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Measurement of liquid flow in open channels — Methods for measurement of bedload discharge

Mesure de débit des liquides dans les canaux découverts — Méthodes de mesurage du débit des matériaux charriés sur le fond

Reference number
ISO/TR 9212:1992(E)

Foreword

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ISO/TR 9212, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 113, *Measurement of liquid flow in open channels*, Sub-Committee SC 6, *Sediment transport*.

This document is being issued in the type 2 Technical Report series of publications (according to subclause G.4.2.2 of part 1 of the ISO/IEC Directives) as a "prospective standard for provisional application" in the field of measurement of bedload discharge, because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

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This document is not to be regarded as an "International Standard". It is proposed for provisional so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this type 2 Technical Report will be carried out not later than two years after its publication with the options of: extension for another two years; conversion into an International Standard; or withdrawal.

Annex A of this Technical Report is for information only.

Introduction

Bedload generally is considered that portion of the total sediment transported in a stream that is in almost continuous contact with the bed. Such sediment creates numerous problems for engineers responsible for river management, especially in the design and operation of flood-control works, navigation channels and harbours, irrigation reservoirs and canals, and hydroelectric installations. Knowledge of bedload transport rate is necessary in designing reservoir capacity, because virtually 100 % of all bedload material entering a reservoir accumulates there. Bedload material must be kept from entering canals and distributaries, and diversion structures must be designed to minimize the transfer of bedload material from rivers to canals.

Bedload transport rates can be measured either as mass per unit time or volume per unit time. Volume measurements generally must be converted to a mass rate. Measurements of mass rates of movement are made during short time periods (seconds, minutes), whereas measurements of volume rates of movement are measured over longer time periods (hours, days). Regardless of whether mass or volume rate is measured, the average particle size distribution of the moving material must be determined. Knowledge of particle size distribution is needed to estimate the volume that the bedload material will occupy after it has been deposited. Also, knowledge of particle size distribution should aid in the estimation of bedload transport rates in other rivers transporting sediment.

The movement of bedload material seldom is uniform across the bed of a river. Depending upon the river size and gradation, the bedload material may move in various forms, such as ripples, dunes or narrow ribbons. Its downstream rate of movement also is extremely variable. It is very difficult to actually sample the rate of movement in a river cross-section, or to determine and verify theoretical methods of estimation.

Measurement of liquid flow in open channels — Methods for measurement of bedload discharge

1 Scope

This Technical Report reviews the current status of direct and indirect bedload measurement techniques. The methods are mainly based on size distribution of the bedload material, channel width, depth and flow velocity. This Technical Report outlines and explains several methods for direct and indirect measurement of bedload in streams, including discussion of various types of sampling devices.

The purposes in measuring bedload transport rates are to:

a) increase the accuracy of estimating total sediment load in rivers,

b) gain knowledge of bedload material transport that cannot be completely measured by conventional suspended-sediment collection methods,

c) provide data to calibrate or verify theoretical transport models, and

d) provide information needed in the design of river diversion and entrainment structures.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Technical Report are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 772:1988, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 4363:1977, *Liquid flow measurement in open channels — Methods for measurement of suspended sediment.*

3 Definitions

For the purposes of this Technical Report, the definitions given in ISO 772 and ISO 4363 and the following definitions apply.

3.1 bedload-transport model: Mathematical relation of hydraulic and sediment variables which can be used to predict the bedload-transport rates of sediment.

3.2 bedload-sampler efficiency: Ratio of the quantity of sediment trapped in a bedload sampler to the quantity of the sediment in the stream that would be transported as bedload through the section occupied by the sampler without the sampler in position.

4 Units of measurement

The units of measurement used in this Technical Report are SI units. The transport rate of bedload is expressed preferably in kilograms per metre (of width) per second.

5 Measurement of bedload

5.1 General

Two types of bedload transport measurement methods are used, namely:

a) Methods in which mechanical devices or samplers are required. The bedload sampler is designed so it can be placed directly on the channel bed in the flow or beneath the channel bed to collect a sample of the moving bedload material over a specific time interval. A sample thus obtained should represent a time-averaged mass per unit width per unit time.

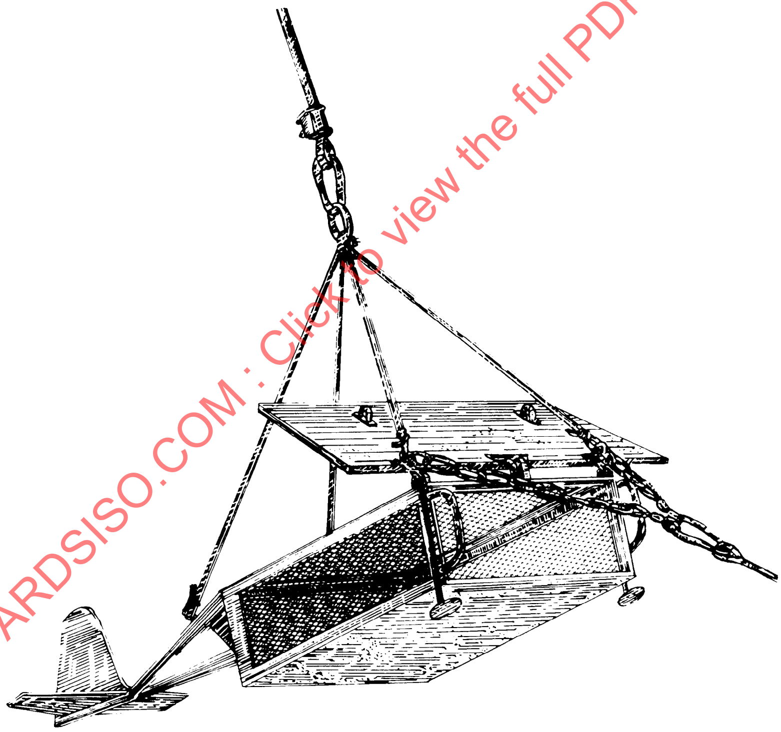
b) All other methods of measurement in which no mechanical device or bedload-sampler is used.

