

## **Recent developments in pump samplers for the measurement of sand transport**

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**ABSTRACT** It continues to be the practice of the Hydraulics Research Station to compute suspended sand fluxes in rivers and estuaries from depth profiles of sediment concentration and velocity. The profiles are defined by point measurements using pump samplers and current meters. Special bed frames are described that have been designed to allow reliable positioning of the sampling intake and the current meter with reference to the bed surface. On-site extraction of the sediment is obtained by filtration or by hydrocyclone and the flux of individual size fractions is computed by combining the best-fit profiles of velocity and concentration. Specimen results for river and tidal flow are given.

### Récents progrès dans les pompes pour échantillons en vue de la mesure des transports de sables

**RESUME** Hydraulics Research Station continue à calculer les transports de sable en suspension dans les rivières et estuaires à partir de profils en travers de la concentration en sédiments et de la vitesse. Les profils sont définis par des mesures ponctuelles effectuées à l'aide de pompes d'échantillonnage et de moulinets. Le rapport décrit des châssis spéciaux équipés d'instruments de mesure, posés sur le lit des cours d'eau. Ces châssis ont été conçus pour permettre la mise en place correcte de l'organe de prise d'échantillons, et du moulinet par rapport à la surface du lit. On effectue l'extraction du sédiment sur place par filtrage ou par hydrocyclone, et on calcule le flux des fractions de diverses granulométries combinant les profils de vitesse et de concentration qui s'adaptent le mieux. Le rapport fournit des résultats représentatifs pour les flots de marée et l'écoulement des rivières.

## **INTRODUCTION**

There is a continuing need for the provision of reliable data on sediment transport to guide the hydraulic engineer in his assessment of the effects of sediment mobility on port works, irrigation and drainage networks, water power development, submerged tunnel crossings and other such diverse applications. Notwithstanding the considerable research effort devoted to trying to understand the interaction of sediment movement with its carrier medium and thus open the way to predicting sediment transport from the

measured water flow characteristics, no single formula has gained general acceptance. Indeed the large number of formulae, the variability in their results and in most cases their derivation from experimental studies at shallow water depth provoke uncertainty and lead to relying on the collection of actual field data to underpin our engineering predictions.

The gathering of this information can present difficulties and it is not surprising that a variety of devices have been tried. However, no general purpose tool capable of filling a role equivalent to that played by the impeller current meter in water discharge measurement has emerged. It seems that the measuring instrument must be tailored to a specific area of application. We have focussed on estuaries with fine sand beds because in the UK these pose the greatest questions in response to new works. Water depths of 3-30 m are typical and we put emphasis on sediment sizes of 60-300  $\mu\text{m}$  moving in suspension while transport taking place as bed creep can normally be neglected as constituting only a small proportion of the total sediment load.

## MEASUREMENT METHOD

From a knowledge of the velocity and the concentration of individual size fractions of the suspended sediment at say 10 points over the vertical the sediment flux at each elevation may be defined and then by integration over the water depth the total suspended flux per unit width is computed.

For many years we have relied on the portable pump sampler for measuring suspended sediment concentrations and the present paper reports on its extension in association with a current meter and accurate elevation sensing into a practical tool for determining suspended sand transport. Primarily the developments have been directed at obtaining reliable readings in the near-bed zone where concentration and velocity gradients are steep and the sand flux is at a maximum, and in achieving the recovery of sufficient sediment for size analysis even where concentrations are low.

The refinement of splitting the suspended sediment into separate size fractions brings a two-fold benefit: first for most field applications it allows curve-fitting to the concentration distribution over the water depth; and secondly knowledge of the fluxes of sediment of specific particle sizes is frequently germane to predicting the consequences of new works.

## SAMPLING OF SUSPENDED SOLIDS

Velocity measurements are readily obtained by a simple impeller current meter typical of those used for water discharge gauging. However the choice for sampling the suspended solids concentration is not so clear cut. We favour the use of a pump sampler with its intake mounted alongside the current meter in preference to the more conventional "bottle" sampler. Pumping allows flexibility in the recovered volume as well as extended sampling times for smoothing the high frequency fluctuations in concentration

that are inherent in the movement of sand. In combination with a suitable means of extracting the sediment from the pump delivery, sample volumes of 50 l may be handled with ease and permit a concentration resolution of  $1 \text{ mg l}^{-1}$  on each of five sieved size fractions.

