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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 71-46

THE GEOLOGICAL SURVEY OF CANADA SEDIMENTATION FLUME

(Report and 10 figures)

Barrie C. McDonald

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THE GEOLOGICAL SURVEY OF CANADA SEDIMENTATION FLUME

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

A recirculating, tiltable, sedimentation flume has been constructed, primarily for research on fluvial processes, although the apparatus can be adapted easily to studies of lacustrine and certain beach phenomena. The main channel is 18.3 metres long, 0.76 metres wide, and 0.6 metres deep. A transparent acrylic section 5 metres long exists in each of the two return pipes. Various devices have been installed to aid measurement of flow variables.

RÉSUMÉ

La Commission a construit un canal expérimental de sédimentation, à pente variable et fonctionnant en circuit fermé; le canal est destiné principalement à l'étude des processus de formation des sédiments fluviaux, mais il est facile de la modifier pour l'adapter à l'étude des phénomènes qui donnent naissance à la sédimentation lacustre et à certaines formes de sédimentation littorale. Le canal d'étude a 18.3 mètres de long et 0.76 mètre de large, pour une profondeur utilisable de 0.6 mètre. Chacun des deux conduits de renvoi comporte une section en résine acrylique transparente, longue de 5 mètres. L'installation a été dotée de divers dispositifs permettant la mesure des variables d'écoulement.

THE GEOLOGICAL SURVEY OF CANADA SEDIMENTATION FLUME

INTRODUCTION

Understanding the processes of erosion, transportation, and deposition of sediment, and their relationships to bed forms and sedimentary structures is essential to reliable interpretation of unconsolidated sediments, sedimentary rocks, and many landforms. For example, an appreciation of the development of bed forms and how the migration of bed forms generates sedimentary structures is necessary before a sedimentary structure can be related to sedimentation environment in terms of paleocurrent direction and such former flow conditions as water velocity and water depth. In addition, fuller understanding of these processes, their rates and their controlling variables, is required for an adequate information base from which to approach an increasing number of environmental problems involving erosion and sedimentation.

The traditional approach to interpretation of sedimentary environments has been through detailed examination of field configurations of sedimentation sequences that are now inactive. Processes and former sedimentary environments are inferred from these configurations. "Control" data for the interpretations are provided by investigation of modern sedimentary environments and by laboratory experiments where isolation and measurement of individual variables are possible.

In 1968 the Geological Survey of Canada decided to develop flume facility that would be sufficiently flexible for a wide variety of sedimentary environments to be studied experimentally. Consequently, a recirculating tiltable sedimentation flume was designed which, while primarily suited to studies of fluvial processes, can be adapted easily to studies of lacustrine and certain beach phenomena. Variables that can be controlled are discharge, slope, depth, and sediment characteristics.

Construction of the flume commenced in March, 1970, and was completed in November, 1970.

Although the flume is intended primarily for research in support of Geological Survey projects, it will be made available to anyone, either within or outside the government, for research projects dealing primarily with sedimentary processes. Persons wishing to use the flume should arrange for time on the apparatus by writing to the Director, Geological Survey of Canada, 601 Booth Street, Ottawa.

ACKNOWLEDGMENTS

Initial requirements, specifications, and designs were drawn up by I. Banerjee and the author. Final designs and specifications were drawn up by F.H. Siemonsen, P. Eng., in consultation with the author. Construction and installation of the flume was carried out by F.H. Siemonsen. Photographs were taken by J.W. Kempt, Geological Survey of Canada.