5.2 Principle

5.2.1 Measurements using bedload samplers

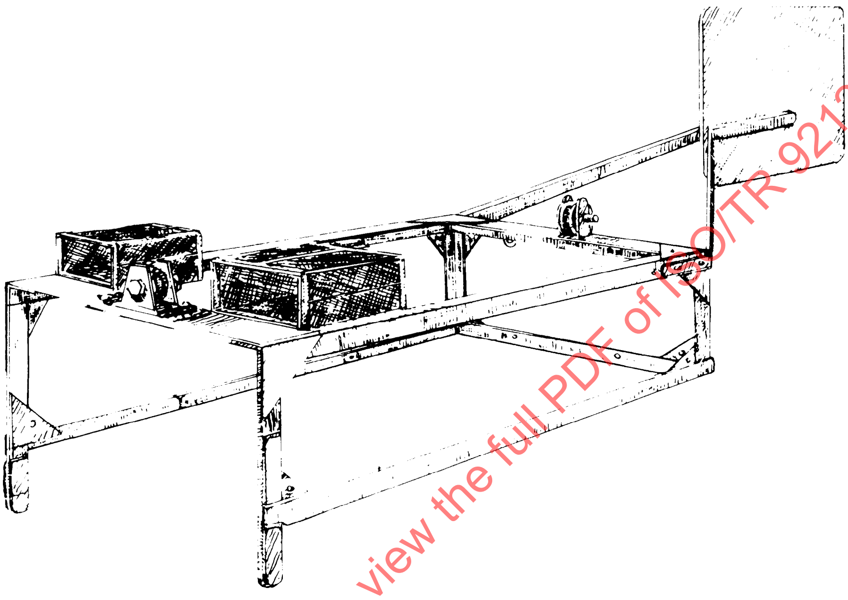
5.2.1.1 Basket sampler

This type of sampler (see figures 1 to 4) generally is composed of a frame covered with wire screen or mesh material on all sides except the front. The bottom may be solid or mesh. The sampler is placed on the channel bed, with the front perpendicular to flow, to trap bedload material for a measured time period.



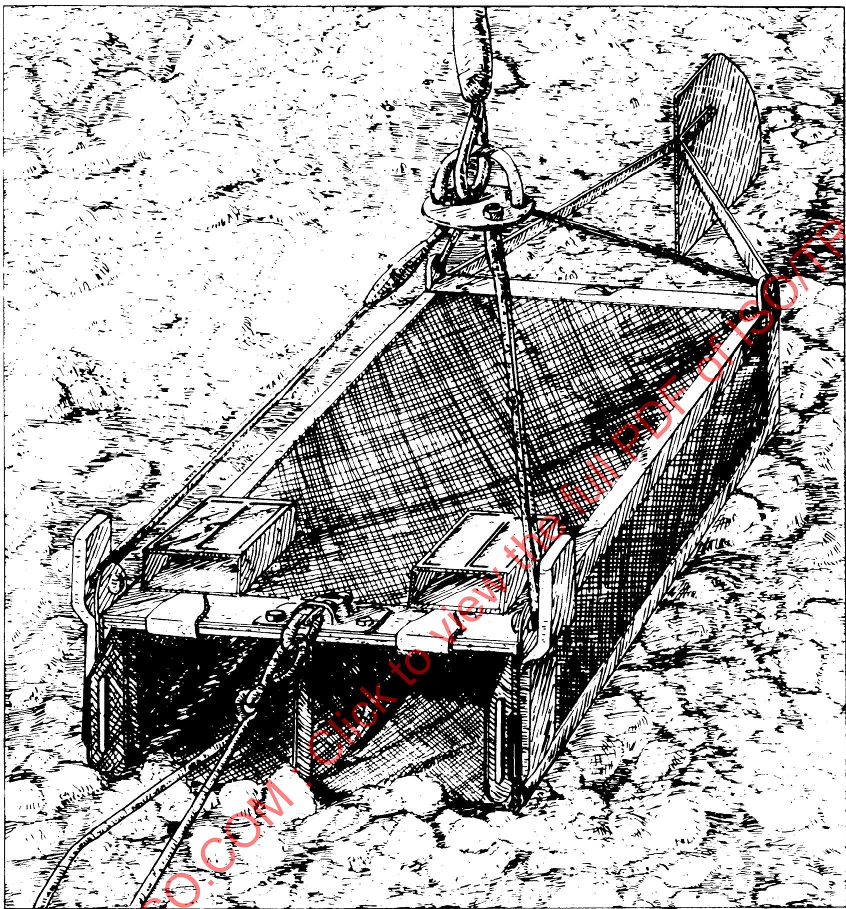
NOTE — This sampler is classed as a basket sampler with a solid bottom. No efficiency data is available.

Figure 1 — Muhlhofer sampler (1932)



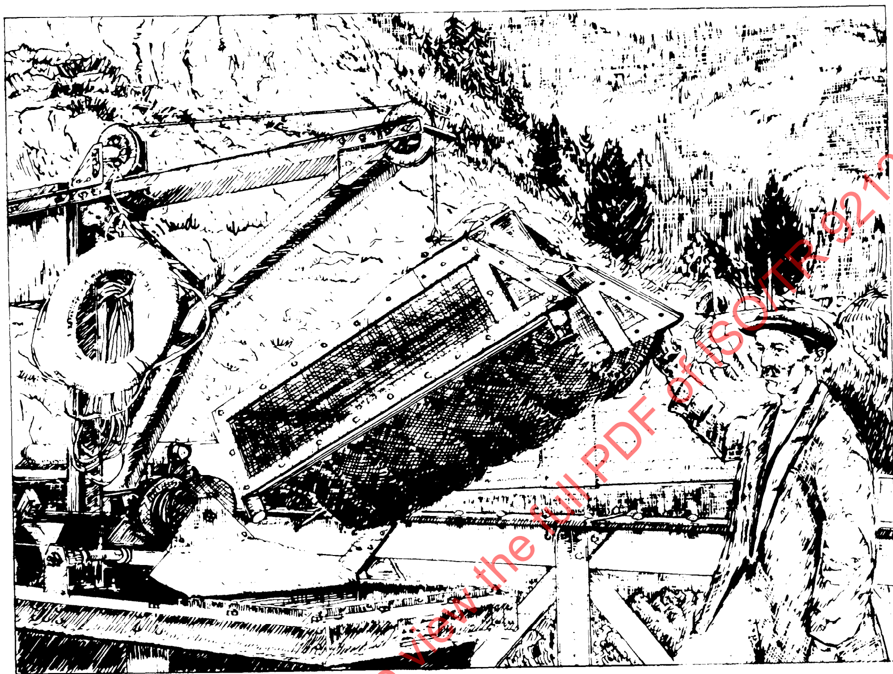
NOTE — This is a basket-type sampler designed in 1931. Similar to the Muhlhofer sampler (figure 1), 1 m long, 25 cm high and 50 cm wide with back, sides and top of 4,5 cm mesh. The bottom is of loosely woven iron rings. For bedload material 10 mm to 50 mm diameter.