For effective pump sampling a velocity of nearly  $1 \text{ m s}^{-1}$  must be maintained in the pumping line otherwise the sediment is not carried effectively around bends or along any horizontal runs of the hose. A pump discharge of  $12 \text{ l min}^{-1}$  through 16 mm bore hose is found to be adequate for this purpose and is used in conjunction with sampling periods up to 4 min. Flume tests having an intake 100 mm above a rippled sand bed ( $D_{50}$ :  $150 \mu\text{m}$ ) and a steady flow of  $0.62 \text{ m s}^{-1}$  showed that an integration time of 4 min reduced the coefficient of variation of the sampled concentration to 7%. Provided the criterion of having a line velocity of  $1 \text{ m s}^{-1}$  is satisfied there is much inconvenience and little benefit to be gained from any attempt to match the intake velocity with that of the ambient flow. Crickmore & Aked (1975) have demonstrated that at least for sediment diameters up to  $200 \mu\text{m}$  at sampling ratios (intake velocity/ambient velocity) of 0.5-5.0, isokinetic considerations can be ignored and indeed major misalignment between the nozzle intake and the flow direction can be tolerated without serious underestimation of the concentration. For instance, the extreme flow curvature brought about by a  $180^\circ$  misalignment resulted in a sampling deficiency of only 18%.

Internal friction losses require that the bore of the pumping line be kept as large as possible while external loads imposed by the ambient flow require its outside diameter to be held as small as possible. We find that a bore of 16 mm is a reasonable compromise allowing the use of 50 m hose lengths on the suction side of the pump and yet remaining manageable in 10 m-depth flows up to about  $1.8 \text{ m s}^{-1}$ . Stream drag is the most serious limitation to wider applicability of the pump sampler. Operation in faster flows is impractical unless recourse is made to heavy winching arrangements in conjunction with special-purpose combined hose/electrical/strain umbilicals having integral fairing to minimize stream drag.

Having pumped the sediment/water mixture to the boat the sediment has to be extracted from the flow if full advantage is to be gained from the pump sampling technique. The preferred method is simply to pass the pump discharge through a large area filter (140 mm diameter,  $40 \mu\text{m}$  aperture polyester) and separate the solids for subsequent sieve analysis back at the laboratory while the water discharge is metered before going to waste. This works well for clean sand but if the flow has a fine-grained mud component in excess of  $500 \text{ mg l}^{-1}$ , rapid filter blockage prevents the recovery of a time-averaged sample. For these more muddy flows we favour using a hydrocyclone to bring about a reduction in the quantity of the suspension to be returned to the laboratory but without losing a significant part of the sand-sized sediment in the overflow. Kiff (1977) describes a 75 mm diameter aluminium hydrocyclone which performs well provided the flow suspension input is maintained at  $13\text{-}15 \text{ l min}^{-1}$ . It achieves an efficiency of better than 95% in recovering quartz particles in

excess of 60  $\mu\text{m}$  from suspensions containing 1000's  $\text{mg l}^{-1}$  mud. At the same time it reduces a total pumped volume of 50 l to only 2 l of underflow for convenient storage and transport.

## EQUIPMENT

For representative measurement over the entire water column it is normally necessary to employ two different rigs. One is a simple wire-suspended assembly comprising a directional current meter, sampling intake, streamlined weight and associated conductors and hosepipe. The underwater package is equipped with a small high-frequency echo-sounder so that it can be positioned with reference to the bed to sufficient accuracy for readings from the water surface down to about 0.6 m above the bed. However, the lowest 0.6 m of the flow is of course normally the most important to sediment flux measurement and any unit relying on suspension from the surface is too indeterminate in elevation control to be satisfactory here. The need is met by a second category of rig which consists of a support frame lowered to rest on the bed to serve as a stationary reference against which to determine the elevation of the measuring head. Several versions of this type of bottom rig described by Crickmore & Aked (1975) have now been largely superseded by two second-generation frames which we find meet most estuary and river applications.

The new support frames operate on the principle of having a single current meter with associated sampling intake that can be set remotely at any elevation between 0.05 and 0.6 m above the bed.

The simpler of the two is a small unit (Fig. 1) light enough to be handled from small craft and adequate for flows up to about 6 m in depth. The central column is free to slide vertically in its alloy supporting frame, enabling the column's base plate to be lowered to rest on the bed irrespective of the level of the frame's tubular skids. The carrier for the current meter and sampling intake is pivoted about the central column and its height controlled by means of a push-pull Bowdenflex cable operated from the attendant boat. A self-priming deck-mounted 24 V d.c. pump serves to lift the sediment suspension. The Bowdenflex cable acts as a rather inflexible connection between the bed frame and the surface boat with the result that operational scopes are generally limited to no more than 15 m.