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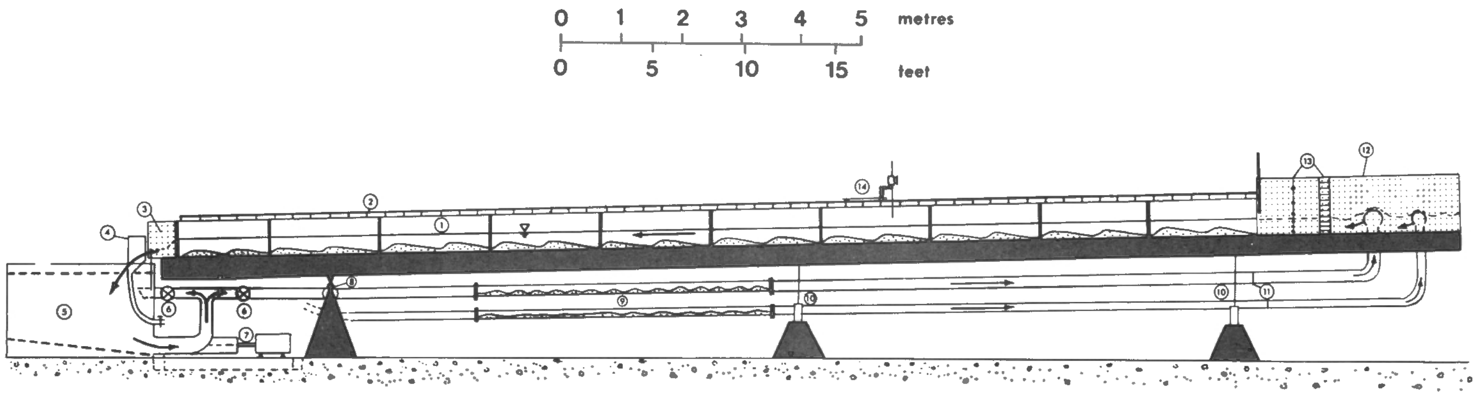

1. main channel
2. rails
3. tailgate assembly
4. total lead sampler
5. tail tank
6. flow-control valves
7. pump and motor
   (small pump, not shown, feeds the 25 cm return pipe)
8. pivot support
9. transparent sections of return pipe
10. jack supports
11. orifice plates
12. headbox
13. baffles
14. instrument carriage

Figure 1. Generalized longitudinal diagram of flume. GSC photo 201787.

