MINISTRY OF WATER ENERGY AND MINERALS
TANZANIA

MANUAL ON PROCEDURES IN OPERATIONAL HYDROLOGY

VOLUME 5

SEDIMENT TRANSPORT IN STREAMS
SAMPLING, ANALYSIS AND COMPUTATION

1979

MINISTRY OF WATER
ENERGY AND MINERALS
TANZANIA

NORWEGIAN AGENCY FOR
INTERNATIONAL DEVELOPMENT
(NORAD)

MANUAL ON PROCEDURES
IN
OPERATIONAL HYDROLOGY

VOLUME 5

SEDIMENT TRANSPORT IN STREAMS
SAMPLING, ANALYSIS AND COMPUTATION

ØSTEN A. TILREM

1979

PREFACE

This Manual on Procedures in Operational Hydrology has been prepared jointly by the Ministry of Water, Energy and Minerals of Tanzania and the Norwegian Agency for International Development (NORAD). The author is Østen A. Tilrem, senior hydrologist at the Norwegian Water Resources and Electricity Board, who for a period served as the Project Manager of the project *Hydrometeorological Survey of Western Tanzania*. The Manual consists of five Volumes dealing with

1. Establishment of Stream Gauging Stations
2. Operation of Stream Gauging Stations
3. Stream Discharge Measurements by Current Meter and Relative Salt Dilution
4. Stage-Discharge Relations at Stream Gauging Stations
5. Sediment Transport in Streams – Sampling, Analysis and Computation

The author has drawn on many sources for information contained in this Volume and is indebted to these. It is hoped that suitable acknowledgement is made in the form of references to these works. The author would like to thank his colleagues at the Water Resources and Electricity Board for kindly reading and criticising the manuscript. A special credit is due to W. Balaile, Principal Hydrologist at the Ministry of Water, Energy and Minerals of Tanzania for his review and suggestions.

CONTENTS

TABLES

1 INTRODUCTION

This Volume describes equipment, methods and procedures used in fluvial sediment sampling and computation.

In the control and development of water resources, excessive water-borne sediment often causes difficulties and complicated problems. Some of these will be discussed briefly.

Meandering of streams. On account of excessive sediment load rivers often begin to meander. Meandering rivers in thickly populated river-plain areas may cause devastation by carving out new channels washing away towns and rich agricultural lands.

Flood acceleration. Deposited sediments may often clog stream channels raising the flood stages. Flood water contained normally between the banks will overtop and break these, flooding and causing damage to the surrounding river plain.

Reservoir sedimentation. The effects of reservoir sedimentation are felt in many ways, the most obvious being depletion of water storage capacity due to accumulation of sediment deposits. The available water supply may also be reduced by increased evaporation losses due to sediment accumulation, which will increase the area-volume relation in a reservoir, due to the fact that equal surface area will be exposed at less storage than was found before the accumulation of sediment. The increased evaporation may be considerable in hot climates. Sediment accumulating at the head of a reservoir may cause a delta to be formed, which may soon become coated with various types of vegetal cover resulting in an increase of transpiration losses, which can also be quite large.

Other serious effects following the deposition of sediment in a constructed reservoir are the degradation of the streambed immediately downstream from the dam and aggradation further down.

Degradation of the streambed below a dam is known to have caused failure of several dams by undercutting on the downstream side. When a dam is constructed on a stream which carries an appreciable amount of sediment, clear water released from storage will pick up sediments (if available) until its sediment-carrying capacity is again balanced. Further downstream, on account of the reduced river slope caused by the upstream degradation and the accompanying reduction in the carrying capacity of the stream, deposition and aggradation will take place. These changes, caused by upsetting the natural river regime, may have damaging effects for hundreds of kilometres downstream from the dam site (refer Lake Mead Reservoir, U.S.A.). The possibility of this problem occurring must be recognized before the dam is built and allowances must be made for it in the overall design.

Scour and *deposition* in irrigation canals are very troublesome and expensive features of the sediment problem in irrigation systems. Irrigation canals are generally constructed in erodible material and may be divided into three classes: 1) those where scour but no deposition occurs, 2) those in which deposition occurs, but which do not scour, and 3) those in which both scour and deposition occur. The ultimate aim of the designer of canals in erodible material is to select the shape and slope of the canal so that it will not be scoured or filled with sediment to an undesirable extent. When a canal of satisfactory shape and slope capable of carrying the required sediment load cannot be obtained, it is necessary to reduce the amount of sediment which will be supplied to the canal and a great variety of devices have been developed to accomplish this purpose.

Sediment entering the *penstocks* and eventually the *turbines* of a power station is a problem. If sediment is not excluded from the penstocks, considerable damage can be done to the turbines, in many cases necessitating their complete replacement due to abrasion of the turbine runner blades, bearings and other vital parts of the runner.

Some of the harmful effects of sediments have been mentioned above. In the development of water resources these and other sediment problems may be reduced and controlled by careful design if adequate sediment data are available. Thus, reliable information regarding the amount and characteristics of sediments carried by the streams is basic and important. However, it should also be realized that erosion, transportation and deposition of sediment are natural processes that will always take place. Some of these processes and their effects may be reduced and partly controlled, but never wholly eliminated.

Reference [1].

2 SEDIMENT

2.1 Sediment Production

Sediment is mainly fragmental material produced by weathering of the parent rock. The rock is broken down into fragments by mechanical and chemical agents forming boulders, gravel, sand, silt and clay. The disintegration is mainly brought about by changes in temperature, by wind action and by the solvent action of water. The physical and chemical properties of the rocks affect the weathering and the sediment produced. Igneous rocks which are hard consolidated, crystalline and impermeable, weather much less than porous sand stones and shales. Rocks rich in aluminium silicate disintegrate into fine clay while those having a high percentage of quartz weather into coarse sand.

The disintegrated material is transported to its ultimate destination – the floor of the sea – by flowing water. When rain is falling on the surface of the land, some of the weathered material is dislodged, picked up and carried along by overland flow into rivulets and small channels which join with others further downstream to form larger channels, eventually forming a stream or joining a stream already formed. In this way, the products of weathering are carried away from their place of origin into streams, becoming fluvial sediment. Another contribution to the supply of fluvial sediment is water flowing in channels in alluvium causing erosion of the unconsolidated streambed and banks.

In addition to the disintegrated material, the products of weathering include soluble substances that are carried away by ground-water and streamflow and are finally added to the salts in the ocean.

Sediment carried by the wind (aeolian sediment) will not be considered in this Volume.

The amount of sediment carried by a stream depends largely upon the characteristics and nature of the drainage basin of the stream. Streams originating in regions of igneous and metamorphic rocks have clear head-waters, while those rising in young sedimentary rocks are generally loaded with sediment. The characteristics of the basin, the vegetative cover and constitution of the soil through which the streams flow are also important factors in the sedimentary process. Deforestation, unrestricted grazing and cultivation on steep slopes are some of the man-made factors causing erosion and sediment production.

In the head-waters, the sediment load generally consists of coarse material such as boulders and gravel, generally in small quantities. In the lower-lying plains, the size of the material becomes smaller, but the total load will increase. In fact, the particle size of the material will, as a rule, keep on decreasing as the distance from the source of the stream increases. The material is transported by traction along the streambed and in suspension. Generally, the fraction carried in suspension is by far the greatest.

From the above considerations, it appears that a sediment particle carried past a given location on a stream has been subjected to two pre-conditions, namely, 1) it must have been weathered somewhere upstream in the drainage basin of the stream, and 2) it must have been transported by the flowing water from its place of weathering.

It is important to realize that each of these two conditions places a restriction on the sediment load carried by streams. That is, the sediment load of a particular stream depends on both the availability of sediment in the drainage basin of the stream and by the transporting capacity of the streamflow.

2.2 Movement of Fluvial Sediment

Fluvial sediment may be classified according to particle size, specific weight, shape and other characteristics. With respect to transport by water, the particle size is the most significant factor.

Table 1. General Classification of Sediment Particle Size [3].

Size, diameter in mm	Designation	Remarks
< 0.0005	Colloids	Always flocculated
0.0005 – 0.005	Clay	Sometimes or partially flocculated
0.005 – 0.062	Silt	Nonflocculating individual particles
0.062 – 2.0	Sand	Rock fragments
2.0 <	Gravel, boulders	Rock fragments

The general classification by sediment size divides the sediment into fractions having characteristic modes of motion in flowing water. The gravel and boulders move as bedload, that is, rolling and sliding along the streambed, while silt and clay will remain in suspension almost evenly distributed in the water. The sand fraction will undergo both types of motion depending on the degree of turbulence and other factors (Figure 1). In fact, there is no sharp dividing line between the different modes of sediment movement. Depending upon hydraulic conditions and composition of the sediment, the different phases of sediment movement will change gradually and continuously from the one to the other. Nevertheless, for convenience of *analysis, sediment load is commonly divided* into two categories, namely, *bedload* and *suspended load.*

From various studies, it has been established that the transport of bedload is a function of the tractive force which the flowing water exerts on the boundary of the streambed, while the amount of sediment a stream is able to carry in suspension depends primarily upon the presence of eddies and the degree of turbulence of the flow.