Figure 2 — Ehrenberger sampler frame with mesh basket inserted into frame



NOTE — This is a basket-type sampler made of steel mesh used to sample particle sizes from 5 mm to 75 mm. Tests show efficiencies varying from 20 % to 90 %, depending upon particle size and transport rate of bedload.

Figure 3 — Nesper sampler (1937)

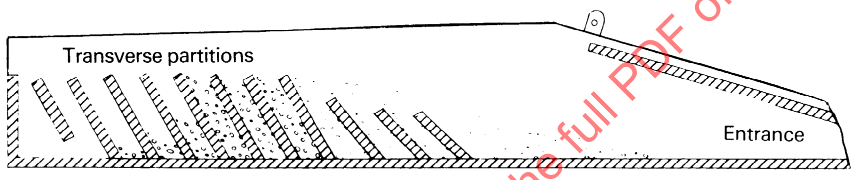


NOTE — This is a basket-type sampler using loosely-woven iron rings that conform to the shape of the bed. Efficiencies vary with sampling time and transport rate of bedload.

Figure 4 — Swiss federal authorities sampler (1939)

5.2.1.2 Pressure difference sampler

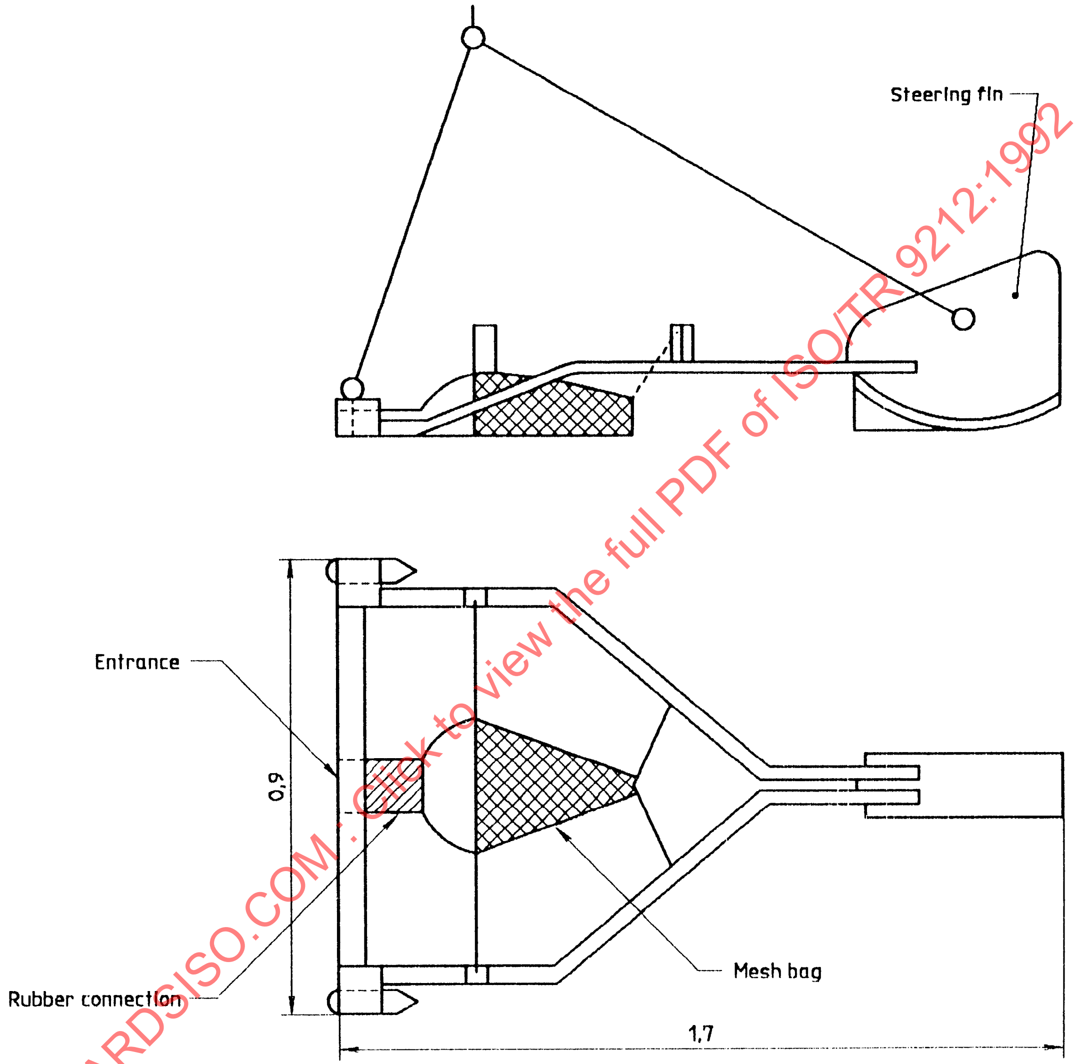
This type of sampler (see figures 5 to 11) is designed so the velocity of water entering the sampler and the stream velocity are approximately the same. Equalization of velocity is accomplished through creation of a pressure drop at the exit due to a diverging configuration between the entrance to the exit. These are flow-through samplers that trap coarse material behind baffles or in a mesh bag attached to the exit side or in a specially designed chamber.



