wall and ν is the kinematic viscosity. Noting the similarity between the flow in the outer regions of the boundary layer and wake flow, Coles (2) introduced a function to describe the deviation of the velocity from the logarithmic distribution. This function, called the wake function, is zero at the wall and is a maximum at the top of the boundary layer. The general velocity distribution, given by the logarithmic distribution plus the wake function, describes the velocity throughout the whole depth.

Coleman (1) demonstrated that different values of κ were obtained by previous investigators because they fitted the logarithmic distribution to the data for the upper part of the flow, where the logarithmic law is not valid. When the values of κ were determined by an asymtotic fit of the logarithmic distribution to the bottom 10% of the flow, Coleman found that κ remains the same in clear water flow as in flows with suspended sediment. The data fitted the general velocity distribution and the only effect of suspended sediment is to increase the value of the wake parameter Π. Thus the velocity distribution is given by the equation

$$\frac{U}{U_*} = \frac{1}{\kappa} \ln \frac{yU_*}{\nu} + A - \frac{\Delta U}{U_*} + \frac{\Pi}{\kappa} 2 \sin^2 (\frac{\Pi}{2} \frac{y}{h}) \qquad (1)$$

in which A is an integration constant; ΔU is the downshift in the velocity distribution because of wall roughness (6, 12); and h is the boundary layer thickness or flow depth. The last term in Eq. 1 is the wake function.

In Coleman's experiments, the value of Π increased from 0.19 for clear water flow to 0.86 for a flow with average sediment concentration of 5×10^{-3}.

FLOW RESISTANCE

Consider a uniform flow in clear water with a given discharge Q and a given bed slope S. If the discharge and slope are held constant and suspended sediment is introduced, any change in flow resistance will result in a change in the depth of flow. Assuming that the flow resistance is increased, the resulting uniform flow will have a larger depth than before. From Eq. 1 the velocity gradient is given by

$$\frac{dU}{dy} = \frac{U_*}{\kappa}[\frac{1}{y} + \Pi \frac{\pi}{h} \sin (\frac{\pi y}{h})] \qquad (2)$$

regardless of wall roughness. With a larger flow depth, the value of $U_* = (ghS)^{1/2}$ will be larger than before. Therefore, close to the wall, where the sine function is insignificant, the velocity gradient will definitely be larger than for the clear water flow. The velocity at a small distance from the wall should then be larger than in the clear water flow. The increase in velocity gradient is likely to occur throughout the flow because Π/h should also be larger than before - Π has been shown to increase more than four times and the change in flow depth is nowhere close to such magnitude. Hence one has the condition that, if the flow resistance is increased, the depth will be larger and the velocity gradient will also be larger throughout the depth. This is, of course, not possible because the discharge cannot then remain constant.

The same line of reasoning shows that the depth also cannot remain unchanged once Π has increased.

Now assume that the flow resistance is reduced by the presence of suspended sediments. With discharge and slope being held constant, the depth wil be smaller. U_* is therefore reduced. According to Eq. 2 the velocity gradient close to the wall will be smaller than before. However, as one moves away from the wall, the increase in the value of Π/h will make the velocity gradient larger than for the clear water flow. A comparison of the two velocity distributions will appear as shown in Fig. 1. With such a distribtuion, it is possible for the depth to decrease while the discharge remains constant. Thus it is seen that, based on the general velocity distribution given by Eq. 1 and the fact that Π increases with sediment concentration,—the flow resistance must be decreased by the presence of suspended sediment.

Three sets of velocity distributions from the data of Einstein and Chien (3) and Vanoni and Nomicos (11) are presented in Figs. 2 and 3. The discharges and slopes are more or less constant for each set. It can be seen that the changes in the velocity profile when sediment is present do indeed follow the trend shown in Fig. 1.

The same conclusion can be reached when the velocity distribution is integrated to obtain the discharge per unit width, q. For a flow with a smooth wall,

$$\frac{U}{U_*} = \frac{1}{0.4}\ln\frac{yU_*}{\nu} + 5.5 + \frac{\Pi}{0.4}\,2\sin^2\left(\frac{\Pi}{2}\,\frac{y}{h}\right) \tag{3}$$

$$q = \int_o^h U dy = \int_o^h\left[\frac{1}{0.4}\ln\frac{yU_*}{\nu} + 5.5 + \frac{\Pi}{0.4}\,2\sin^2\left(\frac{\Pi}{2}\,\frac{y}{h}\right)\right] dy$$

$$= \frac{U_*h}{0.4}\left[\ln\frac{U_*h}{\nu} + 1.2 + \Pi\right] \tag{4}$$

As Π increases when suspended sediment increases, (U_*h) must decrease in order for q to remain constant. Therefore the depth must decrease, which means that the flow resistance is reduced.