Normally, a stream never carries the finer fractions of sediment to its full capacity. The silt and clay fractions of the suspended load are controlled, as a rule, by their availability in the drainage basin, and the supply is usually much less than what the stream can carry. Thus, the concentration of fine particles is relatively independent of flow characteristics in a given stream section. Contrarily, the supply of coarse material is usually greater than the stream can transport and therefore the load of coarse particles is regulated mainly by the ability of the stream to transport them. This means that the quantity of coarse sediment is mainly a function of factors such as velocity and channel slope at a given stream section.

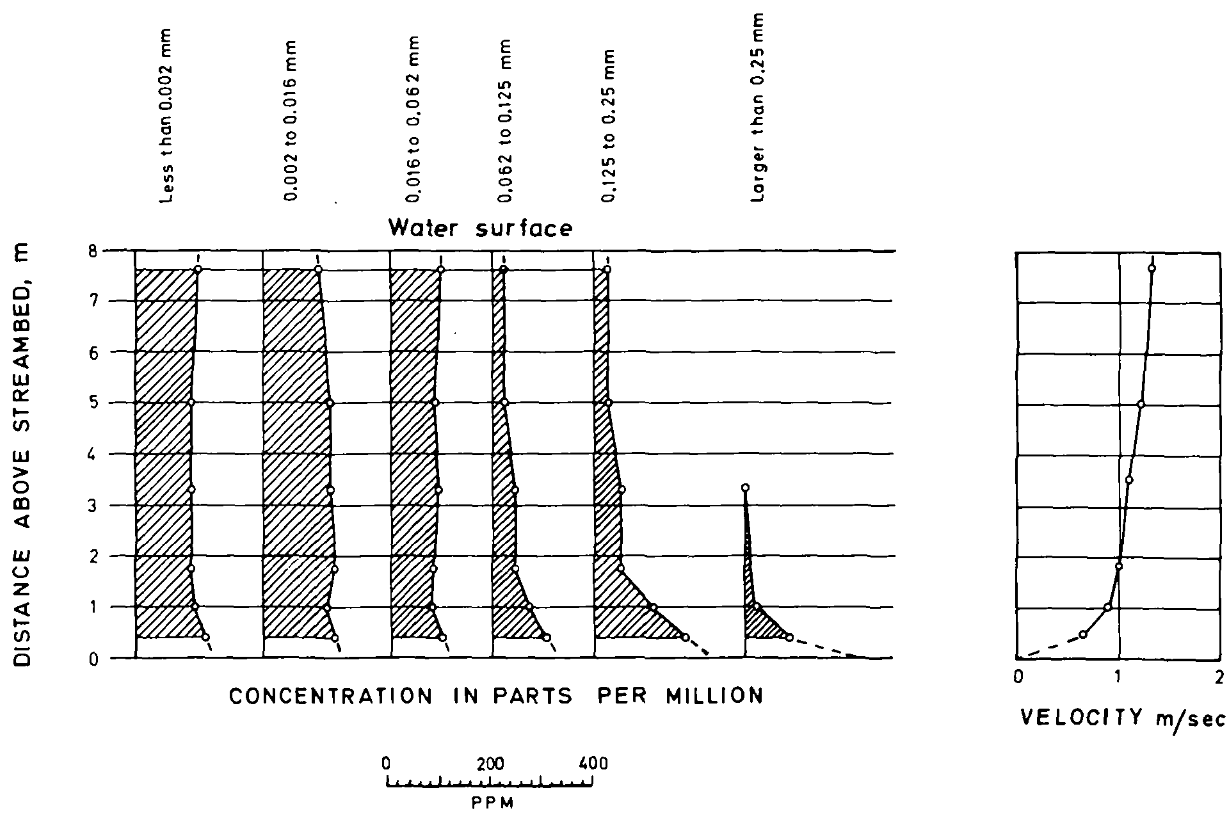


Figure 1. Typical distribution of different sediment particle sizes in a large river [2].

From the foregoing, it is evident that transport of fluvial sediment by streams is a complex mechanism, because many interrelated variables are involved. The variables relate not only to available supply of sediment but also to sizes, shapes and densities of the particles, velocities of flow, channel widths, depths and slopes, bed roughness and bed configuration, density, temperature and even to chemical composition of the water. Most of these factors change not only with time and with distance along a channel, but also with depth and with lateral distance across a given section.

Because of the interrelated and complex nature of fluvial sediment phenomena, the determination of sediment transport in streams is based principally on direct measurements. As may be expected, measurements of the sediment load of a stream show great variation with time and with location in the measuring cross-section. These variations are both random and periodic. They are often related to moving sand and gravel dunes in the stream channel. It is important to be aware that these fluctuations may have periods comparable to the time needed for the dunes to travel past a given location on the stream. These periods may be in the order of seconds and minutes that are easily averaged by most sampling methods. Other fluctuations, particularly those due to the travel of large gravel bars, may show periods of up to a full season, making proper sampling almost impossible.

The largest vertical variation in suspended sediment concentration in a given stream cross-section is found in streams where the suspended sediment consists mainly of sand (Figures 2 and 3). On the other hand, the least variation occurs in streams where the suspended material consists largely of clay and silt. In the latter case, these fine fractions are almost uniformly distributed both vertically and laterally over a section (Figures 4 and 5). In shallow sand-bed channels, it has been observed that the concentration of samples collected consecutively at verticals spaced across a stream may vary as much as 25 percent in the same vertical and as much as 70 percent among verticals. Regarding the bedload, it has been demonstrated that the concentration of sand being transported as bedload may vary up to five times between the lowest and highest sampling value across the stream. In streams with solid or semi-solid boundaries such as coarse gravel, cobblestones or boulders, the sand fraction of the load tends to move in streaks.

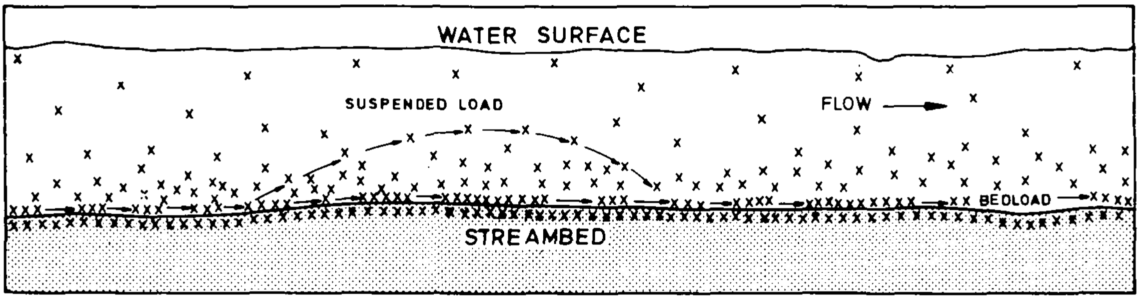


Figure 2. Diagram showing typical uneven distribution of coarse sediment in a longitudinal stream section.

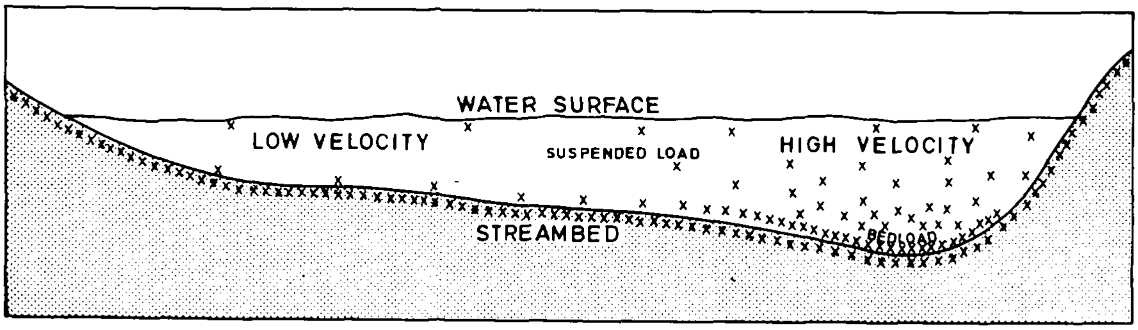


Figure 3. Diagram showing typical uneven distribution of coarse sediment in a cross-section of a stream.