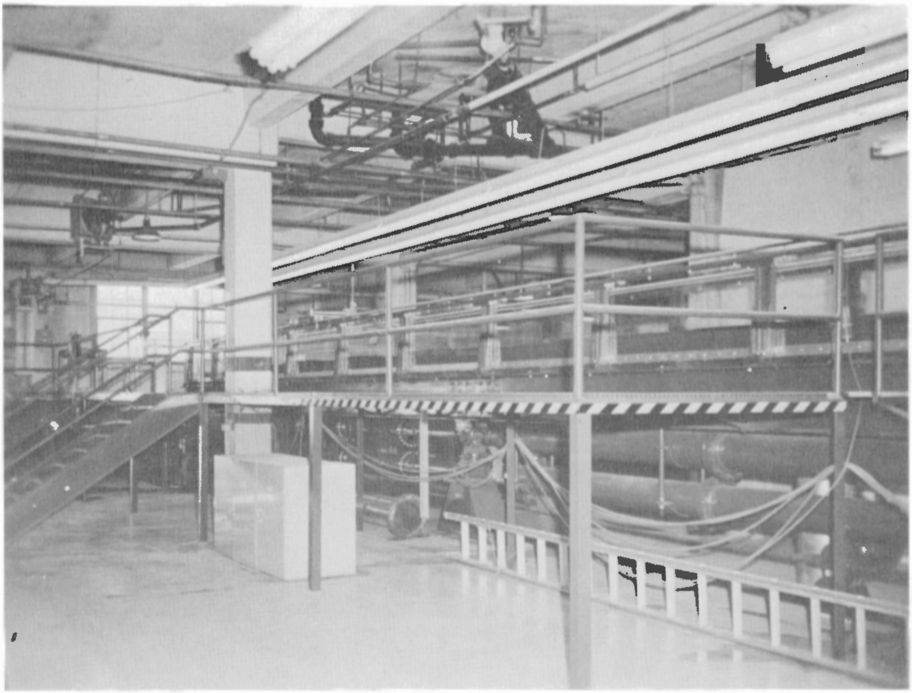

Figure 2. Flume assembly, looking downstream. GSC photo 201625-A

The author is grateful to many people for useful discussion of flume design, in particular to R.V. Asmus, R.K. Fahnestock, H.P. Guy, B.M. Hand, J.C. Harms, A.V. Jopling, J.F. Kennedy, E.D. McKee, J. Ploeg, E.V. Richardson, V.R. Schneider, D.B. Simons, V.A. Vanoni, G.P. Williams, A.M. Winkelmolen, and M.G. Wolman. In addition, the author benefitted greatly from visits to flume laboratories at the following places: Colorado State University, Fort Collins, Colorado; State University of Iowa, Iowa City, Iowa; University of Massachusetts, Amherst, Mass.; and the United States Geological Survey in both Washington, D.C. and Denver, Colorado.

DESCRIPTION OF THE FLUME

The flume described is an open-sand bed, tilting, recirculating sedimentation flume (Figs. 1-3). The entire apparatus is set above laboratory floor level. Steel grating 1.5 m above the laboratory floor provides a large stationary working platform along the full length of both sides of the channel and is continuous across the top of the water tank at the tail end of the flume.

Main channel

The main channel is 18.3 m long, 0.76 m wide, and 0.6 m deep. A headbox of plate aluminum provides an additional 3 m of length through which the flow is introduced into the main channel.

Figure 3. Main channel, looking upstream. GSC photo 201625-B

Rigidity of the main channel is provided by two longitudinal supporting I-beams. The channel floor is anodized aluminum plate in which piezometer tappings are flush with the floor every 0.9 m along the centre line of the channel. Channel walls are specially toughened half-inch plate glass in individual panels 1.8 m long. Adjustable stainless-steel rails are mounted above the full length of the channel walls. The rails guide and support a three-wheeled instrument carriage that can be clamped at any station along the channel, and from which measurements can be taken at any location along or across the channel. Catwalks 0.6 m wide are fastened to the channel supports along the full length of the flume and tilt with the apparatus.

Two types of tailgates are located at the downstream end of the channel: (a) a vertically hinged louvered tailgate (Fig. 4) to allow control of the backwater curve without inhibiting the through-flow of bedload; and (b) a combination undershot sealing tailgate and sharp-crested weir for stopping the flow, filling the flume, and providing auxiliary measurement of discharge.

Once past the tailgate, the flow free-falls into the tail tank.

Flow-return system

Tail tank - The tail tank measures 6.7 m long, 2.4 m wide, and 1.5 m deep and contains 3 compartments: a "passive" reservoir at each end and the "active" reservoir in the middle. The two end reservoirs have a combined capacity of 13.6 m^3. They are connected near the floor by a pipe which can