NOTE — This is a pressure-difference type of bedload sampler. The SRIH sampler was the first of this type to be developed. A pressure-difference sampler is designed so that the entrance velocity is about equal to ambient stream velocity. Such samplers can sample particles as small as fine sand to as large as 200 mm. Efficiencies are extremely variable.

Figure 5 — Scientific Research Institute of Hydrotechnics (SRIH) sampler

Dimensions in metres

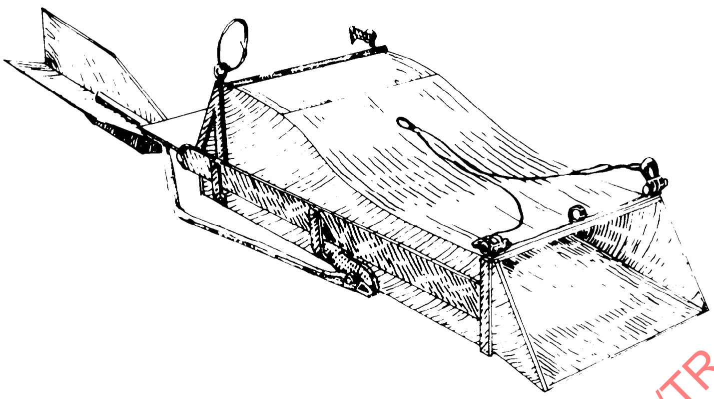


NOTE — This is probably the best known of all pressure-difference type samplers. The Arnhem or Dutch sampler is composed of a rigid rectangular entrance connected by a diverging rubber neck to a basket of 0,2 mm to 0,3 mm mesh. Efficiencies are variable, but generally about 70 %.

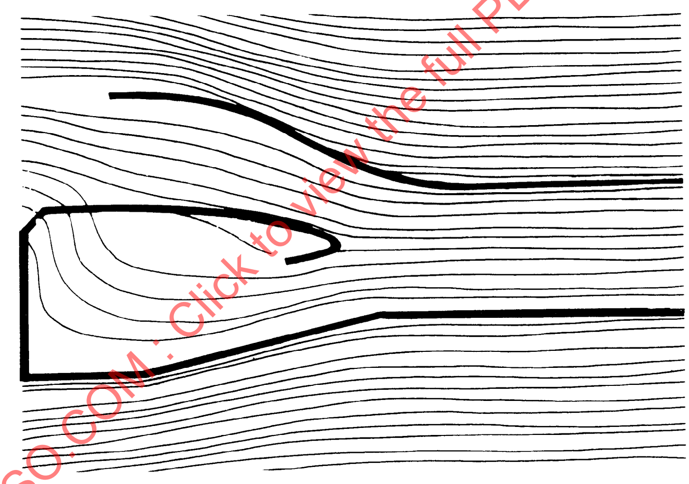
Figure 6 — Arnhem sampler

NOTE — The Karolyi (1947) sampler is a pressure-difference type sampler for measuring bedload transport rates of coarse sand and gravel. Tests indicate that sampling efficiency is about 45 %, and does not appear to vary radically with velocity or particle size. This sampler has a rubber-sheeted bottom which conforms to the shape of the bed.

Figure 7 — Karolyi sampler



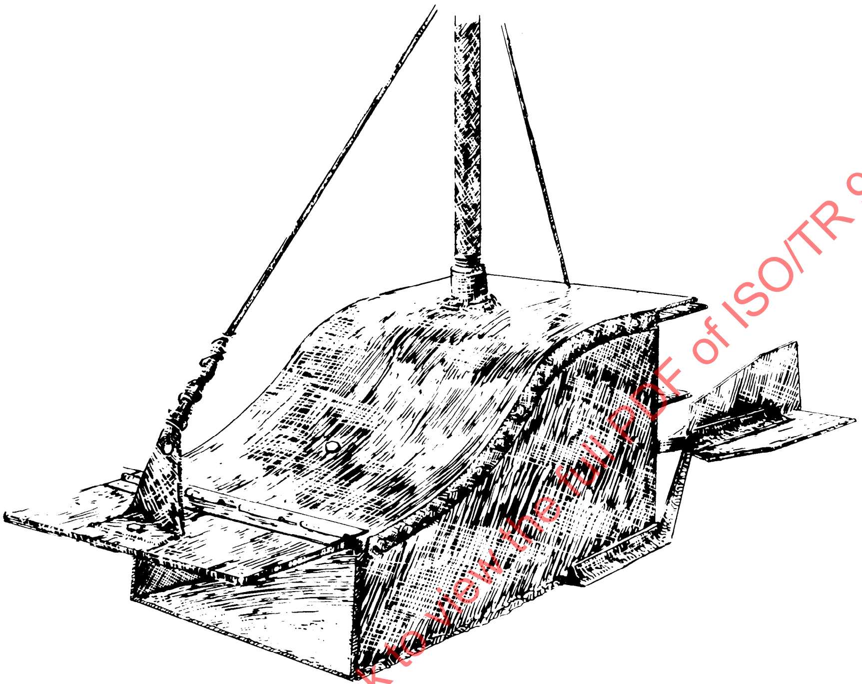
a) Sampler in operating position



b) Flow pattern through the sampler

NOTE — This pressure-difference type sampler was developed by Novak (1947) to measure transport rates of 1 mm to 100 mm size particles. It is a modified Karolyi sampler, 130 cm long, 45 cm high, and 50 cm wide. Sampling efficiency has been estimated to be about 70 %.