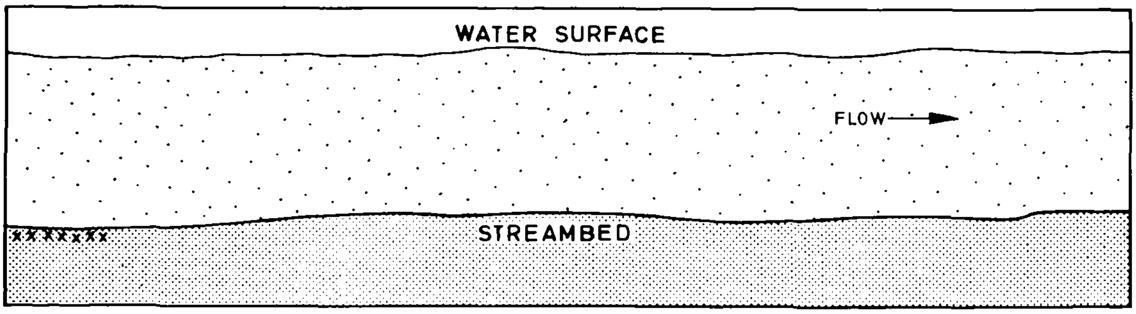


Figure 4. Diagram showing typical even distribution of fine suspended sediment in a longitudinal stream section.

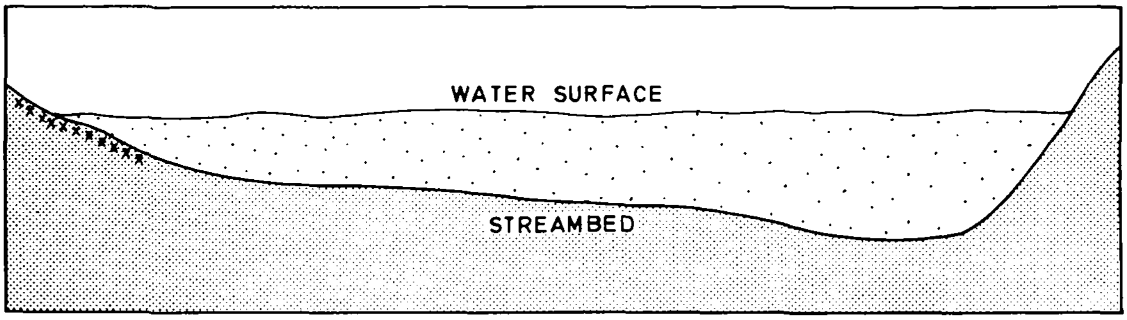


Figure 5. Diagram showing typical even distribution of fine suspended sediment in a cross-section of a stream.

Variations in suspended sediment load and bedload within a cross-section are also governed by other conditions. If the sediment load of a stream is different from that of a tributary, the distribution of sediment across their combined flows will remain separate and distinct for a long distance below the confluence. Also, the distribution of sediment within a cross-section is often abnormal where streambeds or banks are being eroded by the stream.

2.3 Deposition of Sediment

When the sediment transport capacity of a stream changes, either scour or deposition may take place. During flood conditions, the increased discharge and velocity may cause scouring of streambed and banks, if the material can be dislodged and moved by the action of the water. If the stream overflows its banks, deposition will take place in the ponding areas because of the decrease in the velocity of flow in these areas. As a flood recedes, sediment is redeposited in the stream channel, because the carrying capacity of the stream decreases.

A stream carrying a capacity-load as it approaches a reservoir, will deposit the coarsest material where the velocity of the stream is first affected by the reservoir, thus forming a delta. Some fine sediment may be deposited along with the coarse sediment, although most of the fine sediment will be carried further into the reservoir. In large reservoirs, practically all the fine sediment may be deposited before the water moves as far as the outlet. In this case, the reservoir is said to have a trap efficiency of 100 percent. If the reservoir is small and sediment-carrying water is released at the outlet, the reservoir is said to have less than 100 percent trap efficiency.

References [2], [3], [4].

3 SEDIMENT PROGRAMMES

3.1 Information Required

In a sediment programme, usually, there are two basic types of information sought, namely, the quantity and the particle size distribution of the material transported by the streams.

The suspended sediment discharge and its particle size distribution can be determined comparatively easily by collecting and analysing enough suspended sediment samples. Regarding the bedload, there is not as yet any satisfactory sampling method devised and, therefore, the bedload is usually calculated by indirect methods in conjunction with samples taken of the bed material of which the streambed is composed.

Often, a sediment programme may consist of collecting suspended sediment samples at carefully selected sites, analysing and processing them in the sediment laboratory, computing the suspended sediment discharges and filing the data in such a way that they later can be easily obtained and used. Then, when the need arises in connection with specific projects, the bedload and the bed material sampling can be carried out under the guidance of specialists.

3.2 Programme Classification

Generally, a sediment sampling programme may be classified into three classes as follows:

Daily Record. Systematic sampling in order to define the sediment concentration in the river flow at all times during the year.

Partial Record. Sufficient sampling in order to define the sediment concentration during the high water season only. Periodic sampling during the remainder of the year.

Periodic Sampling. Samples taken periodically during the year only.

Additional sampling may be carried out at other stream gauging stations not included in the sediment network. Samples taken during exceptionally large floods at any gauging station are always valuable.

3.3 Density and Distribution of Sediment Sampling Stations

A sediment survey is usually based on already established stream gauging stations. Therefore, the density of sediment sampling stations may be expressed in percent of the stream gauging station network.

Except for special project stations, the density should not be less than 15 percent in arid regions and 30 percent in humid regions of the stream gauging station network. [5].

Each major river basin should have at least one daily or partial record station. In addition, daily or partial stations should be established near important projects where detailed sedimentation data are required. Periodic sampling stations may be more numerous and are located where only general information regarding sediment is desirable.

Sediment data are more expensive to compile than other hydrological records. Therefore, the sampling stations should be carefully chosen and the operation of the sampling programme reviewed and evaluated periodically in order to limit and cut out unproductive and duplicating sampling and procedures.

3.4 Sampling Schedules

The frequency and duration of sampling sediment discharge depend on: 1) the purpose of the investigation, 2) the variation in the sediment discharge of the streams, and 3) the cost of the sediment investigation.

When planning development of water resources in regions where the streams carry significant quantities of sediment, it is essential for the proper design of the water-works (irrigation, flood control, power generation) that data on sediment discharges be available for a number of years. The data must be reliable and correctly collected, as wrong data are worse that no data at all.

In a sediment programme, due attention is to be paid to the variation in the sediment discharge. In regions where streamflow is governed by monsoon conditions, sediment discharge is heavy during the high water season only, while it may be almost nil in the dry season when the streams are fed by ground storage. Thus, sampling during the dry season may be very much limited.

Then, depending on factors such as the season of the year, the runoff characteristics of the basin and the accuracy of the sediment record desired, samples may be required daily or more frequently, weekly, monthly or on a miscellaneous schedule only.

The timing of the sampling may be as important as the technique of taking the samples themselves. In this respect, it is important to note that generally, the variations in sediment concentration during a rising stage are rapid and erratic, while the variations during the falling stage are gradual and fairly consistent. Sampling frequency is determinded also with these considerations in view. Ideally, samples should be obtained as follows: During the rising stage, sample small streams every few minutes and large streams every half hour or hour. After the peak flow has passed, the