The second bed frame is much more elaborate (Fig. 2) and is able to work in water depths of 30 m. It avoids the restriction of a mechanical link between the frame and the boat by having instead an integral reversible 12 V d.c. motor to haul the current meter and sampling intake up-and-down on a chain drive. Downward travel is arrested by a plate mounted beneath the current meter which operates a magnetic reed switch when contact is made with the bed to provide a datum for the setting of subsequent measuring elevations. A micro-switch fitted to the drive motor is used to transmit a pulse to the surface for every 1 mm of vertical travel and enables the height of the measuring head to be set. Two fins on the traversing assembly allow it to adjust to small changes

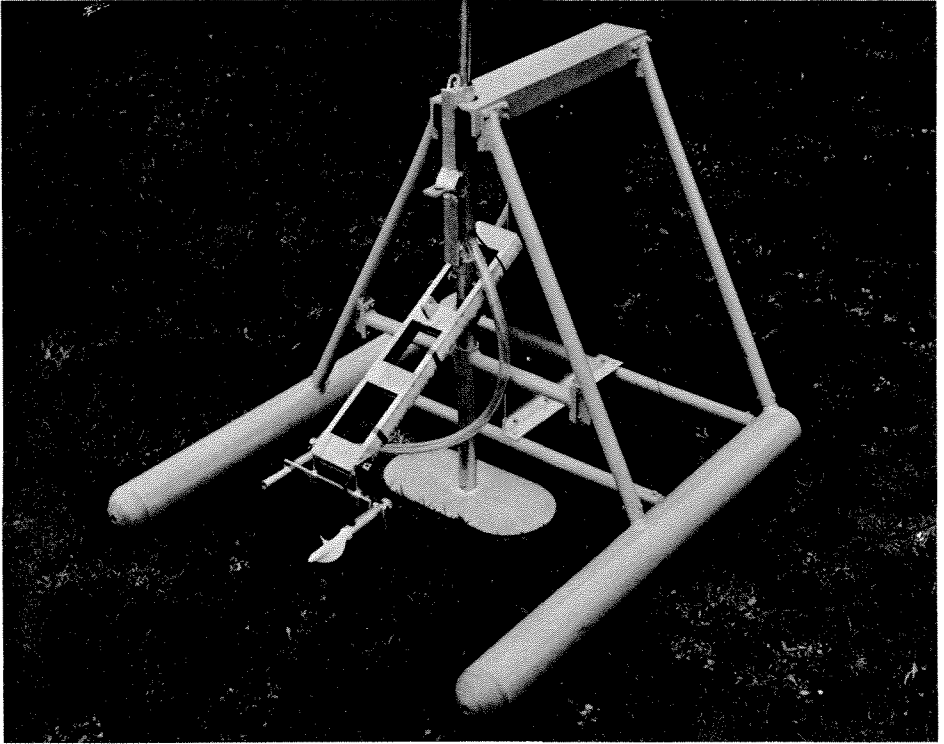


Fig. 1 Lightweight bed frame with cable-controlled traversing head.