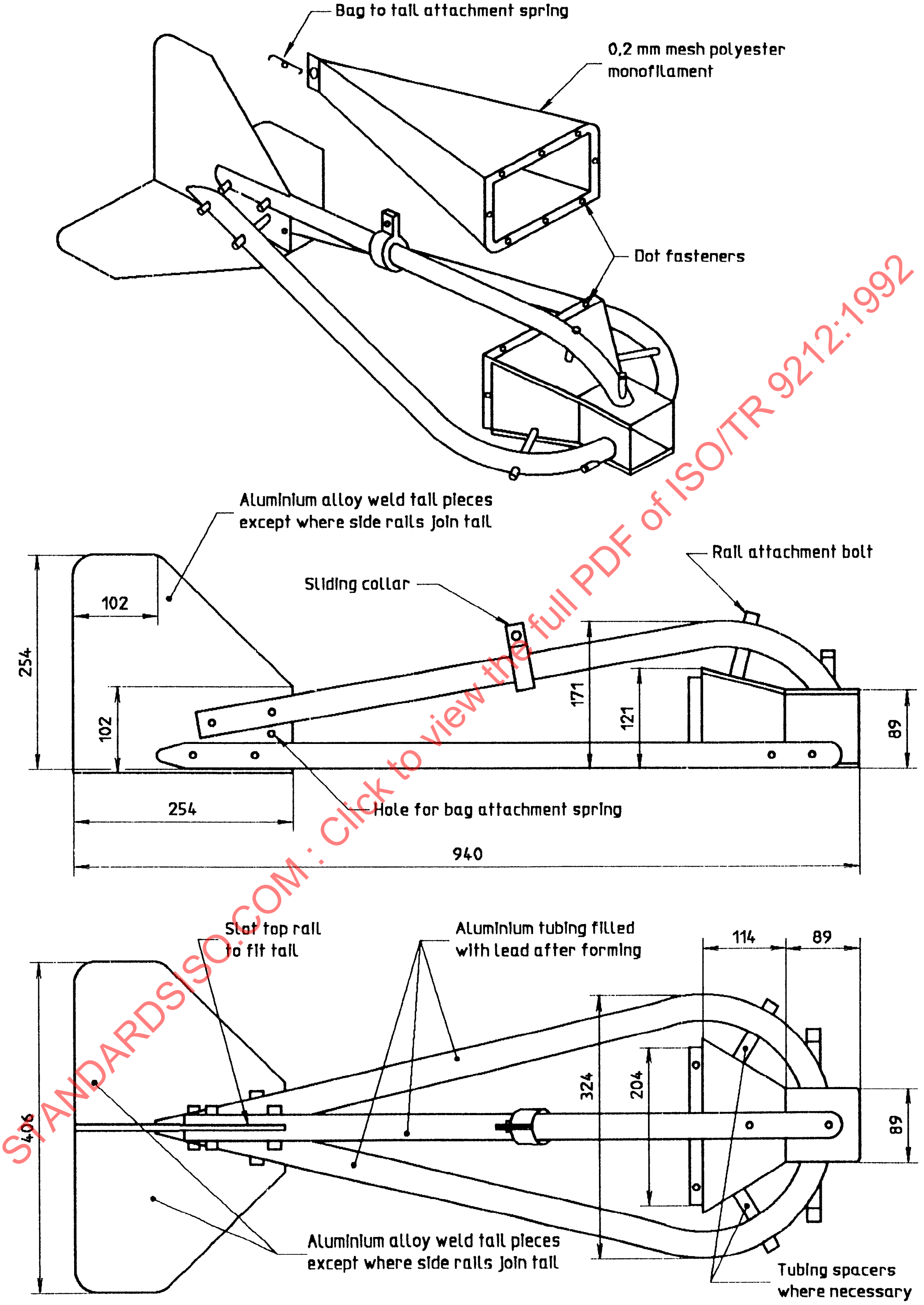
Figure 8 — VUV sampler



NOTE — Uppal and Gupta (1958) developed two pressure-difference type samplers for sand-size bedload, of internal design similar to the Karolyi and VUV samplers. Sampling efficiency is estimated to be about 90 % based on model studies in the laboratory.

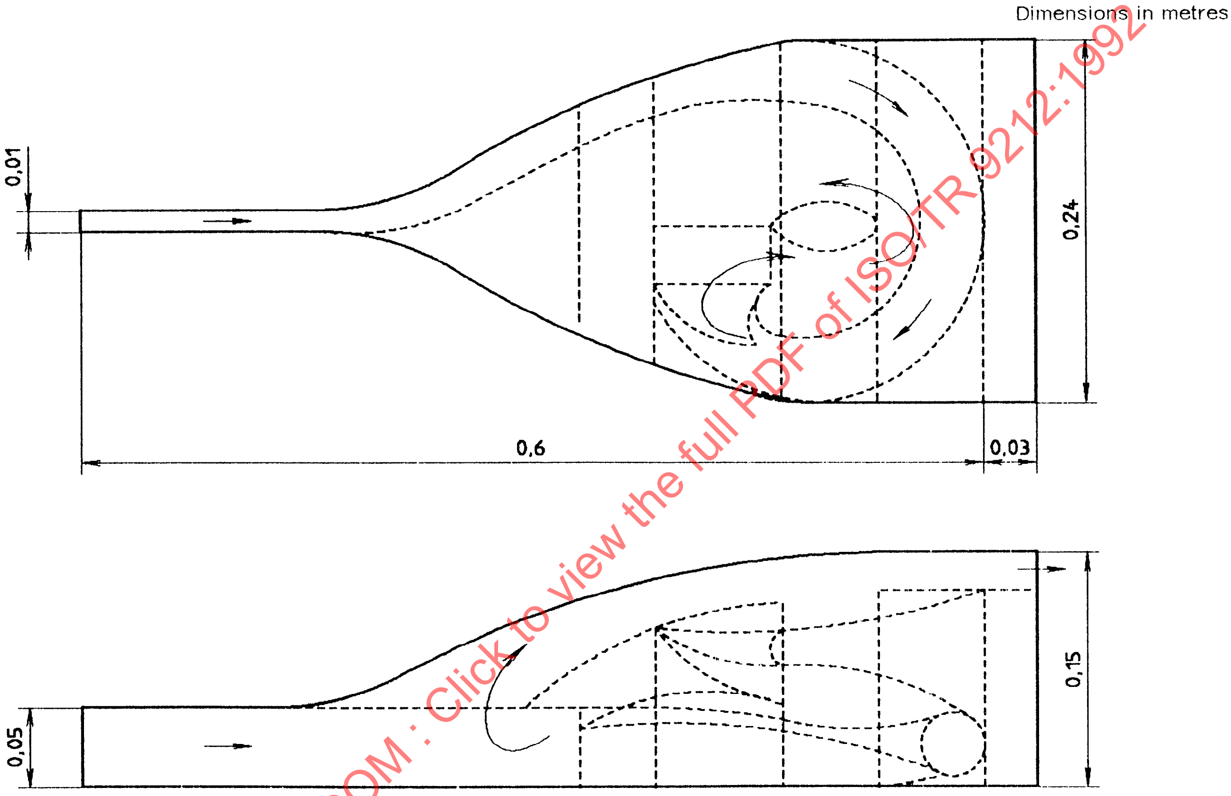
Figure 9 — Sampler B, Irrigation and Power Research Institute, Punjab