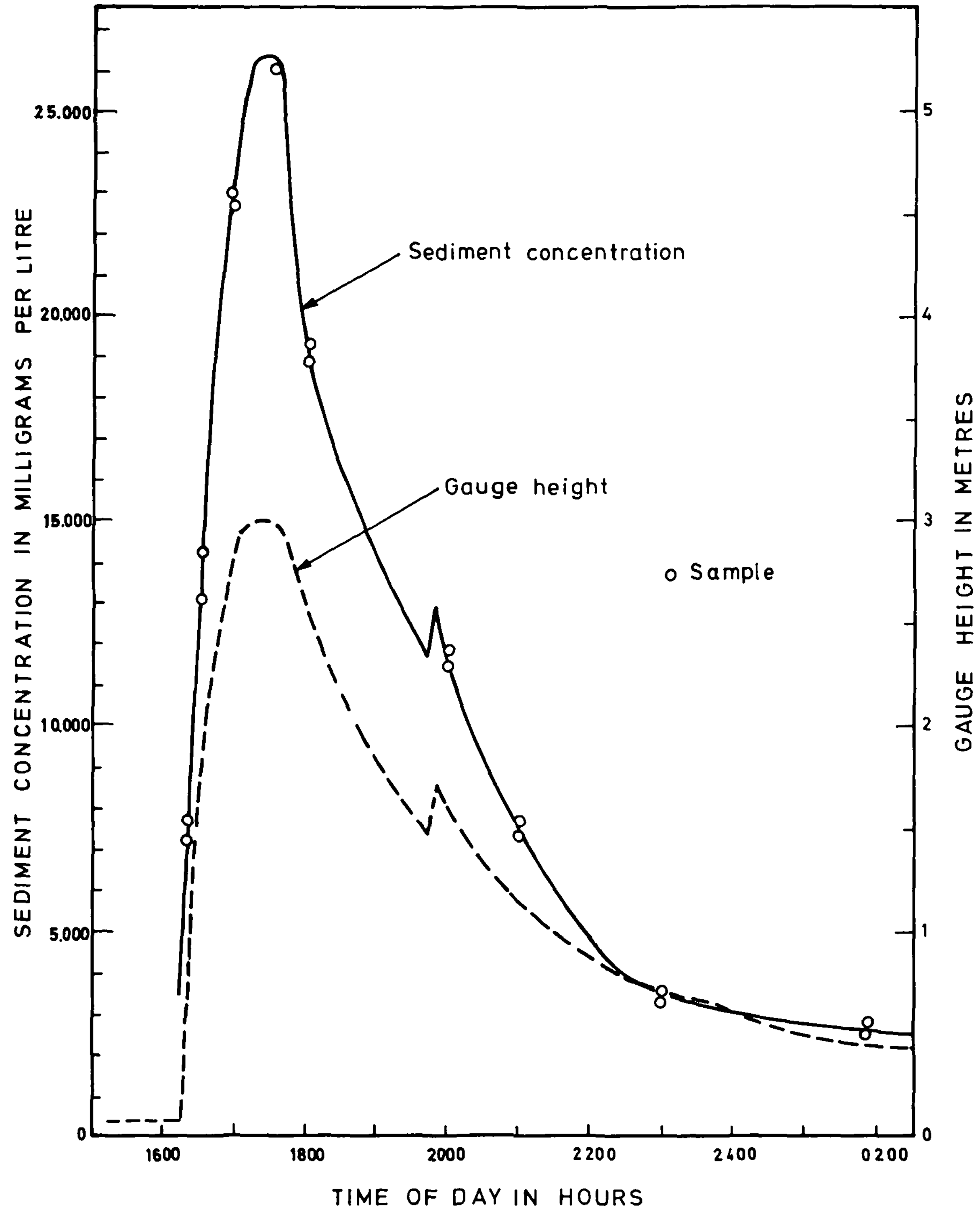


Figure 6. Gauge height and sediment concentration graph, typical of many streams, showing desirable timing of sampling [7].

sampling frequency is reduced, using sampling intervals four times those used on the rising limb, gradually reducing the frequency to the normal schedule as the preceding base flow is approached [7]. Thus, if the rising limb can be adequately defined by sampling at half hour intervals, the falling limb should be sampled every two hours. (Figure 6).

It is to be noted that it should not be taken for granted that the sediment concentration should vary in step with the storm runoff hydrograph. In fact, the sediment concentration graph may be simultaneous, lagged or advanced with respect to the gauge height graph (Figure 7), the latter case being actually the most common. However, an increase in sediment concentration is often accompanied by a rather sudden change in colour of the stream towards the deeper shades (reddish/brownish), thus signalling when to start a more intensive sampling.

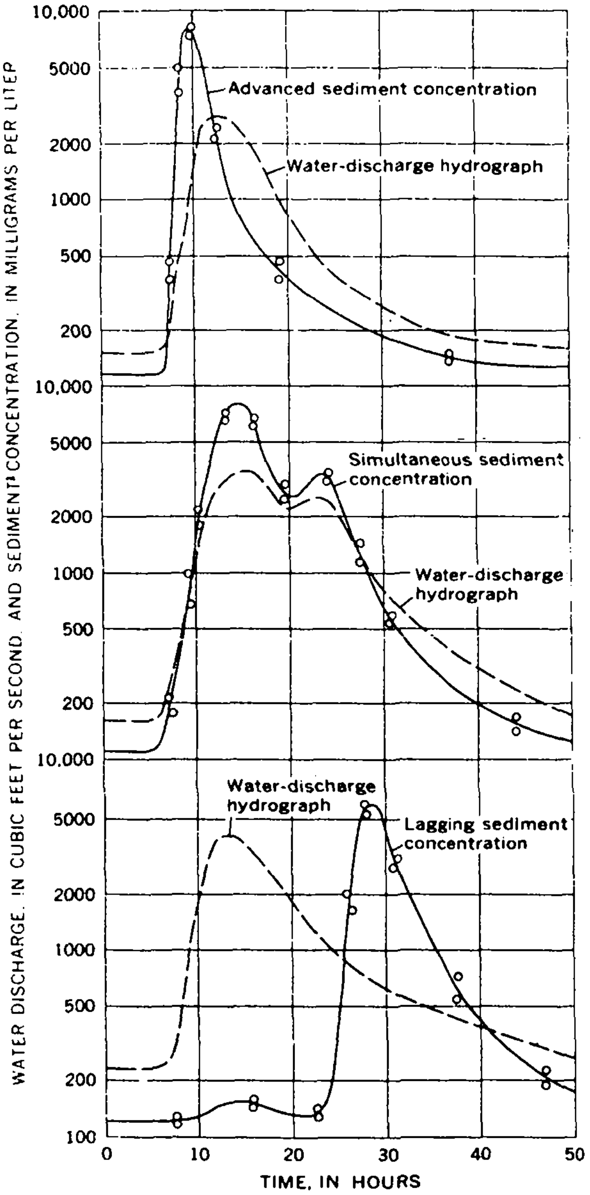


Figure 7. Advanced, simultaneous, and lagging sediment-concentration graphs as related to the temporal distribution of their respective water-discharge hydrographs [4].

However, too elaborate and intensive sampling schedules are not justified in a routine sediment station network. In a general way, stream sediment stations may be operated or sampled on a daily, weekly, monthly or on an intermittent or miscellaneous schedule. The following is a suggestion for a routine sampling schedule in a sediment network.

Daily Record Stations. Suspended sediment samples will be taken daily throughout the year by the local observer, using the fixed sampler method (Section 5.1.4.1) with the following exceptions:

1. If the colour of the river changes noticeably, or the stage changes by half a metre or more within a 24-hour period, the sampling frequency should be increased to twice daily. After the stage or colour of the river has been constant for three days, the observer should return to sampling only once daily.
2. During periods of low relatively clear flow, the sampling frequency can be reduced to twice weekly; however, the observer should reduce his sampling frequency only when instructed to do so by the hydrologist in charge.

When a daily record station is visited by the hydrographer the following procedure should be followed:

1. Visit the automatic recorder and follow the procedures outlined in Volume 2 of this Manual *Operation of Stream Gauging Stations* [8].
2. Make a water discharge measurement.
3. Compute the locations of three or more centroids using the procedure outlined in Appendix D.
4. Check the technique used by the observer as he uses the fixed sampler method.
5. Take a set of check samples by the EDI procedure as described in Appendix D.

6. If particle size samples are required, take a duplicate set of EDI samples.
7. Pick up the samples taken by the observer during the previous month and leave him enough clean sample bottles. Always leave full cases of bottles. This provides the observer with extra bottles in case he needs to take twice-daily samples for a time.

Partial Record Stations. Suspended sediment samples will be taken daily by the observer during the flood or high runoff season only using the fixed sampler method. During the flood season, the instructions for the operation of a daily record station will be followed as outlined above. For the remainder of the year, samples will be taken periodically by the hydrographer when monthly visits are made to the station following the instructions for the operation of a periodic sampling station as outlined below.

Periodic Sampling Station. Suspended sediment samples will be taken only by a hydrographer when monthly visits are made to the station. The observer will have no responsibilities in the sampling programme. When the station is visited by the hydrographer, the following procedure should be followed:

1. Visit the automatic recorder and follow the procedures outlined in Volume 2 of this Manual *Operation of Stream Gauging Stations* [8].
2. Make a water discharge measurement.
3. Take a set of samples by the EDI procedure as described in Appendix D.
4. If particle size samples are required, take a duplicate set of samples.

Particle Size Samples. Particle size samples will be taken at all sampling stations in the sediment station network. The EDI procedure will be used and samples will be taken according to the following schedule:

1. Once shortly before the flood season.
2. At least three times during the flood season: shortly after it has begun, on the first high peak and late in the flood season. Additional particle size samples should be taken on any exceptionally large flood.
3. Once shortly after the flood season.
4. Once during the middle of the low flow period.

The exact dates for taking particle size samples after the flood season, during the low flow period and before the next flood season should be decided by the hydrologist in charge. The exact dates for taking particle size samples during the flood season must be decided by the hydrographer responsible for that particular station.

Miscellaneous Suspended Sediment Samples. A first priority is given to sampling at daily and partial record stations and a second priority to periodic sampling stations. However, valuable sediment data can also be obtained at other gauging stations. Hydrographers should make every effort to obtain suspended sediment samples at any gauging station that has a flood of exceptional size. An exceptionally large flood can be defined as one that overflows its banks or is larger than any previously known flood at that site.

When it is known in advance that such a flood is approaching a gauging station, it may be possible to assemble all equipment in advance and be prepared for its arrival.

Particle size analysis for the daily stations should be made on at least six samples per year so selected as to represent various flow conditions and range of concentrations. Additional samples may be desirable for new stations. For periodic stations, particle size analysis is made on a minimum of one-fifth of the samples. In general, the extent of the particle size analysis will depend on the frequency of sampling, the stream conditions and the proposed use of the data [7].

References [5], [6], [7], [8].

4 SEDIMENT SAMPLING EQUIPMENT

4.1 General

Suspended sediment discharge is determined relatively easily by the use of modern equipment and survey procedures. However, to determine the bedload discharge reliably has proved to be a difficult task. Generally, it is important to use the sampling equipment with care and according to the recommendations and within the limitations set by the manufacturer.