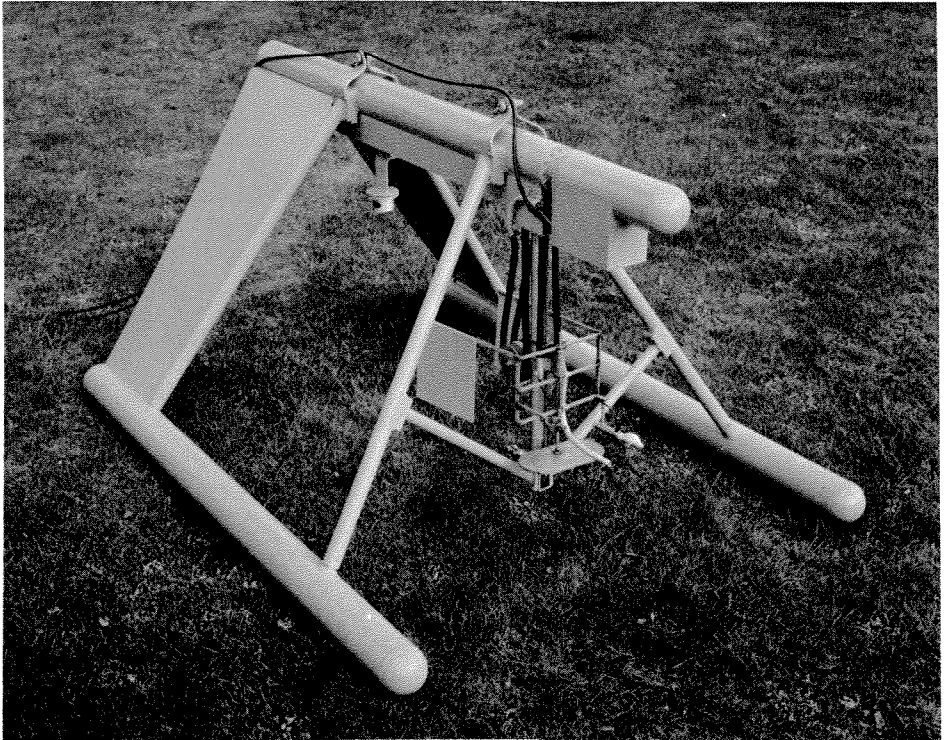


Fig. 2 Bed frame with motor-controlled traversing head.

( $\pm 15^\circ$ ) in flow direction independent of the main support frame. Pitch and roll potentiometers operated by weighted pendulums indicate the attitude of the main frame. With the exception of the upper tube containing the electronics and motor the alloy tubular frame is free-flooding. If additional weight is required the two lower tubes may be loaded to increase the overall weight-in-air from 135 to 400 kg. All cables and the hosepipe are automatically paid out and taken in by a system of pulleys and tensioners to guard against them fouling moving parts. Water velocities are normally measured by a miniature Braystoke impeller current meter but provision is made for substituting a Colnbrook 25 mm diameter electromagnetic current meter (e.c.m.) if any difficulty is experienced with fouling of the mechanical meter. The electronics including the amplifier of the e.c.m. are housed in the upper tube of the frame. As with the lightweight frame a 24 V d.c. pump is used for sampling. If the application calls for hosepipe lengths in excess of 50 m the pump is enclosed in a streamlined housing so that it may be submerged. Small depths of submergence reduce significantly the suction head due to pipe friction losses and permit much greater hose lengths to be used.

## DATA ANALYSIS

For many applications it can be assumed that the velocity ( $u$ ) vs. height ( $y$ ) data are logarithmic in accordance with the Karman-Prandtl equation for steady flow over a rough boundary:

$$u_y = u_{\text{mean}} + (u_*/k) + (2.30u_*/k) \log_{10} (y/d)$$

where  $u_*$  = shear velocity,  $k$  = von Karman's constant, and  $d$  = depth; and, the concentration ( $c$ ) vs. height data follow the suspended load equation:

$$c_y = c_{0.5d} [(d-y)/y]^z$$

where  $c_{0.5d}$  = mid-depth concentration,  $z = w/(ku_*)$ , and  $w$  = particle fall velocity. Best-fit curves satisfying these equations are computed and are generally found to represent the field data closely even for nonsteady tidal flows. If density stratification is strong then the smoothing inherent to the curve-fitting cannot be adopted and it is necessary to compute the flux directly from the velocity and concentration data.

It should be remembered that the field data at successive elevations are measured serially and a single profile may take 30 min to complete. Therefore, for non-steady tidal flows the program carries out a preliminary interpolation between successive readings at the same height above the bed to generate a sequence of "instantaneous" profiles. The curves fitted to these "instantaneous" points become the basis for computation of the suspended load discharge per unit width ( $q_s$ ):