Dimensions in millimetres



NOTE — This is the most recently developed (1971) pressure-difference type sampler. Field experiments indicate near 100 % sampling efficiency for sizes from about 0,5 mm to 16 mm. Laboratory studies indicate that sampling efficiencies vary widely with particle size and transport rate.

Figure 10 — Helley-Smith bedload sampler



NOTE — This is a direct measurement sampler developed by Vinckers, Bijker and Schijft (1953). The hydraulic efficiency varies from about 1,09 for clear flow to about 1,0 for extreme conditions. Sampling efficiency varies from about 93 % for particle sizes finer than 0,2 mm to about 85 % for sizes finer than about 0,09 mm.

Figure 11 — Sphinx sampler

5.2.1.3 Slot or pit sampler

This type of sampler (see figure 12) is a mechanical device installed perpendicular to the direction of flow across and beneath the channel bed. Moving bedload material falls into the slot or pit where it is trapped, removed after a given period of time (or continuously), and analyzed to determine mass transported and particle size distribution

NOTE — This sampler is comprised of pits 1 m deep, 1 m long and 20 cm wide to collect bedload material and determine its particle size distribution.

Figure 12 — Muhlhofer pit sampler

5.2.2 Other methods of bedload transport measurement

5.2.2.1 Differential measurements

Such measurements may be used if three conditions exist simultaneously in a stream, namely

a) if the bedload particles are sand-size or smaller,

b) if an artificial or natural turbulence section exists in which all moving sediment is in suspension, and

c) if there is a normal section nearby where bedload material is moving along the bed.

Suspended-sediment samples may be collected from both the turbulent and normal sections by standard suspended-sediment sampling techniques. The difference between the total sediment discharge measured in the turbulent section and the suspended-sediment discharge measured in the normal section should be considered a good estimate of the bedload discharge in the normal section.

5.2.2.2 Sedimentation methods

Periodic volumetric measurements of changes in shape of deltoid deposits at river mouths may be used to estimate bedload discharge. Periodic volumetric measurements of the accumulation of deposited sediment behind dams or diversion structures may be used to estimate bedload discharge over longer periods of time.

5.2.2.3 Dune tracking

Dune tracking is a hydrographic survey method used when the bed forms are dune-shaped. This method involves the mapping of a relatively short, straight reach of a channel under steady-flow conditions. The average parameters of the dune shapes are measured, and the average velocity of dune movement is determined.

5.2.2.4 Remote sensing

Where the channel bed is clearly visible through the water, time-lapse photography techniques can be used to track the movement of bedload particles. Acoustical sensing and recording devices can also be used to track the movement of very large bedload material, based on the theory that the noise created by particles hitting each other may be correlated with bedload discharge.

5.2.2.5 Tracers

Easily identifiable tracer particles of known mass and size can be injected in the channel bed and the rate of their movement monitored for a specified time period.

5.3 Requirements of an ideal bedload sampler

In order that the samples taken be truly representative of the bedload material of a river at the point of sampling, the ideal bedload sampler should fulfill the following technical requirements.

a) It shall be calibrated for sampler efficiency.

b) It shall be designed to minimize disturbances to normal bedload movement. In particular, local erosion near the sampler mouth shall be avoided so as to not form a scour hole.

c) The lower edge of the sampler mouth should be in quasi-permanent contact with the river bed.

d) The velocity of inflow at the mouth of the sampler shall be as close as possible to the ambient velocity of the stream at the sampling point, irrespective of what this velocity may be. This aspect is very important if large sampling errors are to be avoided.

e) The mouth of the sampler shall always face into the current and the sample shall be taken, parallel to flow direction at the sampling point, into a specially designed chamber.

f) The mouth of the sampler shall be outside the zone of the disturbances of the flow set up by the body of the sampler and its operating gear, and the flow lines shall be disturbed as little as possible, especially near the mouth.

g) The sampler shall be able to collect only those particles moving as bedload without contamination by suspended sediment.

h) The sampler shall be portable, yet sufficiently heavy to minimize deflection of the supporting cable from the vertical due to current drag. A separate anchor is recommended for the sampler wherever possible.

i) The sampler shall be simple in design and robust in construction and shall require minimum maintenance and care in operation.

j) It shall be capable of collecting a representative bedload sample under varying bed configurations.

k) The sampler shall be designed for easy removal of the sampled material into a container for transfer to a laboratory.

l) The volume of the sample collected shall be sufficient for the determination of mass and particle size distribution.

m) The efficiency of the sampler should be independent of length of sampling over a reasonable time.

n) The efficiency of the sampler should be independent of the size of bedload particles and flow velocity.

6 Site selection

6.1 Depending upon the method of measurement, the site for conducting bedload measurements can be either a river reach or a cross-section. The site shall be relatively close to the geographical location where bedload-transport rate information is needed; that is, within a few kilometers. There should be no inflow or outflow from the river between the measuring site and the site where bedload transport estimates will be used.

6.2 When using a method such as dune tracking, a straight reach where the channel width and depth are fairly uniform throughout the reach is desirable. Flow through the reach should be uniform and steady during the bedload-measurement period. The length of straight reach should be approximately 10 to 20 channel widths (see 8.4).