4.2 Suspended Sediment Sampling Equipment

The common procedure of measuring suspended discharge in a stream is to sample the concentration of suspended sediment in the flow and to measure the concurrent water discharge. The suspended sediment discharge is then computed by multiplying the mean concentration of the sediment by the corresponding water discharge.

The first and foremost criterion of a good sampler is that it should be able to collect a representative sample from the flowing stream at any desired point. The presence of the sampler and the process of collecting the sample should not disturb the flow pattern at the sampling point.

The general requirements of an "ideal" sediment sampler may be formulated as follows [6], [10]:

1. The velocity at the entrance of the intake should be equal to the local stream velocity.
2. The intake should be pointed into the approaching flow and should protrude upstream from the zone of disturbance caused by the presence of the sampler.
3. The sampler should be streamlined and of sufficient weight to avoid excessive downstream drift.
4. It should be rugged and of simple design to minimize the need for repairs in the field.
5. It should be inexpensive and consistent with good design and performance.
6. The sample container should fill smoothly without sudden inrush or gulping.
7. The sample container should be removable and suitable for transportation to the laboratory without loss or spoilage of the content.

Suspended sediment samplers in general use may be classified into the following three types [6]:

1. Bottle sampler
2. Instantaneous sampler
3. Integrating sampler

4.3 Bottle Samplers

The simplest and most readily improvised device for collecting suspended sediment samples is an ordinary milk bottle, fruit jar or other standard container, attached to a rod or to a line with a hydrometric sinker. Air escaping through the intake opening produces a bubbling effect at the entrance. Bottle samplers are therefore classified as *slow-filling bubbling* samplers.

An open bottle can be used for dip sampling or a bottle closed with a cork fitted to a string is used for sampling at predetermined depths. Bottles can also be provided with intake and air exhaust tubes thereby eliminating the bubbling effect and improving the accuracy (Figure 8).

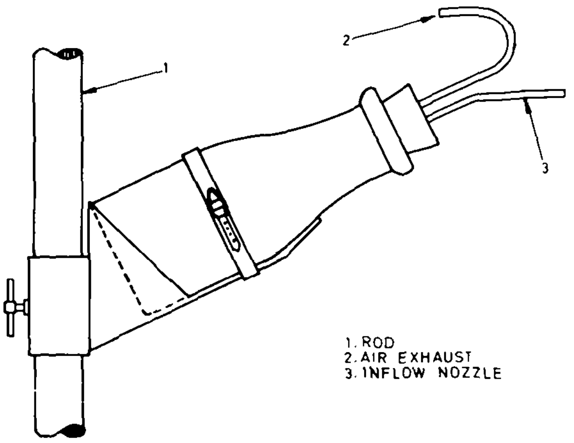


Figure 8. Simple bottle sampler.

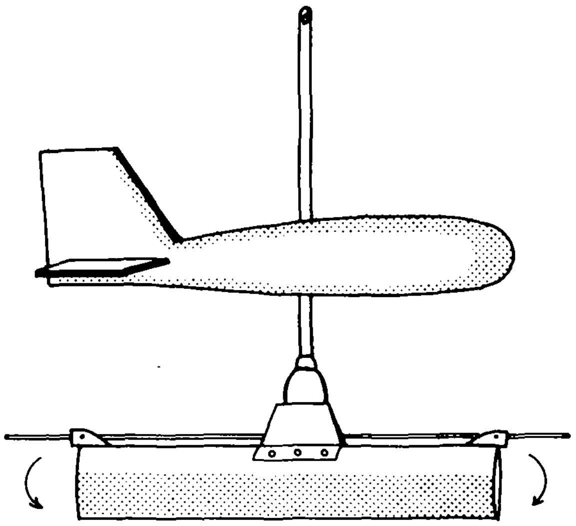


Figure 9. Instantaneous sampler.

4.4 Instantaneous Samplers

An instantaneous horizontal trap sampler consists of a cylinder equipped with a closure mechanism at each end which can be closed suddenly to trap a specimen of the water-sediment mixture.

The sampler is held horizontally and oriented into the flow by vanes. It can sample at any desired depth. The main advantages of this sampler type are the simplicity of operation, the ability to sample close to the streambed and the wide range of adaptability to shallow and deep streams of all velocities (Figure 9).

4.5 Integrating Samplers

There are two general types of integrating samplers: 1) those with a fixed open intake, and 2) those with a controlled intake. The former, called a depth-integrating sampler, is used to collect a specimen of the water-sediment mixture in a vertical in which the concentrations at different depths are averaged. The latter, called a point-integrating sampler, is used to collect a specimen at a point at which the momentary fluctuations in sediment concentration are averaged.

The sample container of an integrating sampler is filled over a time interval from 10 to 120 seconds. The intake nozzle and the air exhaust tube are separated, thus avoiding disturbances to the inflow as the container is being filled.

The integrating samplers developed by the US Federal Inter-Agency Sedimentation Project (F.I.A.S.P.) meet the general reqirements for good performance as previously cited [7].

The sediment sampler made by NEYRPIC, France, is also well designed, it is a rather heavy type suitable for large rivers.

4.5.1 Depth-Integrating Samplers

The depth-intergrating sampler is designed to accumulate a water-sediment sample in a container (bottle) as the sampler is lowered to the streambed and then raised to the surface again.

During transit, the intake velocity through the nozzle is nearly equal to the local stream velocity at all points in the vertical (i. e. within 3–5%). Thus, by using a uniform transit rate, the catch at any point in the vertical will be proportional to the flow velocity at that point, and thereby a representative sample is ensured. If the speed of lowering the sampler is too high, some inflow may also take place through the air exhaust. If the transit rate is too slow, the sample container will be filled before the transit is completed and some outflow through the air exhaust will take place. In both cases, a non-representative sample will result.

By observing the time used to collect the sample and measure the volume of the sample, the mean velocity of flow in the vertical may be calculated provided that the downward and upward transit rates are the same.

Three much used depth-integrating samplers developed by the F.I.A.S.P. are the US DH-48, the US DH-59 and the US D-49 samplers:

a) The DH-48 sampler is a light-weight sampler to be mounted on a wading rod for hand operation in shallow streams (Figure 10).

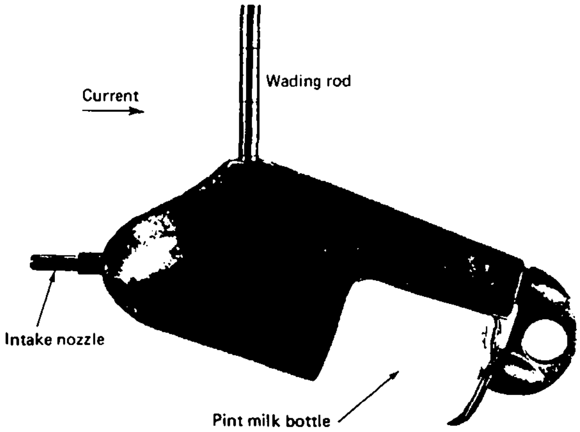


Figure 10. Depth-integrating suspended sediment hand sampler, US DH-48, for use on shallow streams.

The sampler consists of a streamlined aluminium casting partly enclosing a standard US pint (473 ml) glass milk bottle as sample container. The sampler weighs 2 kg, including the bottle and it is 33 cm long. An intake nozzle of brass extends horizontally from the nose of the sampler. An air vent permits the escape of the air from the bottle as the sample is being collected and controls the intake velocity so that it is approximately equal to the local flow velocity at the nozzle intake. The sampler is calibrated and supplied with an