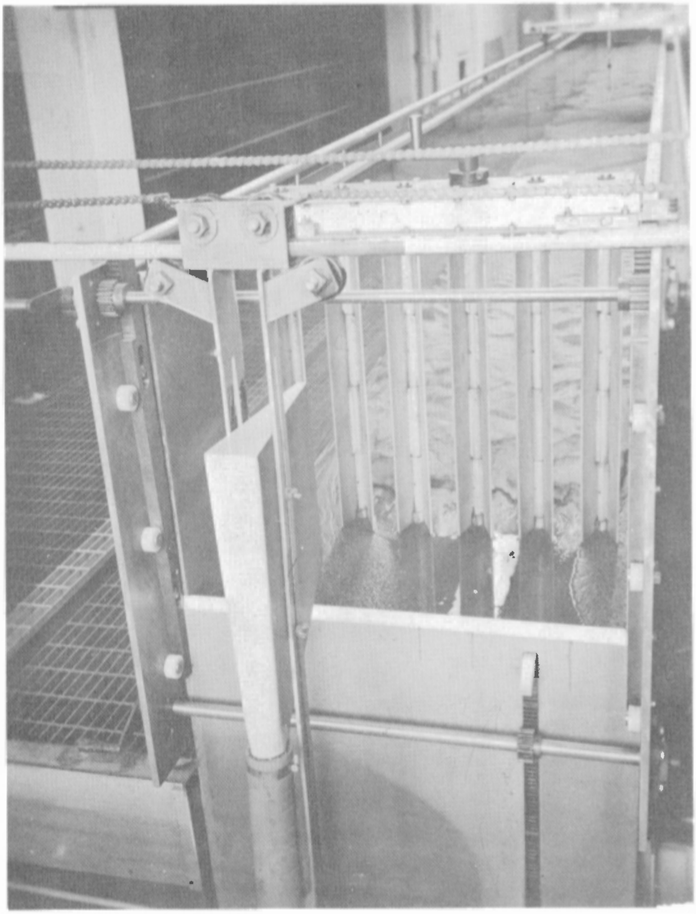

Figure 4. Vertically hinged louvered tailgate and total-load sampler. GSC photo 201625-I

be closed or opened depending on whether they are to be used as separate tanks or as one large reservoir. The middle reservoir, with a capacity of 10.2 m^3, receives discharge from the channel and, from this reservoir, sediment and water are pumped back to the headbox. The floor of the middle reservoir slopes toward the pump intakes in order to minimize storage of sand in the tank. Partitions separating the three compartments are 15 cm below the outer walls of the tail tank. This allows the full capacity of the tail tank to be used as storage; the capacity is sufficient to hold all the water in the system when the flume is not in operation.

Pumps - Water and sediment are pumped from the middle tail compartment back to the headbox of the flume by two electric, constant-speed, direct-drive, axial-flow, open-impeller pumps (Fig. 5). The pumps operate independently; each discharges water and sediment to the headbox along its own return pipe system. The 30-cm and 25-cm pumps have discharges of 230 and 115 litres/sec. respectively. The proportion of this discharge that is

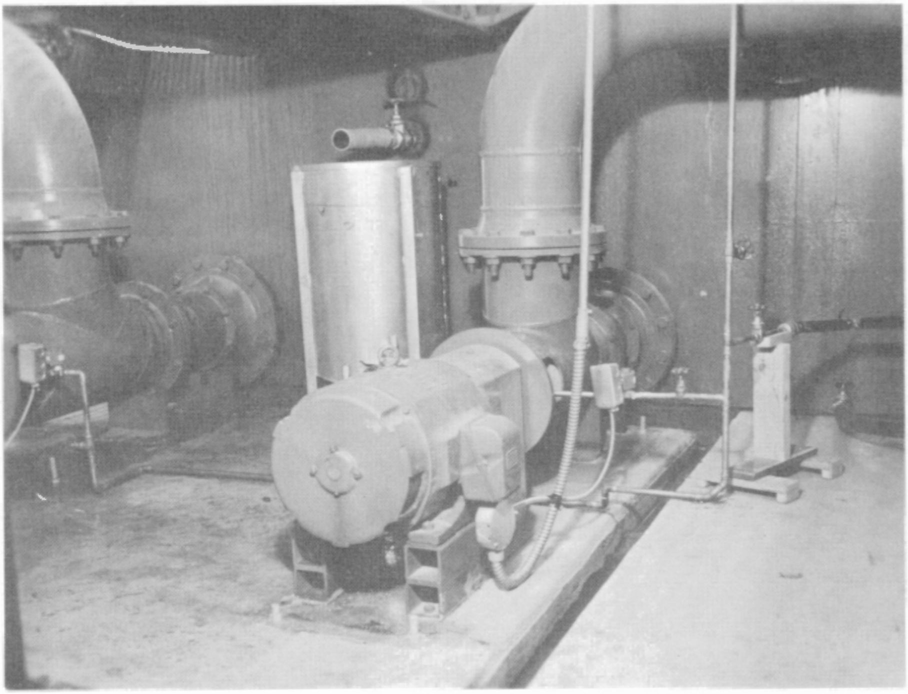

Figure 5. Side view of 25-cm pump. Note spout and container for total-load sampling in background. GSC photo 201625-G

directed to the headbox is controlled by a valve system and a bypass line back to the tail tank. For example, if only half of the pump discharge is wanted for a given experiment, the other half of the discharge is bypassed directly to the tail tank. By using either or both pumps, any discharge from zero to 345 litres/sec. can be used for the experiment.