As an example, take a clear water flow with a depth of 10 cm and a uniform slope of 0.0005. According to Eq. 4, with $\Pi = 0.19$, the discharge per unit width is equal to 50 cm^2/s. The maximum value of Π reported by Coleman (1) was 0.86 which occurred when suspension was at near capacity. For this value of Π, Eq. 4 gives the flow depth to be 9.58 cm, a reduction of 0.42 cm. For lesser values of sediment concentration, the change in depth will be less. Therefore the change in flow resistance is not easily detectable in flume experiments unless very careful measurements are made under two-dimensional flow conditions, and with entrance and exit effects eliminated. This may be the reason why Coleman, who kept depth and discharge constant and adjusted the slope,did not find any change in the slope when sediment was introduced.

SUMMARY

Based on the general velocity distribution in Eq. 1 and the experimental evidence presented by Coleman, it is shown that the flow resistance must be decreased by the presence of suspended sediment. Conflicting opinions still exist in the literature and more definitive experiments are required.

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FIGURES

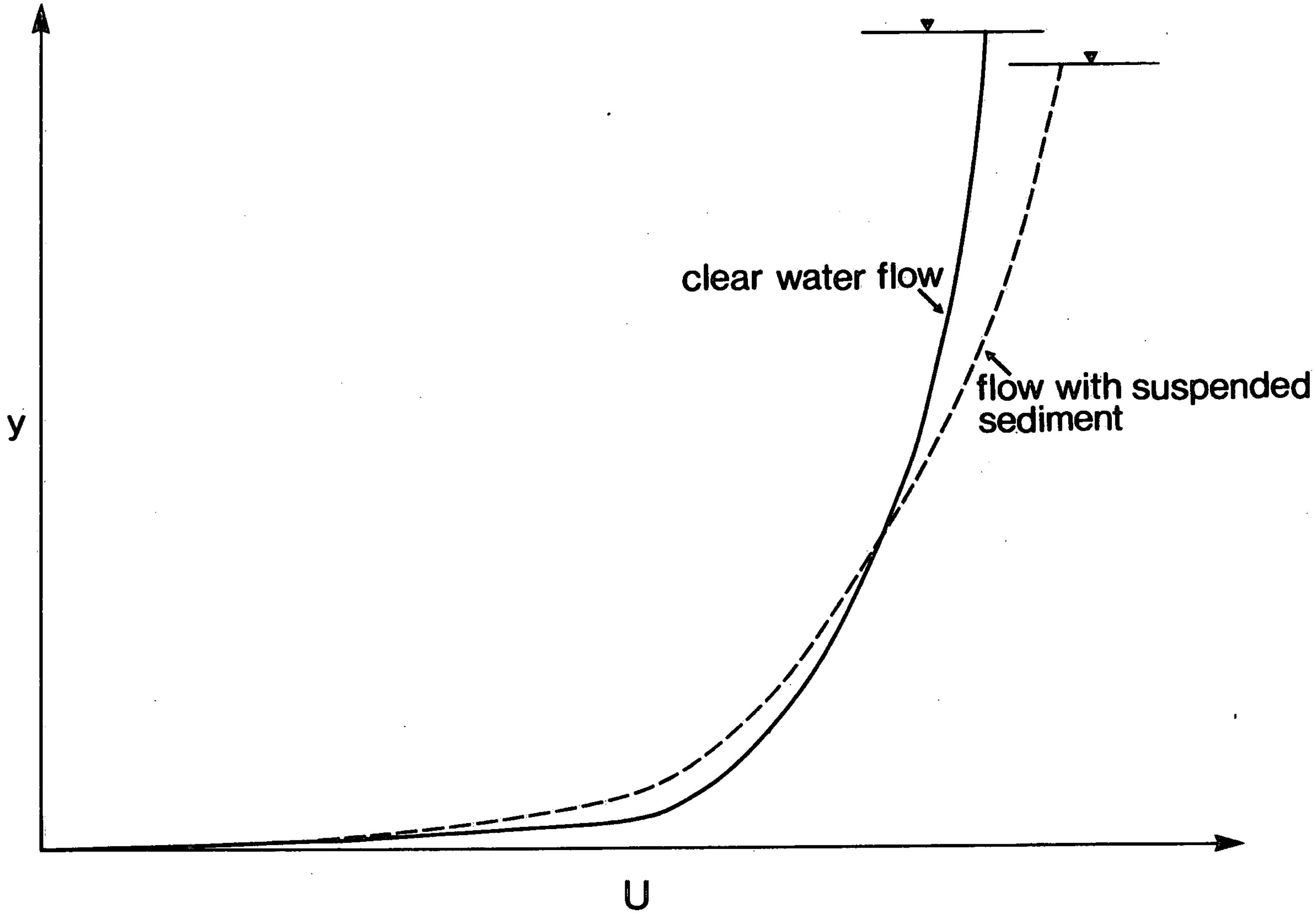

Fig. 1 Velocity Profiles With and Without Suspended Sediments

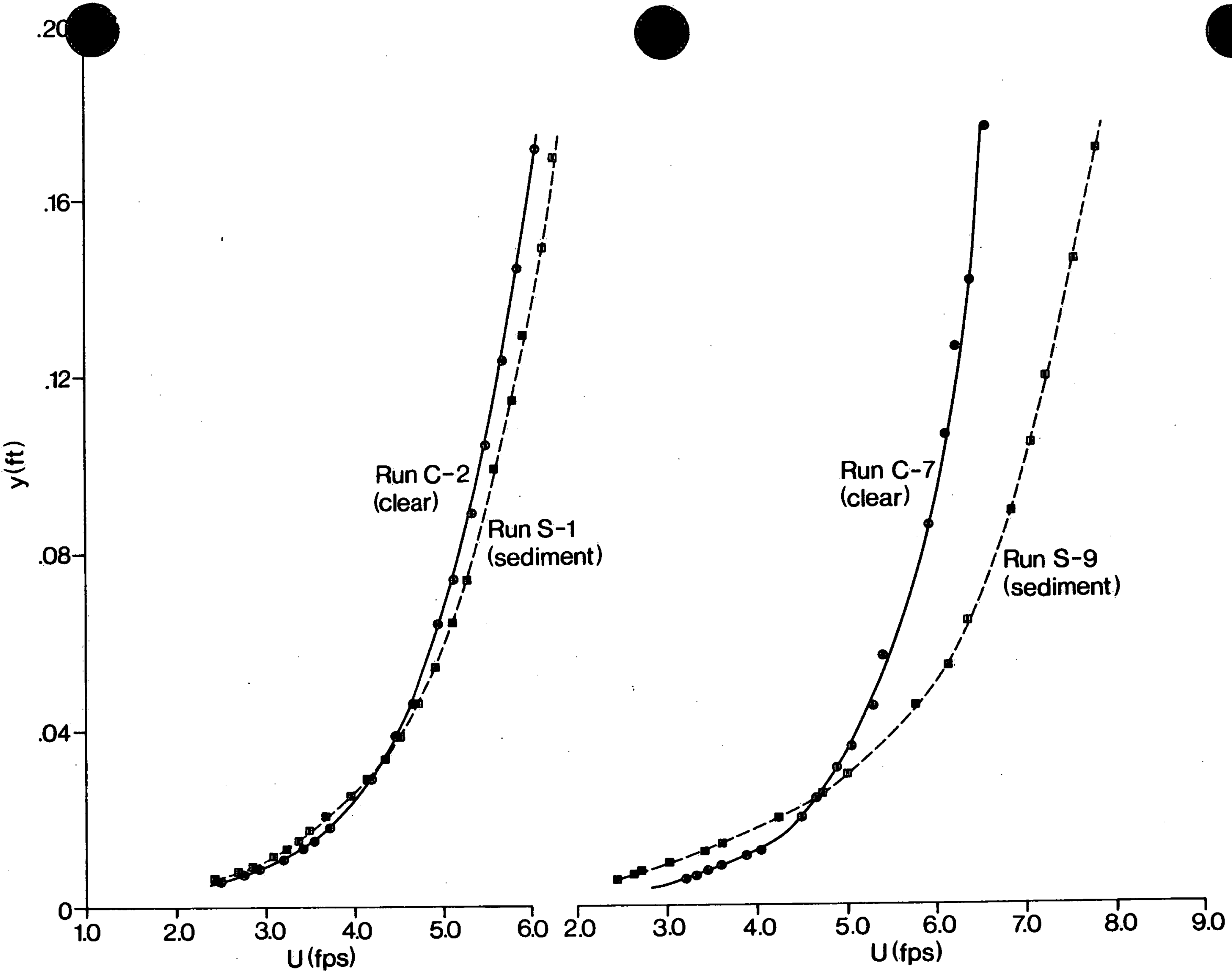

Fig. 2 Velocity Profiles from Einstein and Chien (3)