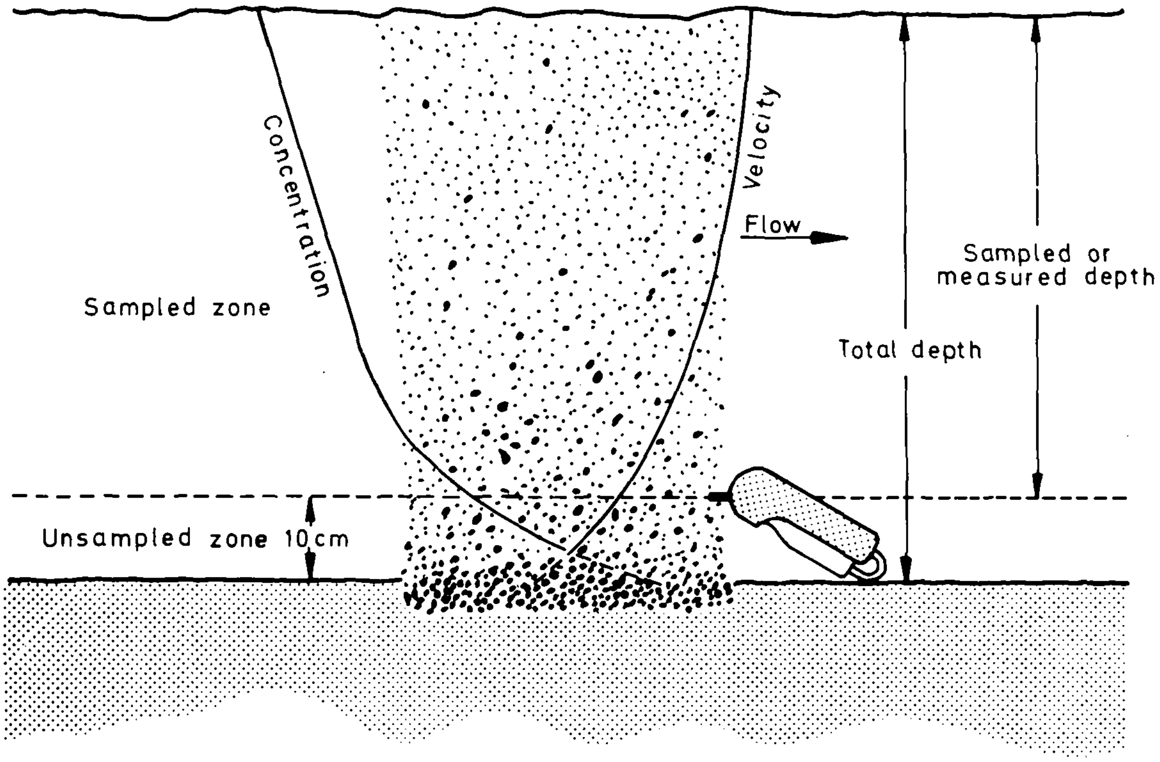


Figure 11. Sampled and unsampled zone in a sediment sampling vertical [7].

1/4 inch (6.3 mm) inside diameter intake nozzle, but a 3/16 inch (4.8 mm) nozzle may also be used. The instrument can sample to within 9 cm of the streambed (Figure 11).

Detailed operating instructions for the DH-48 sampler are given in Appendix A.

b) The DH-59 sampler is a medium sized sampler for hand operation by a handline type of suspension (Figure 12).

This sampler is similar to the DH-48 sampler, consisting of a streamlined bronze casting also partially enclosing a standard pint milk bottle. The sampler weighs about 11 kg and is 38 cm long. It is equipped with tail vanes to orient the intake nozzle into the approaching flow. Because of its light weight, this sampler is limited in use to flow velocities of less than about 1.5 m/sec. It is designed for use in streams not more than 4.5 metres in depth. The instrument is calibrated and supplied with intake nozzles of 1/4 inch (6.4 mm), 3/16 inch (4.8 mm) and 1/8 inch (3.2 mm) inside diameter. It can sample to within 10 cm of the streambed.

Detailed operating instructions for the DH-59 sampler are given in Appendix B.

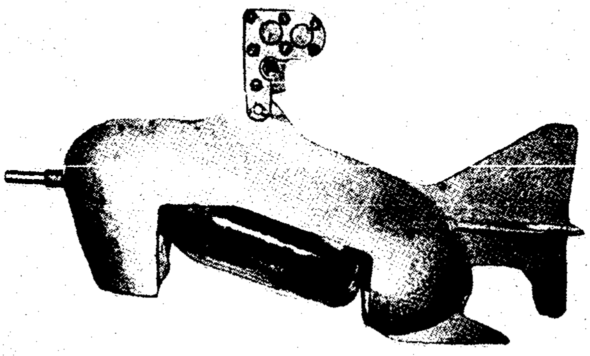


Figure 12. Depth-integrating suspended sediment handline sampler, US DH-59.

c) The D-49 sampler is a heavy type sampler for cable-and-reel suspension (Figure 13).

The sampler consists of a streamlined casting in bronze with a hinged head for closing the standard pint bottle in a cavity within the sampler body. It is 61 cm long and weighs about 28 kg. It is designed for depths of not more than 4.5 metres. The sampler is calibrated and supplied with 1/4 inch, 3/16 inch and 1/8 inch intake nozzles. It can sample to within 10 cm of the streambed.

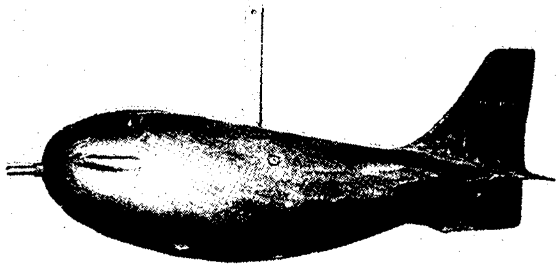


Figure 13. Depth-integrating suspended sediment cable-and-reel sampler, US D-49.

Figure 14 shows a D-49 sampler supported by a so-called bridge crane.

Detailed operating instructions for the D-49 sampler are given in Appendix B.

Regarding the intake nozzles for these three samplers, it is important to know that the nozzles may not be interchanged with the different types of samplers. The nozzles should only be used with the type of sampler for which they are designed. Table 2 will help the operator to avoid using the wrong nozzle.

The maximum transit rate through the vertical when using the depth-integrating method must not exceed 0.4 times the mean velocity of flow in the vertical.

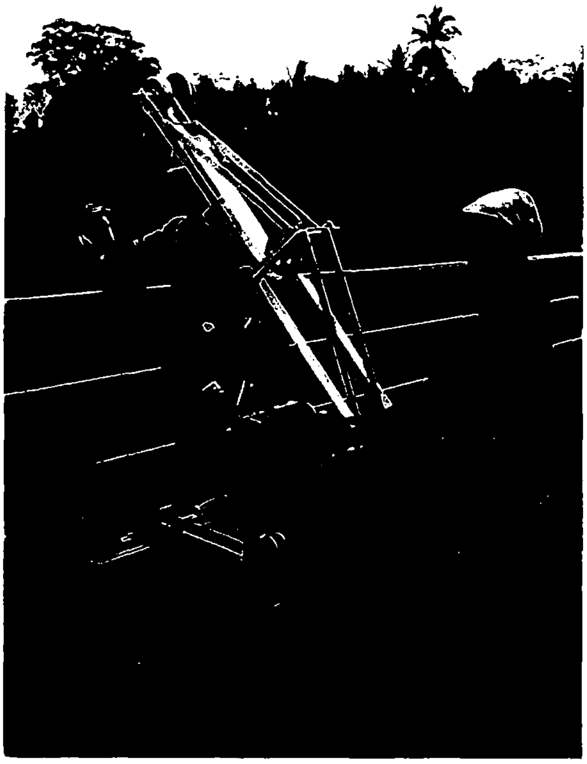


Figure 14. The D-49 sampler suspended from a bridge-crane.

The maximum theoretical sampling depths are:

2.5 metres for the 1/4 inch nozzle
4.3 » » » 3/16 » »
4.6 » » » 1/8 » »

The best and most accurate sample will be obtained with the largest nozzle that can be used in a given situation.

Table 2. Guide for Comparing Intake Nozzles of Suspended Sediment Samplers [7]

Sampler	Length	Exhaust end of nozzle tapered 1/4-inch per foot about 1-inch deep	Flat place on knurled collar of nozzle
DH-48 (wading)			
1/4-inch nozzle only	4 1/8-inches	No	No
DH-59 (handline)			
1/4-inch	4 1/8-inches	Yes	No
3/16-inch	4 1/8-inches	Yes	No
1/8-inch	4 1/8-inches	Yes	No
D-49 (reel mounted)			
1/4-inch	3 7/8-inches	Yes	Yes
3/16-inch	3 7/8-inches	Yes	Yes
1/8-inch	3 7/8-inches	Yes	Yes

4.5.2 Point-Integrating Samplers

Point-integrating samplers are designed to accumulate a water-sediment specimen which is representative of the mean concentration at any selected point in a stream during an interval of time. Point-intergrating samplers are similar to depth-integrating samplers. The main difference is that the point-intergrating sampler is provided with a control device in the intake-exhaust passages in order to start and stop the sampling process. Further, the pressure in the sample container is balanced with the hydrostatic pressure in order to prevent an initial inrush of water as the intake is opened at the sampling point.

Point samplers are also designed so that the intake velocity through the nozzle during sampling is the same as the local velocity at the sampling point. Thus, by observing the time required to collect a sample and measure the volume of the sample, the stream velocity at the sampling point may be calculated.

Because the intake and the air exhaust are controlled, point-integrating samplers may be used to collect depth-integrated samples by leaving the control valve open as the sampler is moved through the vertical.

The F.I.A.S.P. has developed three point-integrating samplers. The samplers are of similar design but of different sizes:

a) The P-61 sampler consists of a streamlined cast bronze body in which the sample bottle is enclosed. It is 71 cm long and weighs about 48 kg (Figure 15).

   The sampler is calibrated with a 3/16 inch (4.8 mm) intake nozzle. It is operated by reel-and-crane from a bridge or cableway and can be used to depths of up to 45 metres.

   During sampling, the intake and exhaust canals are controlled by a battery-operated valve. The resistance of the mechanism is about 24 ohms and the minimum current required is about one ampere. Minimum voltage needed is about 36 volts (10 m suspension cable). However, a current supply of 48 volts is recommended. The battery connection is through a two-conductor current meter cable, diameter about 3 mm, which also serves as the suspension cable.