In order to keep sediment out of the bushings that support the rotating pump shaft, it was necessary to introduce a continuous flow of clear water under positive pressure directly into the bushings from the outside of the pump. The pumps will handle sediment particles as large as 4 mm diameter without undue damage to the impeller. Particles larger than about 4 mm must be screened out as they pass the tailgate.

Return pipes - Two steel return pipes, 30 cm and 25 cm inside diameter respectively, are suspended beneath the main channel and convey the flow from the pumps to the headbox. A short length of rubber pipe near the pumps accommodates adjustment between the stationary assembly at the pumps and the tilting pipe assembly fastened beneath the channel.

In the straight section of each return pipe is mounted a single 5-metre length of transparent acrylic pipe (Fig. 6), whose inside diameter is the same as the rest of the pipe system. In addition to providing a visual check of sand storage in the return pipes, the transparent sections permit examination of bed forms in pipe transport up a measurable slope and under measurable water discharge and flow cross-section.

Figure 6. Transparent acrylic sections in return pipes beneath main channel. GSC photo 201625-E

Headbox - Flow from each return pipe enters the aluminum headbox vertically. T-fittings over the pipes in the headbox (Fig. 7) direct the flow down onto the headbox floor. From there it flows into the main channel through two baffles. One baffle constrains the streamlines for a straight distance of 15 cm through 4-cm square tubular openings in an attempt to minimize artificial turbulence set up in the return pipes. A second baffle consists of a nest of horizontal rods oriented across the channel and spaced so that the basal part of the flow is preferentially retarded; this is an attempt to aid development of a stable vertical velocity profile. The flow then passes beneath an overshot headgate into the main channel.

Pivot and jacking supports

The entire channel is supported at three equally spaced points. The downstream support is the pivot on which the channel tilts. The centre and upstream supports are provided by electric jacks (Fig. 8). The jacks are synchronized and are capable of producing a maximum downstream tilt in the main channel of 0.9 m vertically over 18 m in length (slope = 0.05).

Sediment handling

Sediment storage in the laboratory is provided by raised wooden bins with forward-sloping floors (Fig. 9). Each bin has a sediment capacity of

3.4 m^3 (ca. 5.4 tons). Sand is withdrawn from each bin through a sliding gate at the bottom of the bin. It falls onto a mobile conveyor-belt system and is transported directly to the centre tail tank where it enters the flow system of the flume. Feed rate is manually controlled by the conveyor operator.

Transfer of sand from the flume back to a bin is accomplished in two steps: (a) accumulating sand preferentially in the main channel by maintaining high discharge while keeping a low velocity in the channel. This results in net deposition in the channel; and (b) shovelling the sand from the channel onto conveyor belts for return to the storage bins.

MEASUREMENT OF FLOW VARIABLES

Water slope

First, the rail heights above the channel walls are adjusted to the same level plane by using a conventional tripod-mounted level. This is done with the flume containing an average weight of sediment and/or water for the proposed experiment. Local rail height is adjusted using the supporting bolts, at 45-cm spacing beneath each rail.

Next, the jacks are used to tilt the flume to the slope desired for a particular experiment. The resulting rail slope is then measured with a conventional level.

Figure 7. T-fitting over 30-cm return line in headbox; looking downstream with straightening baffle in background. GSC photo 201625-J