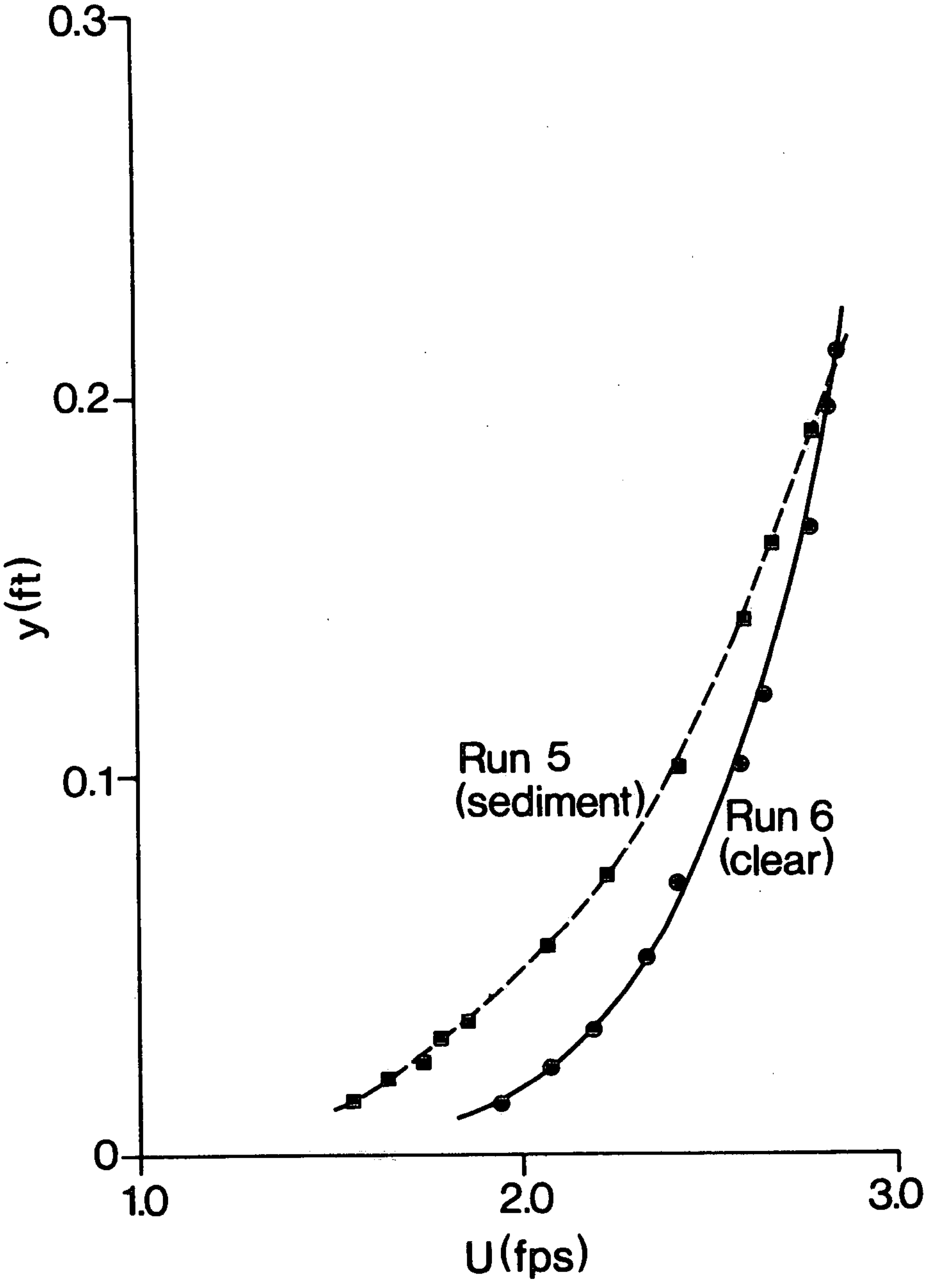

Fig. 3 Velocity Profiles from Vanoni and Nomicos (11)

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