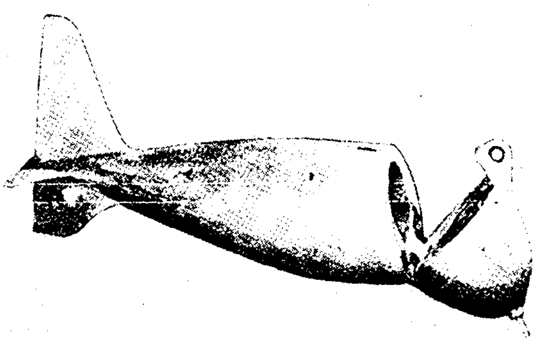


Figure 15. Point-integrating suspended sediment cable-and-reel sampler, US P-61.

b) The P-63 sampler weighs 91 kg and is 86 cm long. The make and form, the valve mechanism and the operation of the P-63 sampler is identical to the P-61 sampler. Standard pint (473 ml) or quart (946 ml) glass milk bottles may be used as sample containers. The sampler is designed for depths of up to 55 metres. Due to its weight, the sampler requires rugged cable-and-reel suspension.

c) The P-50 point sampler weighs 136 kg and is 112 cm long. Its operating characteristics are similar to the P-63. The P-50 sampler is designed for use in extremely deep streams of high velocity. It can be operated at maximum depths of 60 metres. A standard quart milk bottle is used as a sample container. Obviously, this sampler requires very rugged support.

   The NEYRPIC point sampler (Figure 16) is designed to take an undisturbed water sample in flowing water within a range of velocity from 0.3 to 4.0 m/sec. The sampler weighs 93 kg and is 175 cm long ready-assembled. It can sample to within 12 cm of the streambed. Maximum sampling time in seconds at a point is equal to the number 1950 divided by the velocity of flow in cm/sec. The sample container is a glass bottle of one litre capacity.

   A continuous flow of compressed air is used to prevent the stream water from entering the sampler as the sampler is lowered and raised before and after the sampling operation. During the sampling interval, the air is released from the sampling container through two venturi tubes at a rate controlled by the local velocity of flow, allowing the water to enter the sampling tube at the same velocity as that of the flow in the immediate vicinity of the sampler. A special hollow cable, 8.5 mm in diameter, may be used as both support for the instrument and to provide a supply line for the compressed air, either from an air cylinder or from a compressor. The air supply may also go through external rubber tubes connected to the sampler. Maximum sampling depth is equivalent to maximum pressure of compressed air that can be supplied to the instrument.

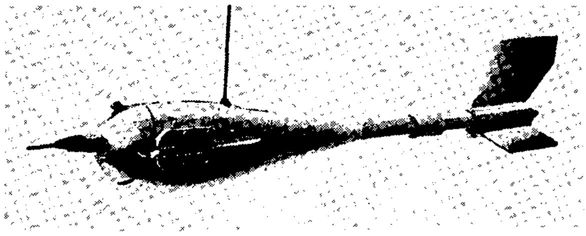


Figure 16. The NEYRPIC point-integrating suspended sediment sampler.

4.6 Care and Maintenance of Suspended Sediment Samplers

Suspended sediment samplers are designed for precise work and should receive careful handling at all times to prevent damage to the body, catch, hinge, exhaust port and the tail vanes.

The intake nozzle is especially vulnerable. The condition of the nozzle tip is of primary importance for the correct functioning of the sampler. Therefore, extreme care of the nozzles is required. A box is provided for transporting the sampler and the instrument should always be kept in it when not in use. The nozzle must be removed from the body before stowing away and put in its proper place provided in the box (Figure 17).

The contact between the bottle and the gasket seal must be airtight. It can be tested for leaks by closing off the air exhaust port and blowing into the intake nozzle.

If leakage appears, the gasket should be checked to see if the mouth of the bottle is sealed properly. If it is not, the gasket seal should be adjusted or replaced.

During use, the sampler should be cleaned and oiled at least once a week. Before stowing away in storage, the sampler must always be cleaned and oiled.

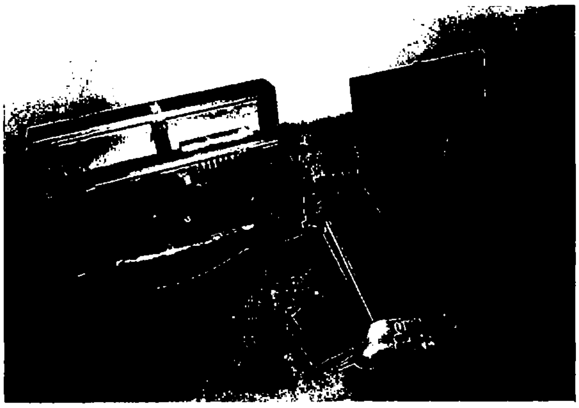


Figure 17. Cases for sediment samplers.

4.7 Sample Containers

The general requirements for sample containers are as follows [10]:

1. The volume of the sample container must be large enough to satisfy laboratory requirements. For routine sediment concentration determination, a sample volume of 300–400 ml is adequate.
2. The container must be made of a material that will not react chemically with the sample and interfere with laboratory analysis. For concentration and size analysis of sediment, low-sodium glass containers are adequate. This is the type usually used for milk bottles.
3. Samples should be collected and transported to the laboratory in the same container. Laboratory tests indicate that as much as 18 percent of the sediment may be lost when a sample is poured from one container to another. The errors are usually greater at low concentrations when the total amount of sediment in the container is small.
4. Containers should have a smooth inner surface free of sharp corners or ridges. Surface irregularities complicate the removal of sediment.
5. Containers must be made of a material sufficiently strong to withstand the ordinary impacts encountered in the field, handling in transport and in the laboratory.

The material should also be hard enough to withstand repeated scrubbing without being scratched.

6. Container material should be transparent to facilitate visual inspection of the samples.
7. Containers should be formed to receive airtight caps. The caps should remain tight through temperature changes and impacts usually encountered in transport.

As noted before, the suspended sediment samplers developed by the F.I.A.S.P. are designed for use with a US standard pint-sized glass milk bottle as sample container (Figure 18). This except for the P-63 and P-50 samplers where a standard quart milk bottle is used.

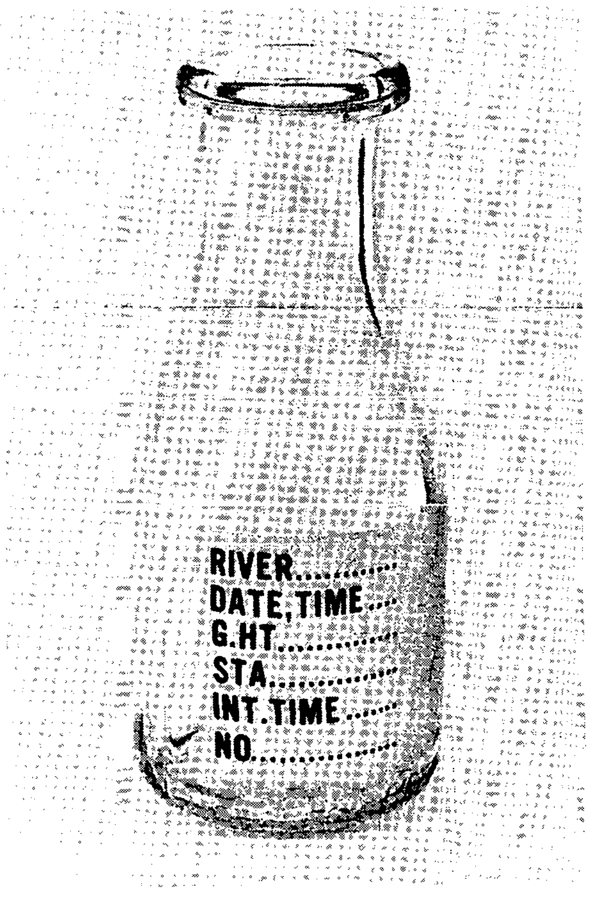


Figure 18. The US pint-sized glass milk bottle as used for sample container.

Because the bottle is at an angle from the vertical during sampling, a pint-sized bottle filled to more than 440 ml will probably be in error due to circulation of the water-sediment mixture through the exhaust passage. A bottle filled to a level between 300 and 400 ml is recommended. For an accurate analysis of sediment concentration of a sample in the laboratory, at least 250 ml is required, see Appendix C.

Table 3 gives the filling time of a 400 ml sample at different velocities of flow.

Table 3. Total Filling Time for a Suspended Sediment Sample of 400 ml of Water-Sediment Mixture

Average flow velocity in vertical m/sec	Filling time in seconds		
	Size of nozzle		
	1/4-inch	3/16-inch	1/8-inch
0.25	47	80	118
0.50	24	42	94
0.75	18	30	63
1.00	13	23	51
1.25	11	19	41
1.50	8	15	33
1.75	7	13	29
2.00	6	11	24
2.25	6	10	21
2.50	5	9	20
2.75	5	8	18
3.00	4	7	17

Bottles are usually transported and stored in wooden cases holding 20 to 30 bottles. In the field, however, it is practicable to use a smaller bottle carrier holding six, eight or 10 bottles, thus providing a convenient place to keep the bottles during sampling (Figure 19).