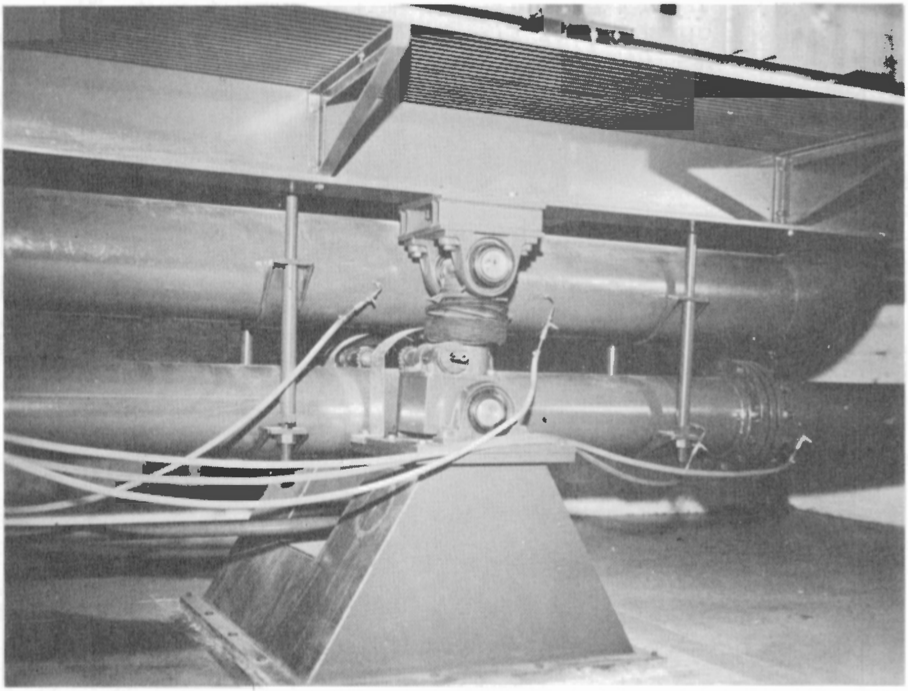

Figure 8. Electric jack at upstream support point. Note piezometer lines leading from orifice plates to differential manometers. GSC photo 201625-F

Finally, the water slope with respect to the rails is measured with an Ott mechanical point gauge mounted on the instrument carriage (Fig. 10). Stations are occupied a metre apart along the main channel. As the point gauge is lowered at a particular station, the lower of two electrodes enters the water. An electric circuit, which leads to an indicator, is completed when the second electrode touches the water. In this way, water surface can be measured to the nearest 0.1 mm. The water slope with respect to the rails is combined with the slope of the rails to give the actual slope of the water surface.

This slope is checked by having two stilling wells, 12 m apart, along the channel and connected by plastic tubes to a piezometer board. When the water levels in the wells are set equal to the water level in the channel, the water level difference in the tubes at the piezometer board is a measure of water surface slope. If the sand bed is thin, a similar check on water surface slope could be made by connecting the piezometer taps along the channel bottom to a piezometer board.

Water depth

Water depth is measured with the mechanical point gauge. At each station occupied for water surface measurement, the point gauge is lowered and a measurement taken at the top of the bed. In order to "feel" the bed with the point gauge, a small stainless-steel foot is mounted lower than the lowest electrode and slightly downstream from it (Fig. 10). The distance from the foot to the upper electrode is then added to the difference of the scale reading at the water surface and at the bed to give a measure of water depth. Incidentally, this also provides a measurement of the slope of the sand bed.

Discharge

A side-contracted, sharp-edged orifice plate, mounted in each return pipe (Fig. 8) generates a pressure differential across it that is a calibrated function of the flow rate through the pipe. Plastic tubes lead from each side of the orifice plate to a differential mercury-water manometer where the discharge can be read.

Mean flow velocity is calculated from measurements of discharge and cross-sectional area of flow.

Temperature

Temperature of the water is measured to the nearest 0.1°C with a conventional mercury thermometer every time samples or flow measurements are taken.