6.3 A single cross-section site should be selected if the method of measurement is by bedload sampler. The channel width and mean depth of the cross-section site should be representative of the average channel width and depth upstream and downstream. Ideally, a cross-section used for bedload measurement by bedload sampler should be at the centre of a straight reach selected for measurement of bedload by the dune-tracking method.

6.4 If it is not possible to place the cross-section site in the centre of an ideal straight, uniform reach, then the cross-section should be located at least 10 to 20 channel widths downstream from any bend in the channel. It should not be located at an excessively narrow section, such as a bridge site, or at an excessively wide section.

7 Procedures for measurement of bedload discharge using bedload samplers

7.1 General

Many problems in determining bedload discharge over the wide range of sediment and hydraulic conditions found in nature have yet to be resolved. Among these problems it should be noted that

a) the definition of physical relations is not complete enough to estimate precisely the bedload discharge,

b) the quantitative measurements are applicable only to specific site studies, and

c) direct-measurement devices are useful for only a very limited range of sediment size and hydraulic conditions.

As a result, no single apparatus or procedure has been universally accepted as completely adequate for the determination of bedload discharge over the wide range of sediment and hydraulic conditions found in nature.

The type of sampler and the technique of sampling used will depend on a large number of factors; namely, stream velocity, depth, width, particle size, transport rate, channel stability and bed configuration. The transport rate of bedload not only changes from point to point in a cross-section but also exhibits widely variable short-term and long-term fluctuations at a fixed point. These variations in the measurement of bedload discharge mean that short-term measurements at a point are very likely to be non-representative of the mean bedload discharge at that point. Therefore, each sampling point must be sampled many times over a long period in order to achieve any reasonable accuracy. The number of sampling points in a cross-section usually is dependent on funding and manpower available. However, it should be noted that the more points sampled, the greater the degree of accuracy.

The sampling time interval will be determined by the volume of bedload material in transport and the capacity of the sampler used. Generally, the quantity of material collected should not exceed two-thirds of the sampler capacity.

7.2 Calculations

The computation of bedload discharge from measurements made by direct methods employs the following general formula which is applicable for all conditions for determining the total sediment discharge of a given particle size range:

$$T = (D/e) + Q_{sM} + Q_{usM_1} - FQ_{sM} + (1 - E/e)\, Q_{ts_2}$$

where

T is the total sediment discharge of the size range considered;

D is the discharge of the size range as measured with the bedload sampler; if the sampler measures more than the bedload discharge, D includes some of the suspended-sediment discharge; if the sampler measures only the bedload discharge, $D = B$ (B being the bedload transport rate);

e is the efficiency of the bedload sampler in measuring the bedload discharge of the size range;

Q_{sM} is the measured suspended-sediment discharge of the size range. It equals the product of the total water discharge, a units-conversion constant, and the velocity-weighted mean concentration in the sampled zone;

Q_{usM_1} is the unmeasured suspended-sediment discharge of the size range at the depth between the lowest point measured by the suspended-sediment sampler and the highest point measured by the bedload sampler; it equals the product of the water discharge at this depth, a units-conversion constant, and the difference between the velocity-weighted mean concentrations in the sampled zone and at this depth;

F is the fraction of flow at the depth measured by the bedload sampler with respect to total flow;

E is the efficiency of the bedload sampler in measuring the suspended-sediment discharge of the size range that passes at the depth measured by the sampler;

Q_{ts_2} is the total suspended-sediment discharge of the size range at the depth measured by the bedload sampler.

Simplifications of the general formula can be made for different combinations of particle size ranges (expressed as bedload or suspended load), vertical distribution of suspended-sediment concentration, and type of bedload measuring apparatus. Table 1 shows, for each combination, the equivalent of each factor in the general equation and the simplified formula.

Table 1 — Simplified formulae for computing the total sediment discharge of a size range (taken from [2])

Particle size range transported as	Type of bedload measuring apparatus	Equivalent					Simplified formula
		D/e	Q_{sM}	Q_{usM_1}	F	Q_{ts_2}	
s	W	0	Q_{sM}	0	0	0	$T = Q_{sM}$
s	Y	$(E/e)\ Q_{ts_2}$	Q_{sM}	0	F	FQ_{sM}	$T = Q_{sM}$
s	Z	$(E/e)\ Q_{ts_2}$	Q_{sM}	0	F	FQ_{sM}	$T = Q_{sM}$
σ	W	0	Q_{sM}	Q_{usM_1}	0	0	$T = Q_{sM} + Q_{usM_1}$
σ	Y	$(E/e)\ Q_{ts_2}$	Q_{sM}	0	F	Q_{ts_2}	$T = (D/e) + Q_{sM} - FQ_{sM} + (1 - E/e)Q_{ts_2}$ 1)
σ	Z	$(E/e)\ Q_{ts_2}$	Q_{sM}	Q_{usM_1}	F	Q_{ts_2}	$T = (D/e) + Q_{sM} + Q_{usM_1} - FQ_{sM} + (1 - E/e)\ Q_{ts_2}$ 1)
β	W	B/e	0	0	0	0	$T = (D/e)$
β	Y	B/e	0	0	F	0	$T = (D/e)$
β	Z	B/e	0	0	F	0	$T = (D/e)$
β, s	W	B/e	Q_{sM}	0	0	0	$T = (D/e) + Q_{sM}$
β, s	Y	$(B/e) + (E/e)\ Q_{ts_2}$	Q_{sM}	0	F	FQ_{sM}	$T = (D/e) + Q_{sM} - (E/e)\ Q_{ts_2}$
β, s	Z	$(B/e) + (E/e)\ Q_{ts_2}$	Q_{sM}	0	F	FQ_{sM}	$T = (D/e) + Q_{sM} - (E/e)\ Q_{ts_2}$
β, σ	W	B/e	Q_{sM}	Q_{usM_1}	0	0	$T = (D/e) + Q_{sM} + Q_{usM_1}$
β, σ	Y	$(B/e) + (E/e)\ Q_{ts_2}$	Q_{sM}	0	F	Q_{ts_2}	$T = (D/e) + Q_{sM} - FQ_{sM} + (1 - E/e)\ Q_{ts_2}$
β, σ	Z	$(B/e) + (E/e)\ Q_{ts_2}$	Q_{sM}	Q_{usM_1}	F	Q_{ts_2}	$T = (D/e) + Q_{sM} + Q_{usM_1} - FQ_{sM} + (1 - E/e)\ Q_{ts_2}$

NOTE — β: bedload; s: suspended sediment having a uniform vertical distribution; σ: suspended sediment having a non-uniform vertical distribution;

W: measures only bedload; Y: measures bedload plus suspended sediment in all of unsampled depth; Z: measures bedload plus suspended sediment in part of unsampled depth.