$$q_s = \int_{y_0}^d cu \, dy$$

where  $y_0$  the lower limit of integration is taken as the level at

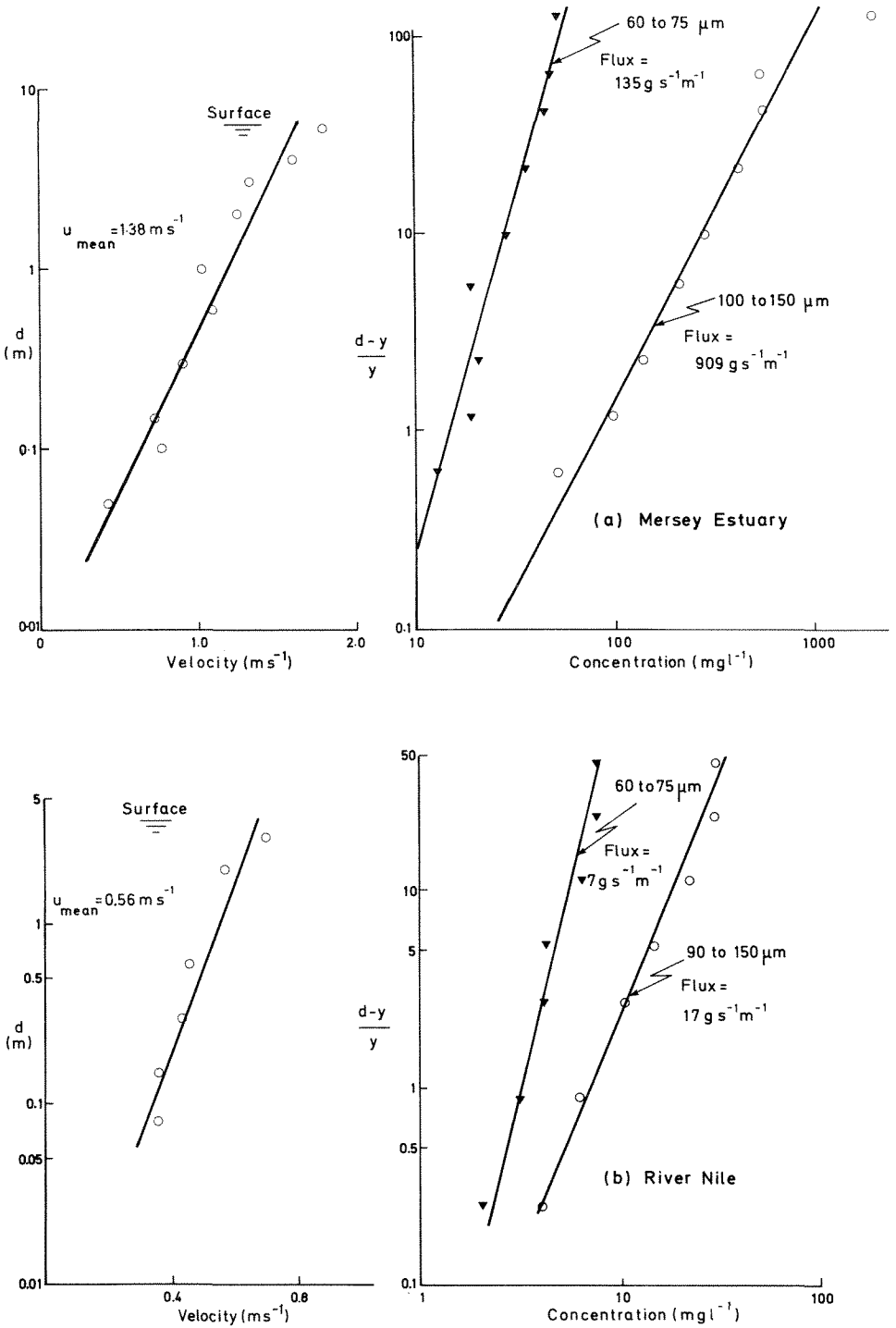


Fig. 3 Velocity and sediment concentration profiles.

which  $u = 0$  on the logarithmic velocity profile.

## RESULTS

Typical results obtained with the two types of bed frame in conjunction with the wire-suspended unit are illustrated in Fig. 3. The ordinates are chosen so that a perfect fit to the velocity and concentration equations plot as a straight line.

The light-weight frame was operated from a small craft (~6 m length) to measure fine sand transport on the River Nile at Assiut. Even at these low transport rates the profiles (Fig. 3(b)) are in close agreement with the theoretical distributions. The other example (Fig. 3(a)) illustrates transport rates some one or two orders greater measured by means of the motorized bed frame in fast tidal flows of the Mersey estuary, UK.

The computed sediment flux accounts for the suspended load only. It omits any transport occurring as surface creep, namely the bed load. It is found that in most engineering applications where fine sand behaviour is important, most of the transport occurs as suspended load. However provision is made on the motorized bed frame to take longitudinal profiles of the bed surface by means of a 2 MHz echo-sounder that is hauled along a 1300 mm horizontal track. The sounder is capable of measuring the height of the bed surface to  $\pm 1$  mm within its operating range of 0.5-1 m. Repetitive traverses at the same position record the height and advancement of the sand ripples from which a close approximation to the bed load transport for a rippled sand bed may be calculated (Crickmore, 1967).

**ACKNOWLEDGEMENTS** The paper describes work carried out by the Hydraulics Research Station and is published with the permission of the Director. We are indebted to the contributions of our many colleagues in the Engineering Design and Field Studies Group both for their design advice and in making the field measurements, and to Mr M. F. C. Thorn for devising the computer programs for the analysis of the field data.

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