Figure 9. Sediment-storage bins with conveyor belts leading to tail tank. GSC 201625-C

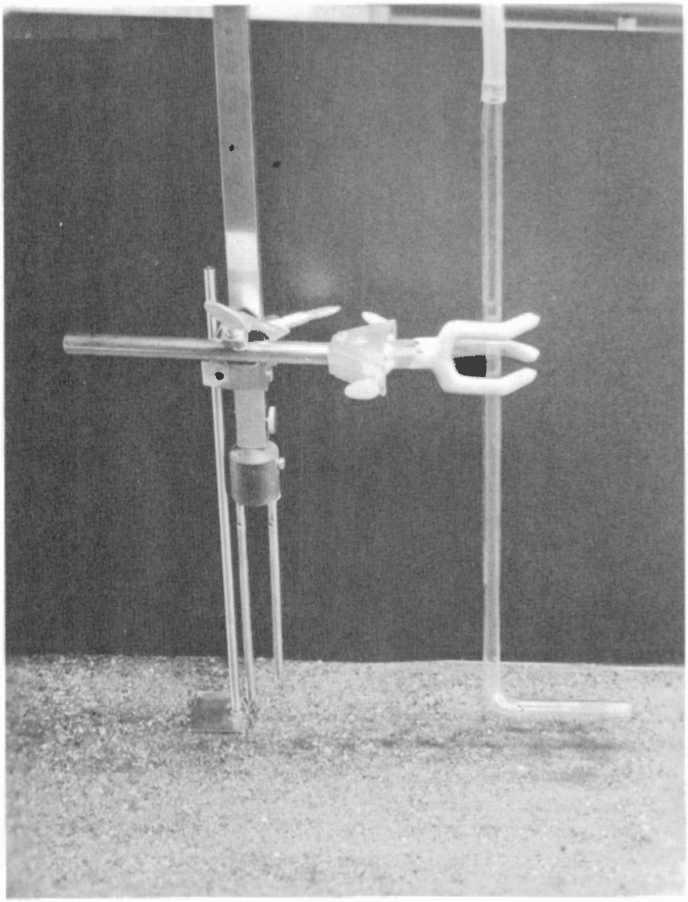

Figure 10. Point gauge mounted on instrument carriage; note stainless-steel foot, lower electrode, and upper electrode. The intake nozzle for the suspended-sediment sampler is clamped to the point gauge. GSC photo 201625-L

Total sediment discharge

Total discharge of water plus sediment in transport is sampled at the tail end of the flume by a vertical-slot width-depth integrating sampler (Fig. 4) similar to that used at Colorado State University. The sampler is transversed slowly back and forth across the flow during the sampling interval. The open slot facing the flow is 1 cm wide, and intercepts the full vertical thickness of the flow nappe. The sampled portion flows in a flexible rubber hose out through the front wall of the tail tank and into a receptacle (Fig. 5). Sediment concentration is measured in parts per million by weight (ratio of weight of solids to weight of water-sediment mixture). Sample volume is approximately 80 litres; sampling time is one to two minutes, depending on the discharge used for a particular experiment.

Suspended sediment concentration

Suspended sediment samples are siphoned from the flow cross-section midway down the main channel. The intake end of the siphon is clamped to the point gauge for maneuverability during sampling (Fig. 10). Depth-integrated samples, taken about every 15 cm across the flow from water surface to within 2 cm of the bed, comprise the total sample. The cylindrical siphon intake, of either 1.0 or 0.6 cm diameter, faces directly into the flow, and the exit end of the siphon line is set at an elevation such that the intake velocity at the siphon is the same as the mean velocity of the flow. This is necessary to avoid preferential sampling of certain grain sizes in the suspended sediment load (Inter-agency Subcommittee on Sedimentation, p. 54). Concentration of suspended sediment is measured in parts per million by weight (ratio of weight of solids to weight of water-sediment mixture). Sample volume is about 3.5 litres and sampling time varies up to 5 minutes, depending on the flow velocity.

TABLE

Conversion factors (metric-English)

metres	x	3.28	= feet
centimetres	x	0.0328	= feet
centimetres	x	0.3937	= inches
cubic metres	x	35.315	= cubic feet
cubic metres	x	219.97	= Imperial gallons
litres	x	0.21997	= Imperial gallons
litres/sec.	x	0.353	= cubic feet/sec.

REFERENCE

Inter-agency Subcommittee on Sedimentation
1963: A study of methods used in measurement and analysis of sediment loads in streams - Determination of fluvial sediment discharge, Report 14, U.S. Gov't., Printing Office, Washington, D.C., 151 pp.