1) Or $Q_{sM} + Q_{usM}$ where Q_{usM} is unmeasured suspended-sediment discharge in unsampled depth.

7.3 Characteristics of bedload samplers

Because the sampling conditions encountered in streams vary widely, a single sampler for all conditions cannot be recommended. Factors such as cost, availability and specific requirements of the sampling also influence the choice of the sampler to a great extent. Table 2, which summarizes the characteristics of most samplers in use, will help in the selection of the sampler in given conditions.

As the data obtained are affected by the sampling action and the mechanism of the sampler, any change in the sampler would itself introduce a variable. Therefore, the results obtained from different samplers might not be comparable.

7.4 Errors

The error in the bedload transport rate measured in a stream is caused by many factors; namely, efficiency of the bedload sampler, variable bedload movement, and the restricted number of verticals sampled in a cross-section.

7.5 Sample identification

In order to properly evaluate the bedload samples, the following items must be recorded on the individual sample container:

a) river name and location;

b) date of collection;

c) time of collection;

d) cross-section location;

e) depth of water;

f) length of sampling time;

g) water discharge;

h) type of sampler used.

8 Others methods of measurement

8.1 General

Some methods (based on collection of samples) do not involve the measurement of the mass rate of transport of bedload. They mostly measure related parameters from which estimates of the volume rate of movement of bedload can be made. The one exception is the differential measurement method which can be utilized at some sites if the bedload material consists mostly of particles finer than about 2 mm.

8.2 Differential measurement method

The differential method for measuring bedload requires the measurement of suspended-sediment discharge at two sites within a river reach. The two sites must meet the following criteria:

a) particles no larger than about 2 mm are being transported;

b) a steady bedload transport rate exists between the two sites;

c) the upstream site represents a normal cross-section, i.e. a normal distribution of the total sediment load between bedload and suspended load, assumed to be representative of the reach in which bedload is being measured;

d) the downstream site is one at which the total sediment load is transported in suspension; this can be an artifically constructed section where turbulence is developed and maintained by a system of baffles;

e) representative cross-section samples can be collected at both sites using accepted suspended-sediment samplers.

8.3 Volumetric methods

Based on periodic measurement of the increased volume of sediment deposited in ponds, lakes, reservoirs and delta formations, volumetric measurements can sometimes be used to estimate average rates of bedload movement. These methods involve the use of capacity survey methods. Techniques for the measurement of elevations of the deposited sediments vary from use of sounding rods or sounding weights in small ponds to echo sounders in larger lakes, reservoirs and deltas.

Periodic volumetric measurements of deposited sediments will be indicative of bedload-transport rates if the volume attributable to the sediment deposited from suspension can be determined. Generally, if suspended-sediment loads entering the area of deposition are measured on a continuing basis during the period of study, the deposited volume of the suspended portion of the total load can be estimated.

Table 2 — Samplers most commonly used for bedload measurements

Type	Description	Disturbance of flow characteristics	Hydraulic stability	Sampler efficiency	Adaptability to various field conditions
Muhlhofer (figure 1)	Rectangular wood frame screened on all sides except front, solid bottom	Variable	Variable	Average about 45 %, varies from 20 % - 70 % depending on particle size distribution of the bedload	Not streamlined, has a large capacity and therefore suitable for sampling large particles; however, small particles, including suspended-sediment particles, can also be collected if the screen mesh is sufficiently small
Ehrenberger (figure 2)	Same as above, except bottom which consists of loosely woven iron rings that conform to bed shape	Considerable	Variable		
Nesper (figure 3)	Same as Ehrenberger	No depth rudder			
Swiss federal authorities (figure 4)	Same as Ehrenberger	No depth rudder			
Arnhem (figure 6)	Consists of a rigid rectangular entrance connected by a diverging rubber neck to a basket of 0,2 mm to 0,3 mm mesh fixed to a large framework by springs in such a way that the entrance is in contact with the bottom when the sampler is lowered onto the bed	Variable	Variable	About 70 %	Generally restricted to collection of fine bedload material (2,0 mm) ; portable
VUV (figure 8)	Metal construction, 130 cm long x 45 cm high x 50 cm wide, collects a 25 kg sample; a perforated wall separates the lower sediment-retaining part from the upper direct-flow-through part	Minimal	Stable in velocities up to *ca.* 3,048 m/s (10 ft/s), depending upon weight of sampler	About 70 %	Capable of collecting sediment particles from 1 mm to 100 mm in diameter; portable
Helley-Smith (figure 10)	Tear-drop shaped, aluminium tubing frame connecting expanding brass entrance to aluminium tail-fins; aluminium tubing filled with lead for weight; bedload particles are trapped in a polyester mesh bag attached to exit	Intake velocities are consistently higher than ambient velocities	Stable in velocities up to *ca.* 3,048 m/s (10 ft/s)	Variable from about 100 % for gravel to more than 150 % for sand	Varying sizes, from hand-held wading sampler to heavy sampler suspended from cables; fairly streamlined; portable
Muhlhofer slot or pit (figure 12)	Rectangular containers placed perpendicular to flow across and beneath channel	Negligible	Stable	About 100 %, depending upon width	Generally restricted to small channels because of cost and installation difficulties. Recent samplers are designed for continuous removal and weighing of bedload material