Each bottle should have a permanent serial number marked on it with water-resistant paint.

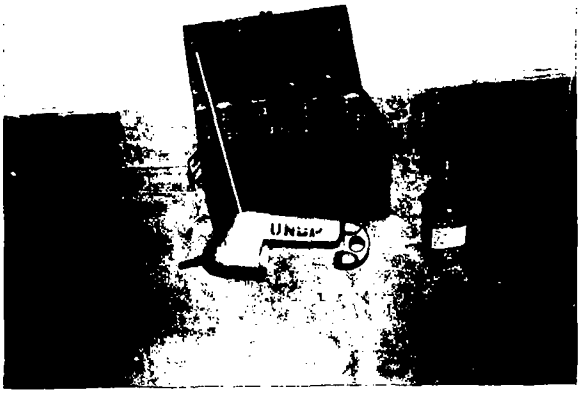


Figure 19. Case for sample bottles.

4.8 Bedload Sampling Equipment

The transportation of bedload material can not be obtained by separate measurements of water discharge and sediment concentration as is done for the determination of suspended sediment load. This is due to the fact that bedload material does not travel at the same velocity as the flowing water.

Different methods of measuring bedload have been devised including samplers of various design, *acoustic* measurements, *volumetric* measurements and the *concentration* method. Methods for indirectly computing bedload transport have also been developed. Presently, there are new equipment and techniques under development. However, there is as yet no satisfactory single method available for determination of bedload transport for all types of streams and for all hydraulic conditions.

The following are some of the factors making reliable bedload measurements difficult to obtain:

1. The extreme fluctuation both in space and time of bedload movement as the bedload usually travels in the form of ripples, dunes and sand bars.
2. Difficult to construct a sampling device that will take the correct position and that will not disturb the bedload movement when placed on the bottom of a stream.
3. Difficult to calibrate bedload samplers as the catch is not constant, it varies with both the hydraulic conditions and with the characteristics of the bedload.

4.8.1 Bedload Samplers

Bedload samplers have been developed to determine rate of bedload transport of sediment particles varying in size from 1 to 300 mm. The samplers are classified according to their construction and principle of operation. There are three types, namely, the *basket* type (Figure 20), the *pan* type (Figure 21) and the *pressure-difference* type (Figure 22).

The basket type samplers are generally made of mesh material with an opening on the upstream end through which the water-sediment mixture passes. The mesh material should pass the suspended sediment but retain the sediment moving along the bed. The pan type samplers are usually wedge-shaped in longitudinal section. The pan contains baffles or slots to check the moving material.

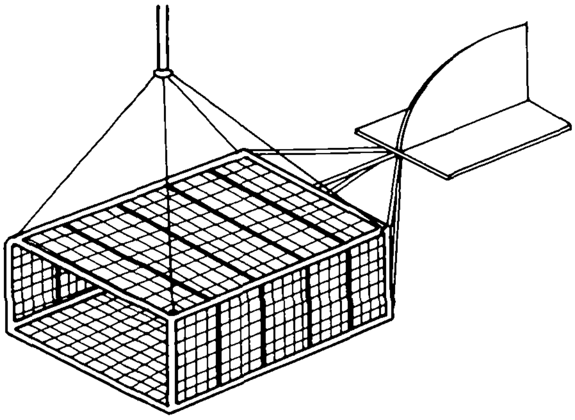


Figure 20. Basket type bedload sampler.

The basket type and the pan type samplers cause a marked decrease of the velocity of flow in front of the sampler with the result that a part of the bedload accumulates at the entrance and some of it is diverted. The pressure-difference type is designed to eliminate or reduce this change in flow pattern in the vicinity of the sampler. A solution to the problem lies in the formation of a pressure drop at the exit of the apparatus just sufficient to overcome the energy losses, thus giving the same entrance velocity as that in the undisturbed stream. This is accomplished by designing the instrument with a section diverging in a downstream direction which will cause suction at the entrance. With such a diverging section, the velocity towards the downstream end of the sampler is decreased and some of the material is deposited. Thus, if this section is of sufficient length, the necessity of a collecting screen at the exit end may be eliminated.

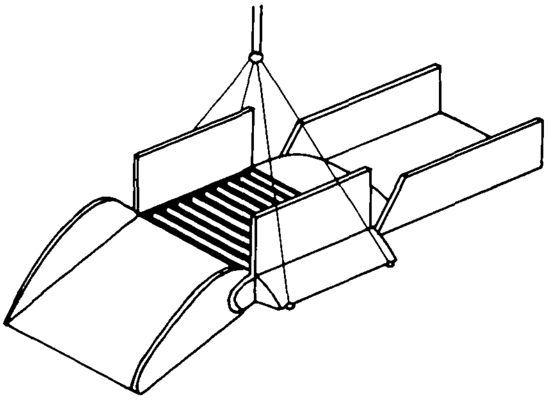


Figure 21. Pan type bedload sampler.

Some of the samplers of this type have a collecting screen, while others have only baffles to check the movement of the material.

Calibration of bedload samplers have indicated a sampling efficiency of about 45 percent for the basket and pan types and about 70 percent for the best-designed pressure-difference type. The efficiency of a bedload sampler (ratio of trapped bedload to that actually moving) is not constant, it varies with method of supporting the sampler, hydraulic conditions, particle size, bed stability and bed configuration.

The basket sampler is best suited for mountainous streams transporting coarse gravel. The pan sampler is best for slow rates of transport in sand-bed streams. However, the pressure-difference sampler is probably the better design for sand-bed streams. The ARNHEM sampler, designed by the Government Hydraulic Structures Bureau of Holland, seems to be the best of its kind today. (Figure 22).

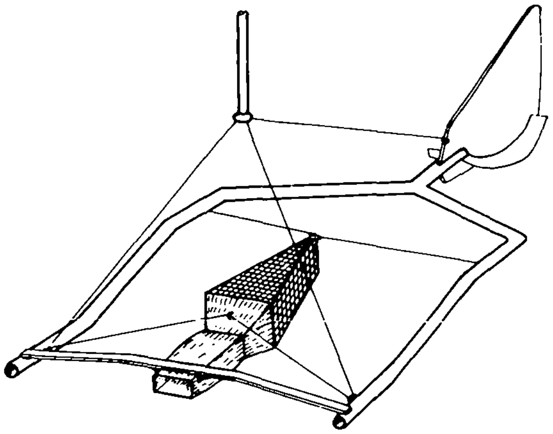


Figure 22. The ARNHEM pressure-difference type bedload sampler.

4.8.2 Acoustic Instruments

Simple mechanical devices (pipes, etc.) to listen to the movement of bedload on the bottom of streams have been in use for a long time. More refined instruments using high-frequency sound waves have been devised in recent years and are under development.

4.8.3 Tracer Studies

Methods using tracers and tagged bed material are currently under development. Such studies can provide useful and detailed information on bedload transport processes. Up to now, the method has been limited to studies of direction of travel and areas affected by sedimentation.

Fluorescent and radioactive tracers are used. The tracer element commonly consists of natural bed material from the stream of interest or graded sand and gravel. The particles are coated with a fluorescent dye or a radioactive substance. The tracer methods require four steps: 1) preparation of the tracer material, 2) injection, 3) sampling of the dispersed tracer, and 4) analysing the samples.

The tracer methods for measurement of bedload transport has made considerable progress and is well established. However, a quantitative interpretation of the measurements has proved to be difficult. In fact, the problem of developing a general expression of the dispersion of bedload tracers still remains to be solved.

4.9 Bed Material Sampling Equipment

Bed material samplers collect samples of the material present in the streambed. As compared to bedload samplers, they are simpler in design and easier to handle. The object of these samplers is only to collect samples of the upper layer of a moving sand-bed without unduly disturbing it or boring too deeply into the bed material. When bringing the sample out from the stream, it should not lose any appreciable part of the sample, especially the coarser portion. Very elaborate arrangements are not generally required for these samplers.

There are several designs of bed material samplers:

a) The *scoop* type hand sampler attached to a rod (Figure 23). This sampler is used in streams not deeper than 2–3 metres.

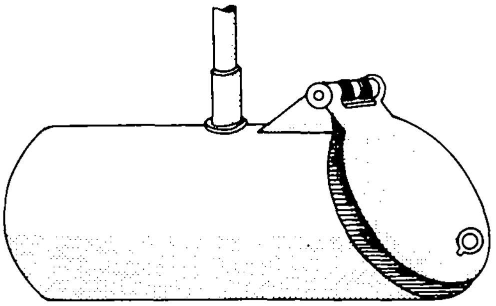


Figure 23. Scoop type bed material sampler.

b) The *piston* type hand sampler, for example, the US BMH-53 sampler (Figure 24). It is used in shallow water where it is possible to wade.

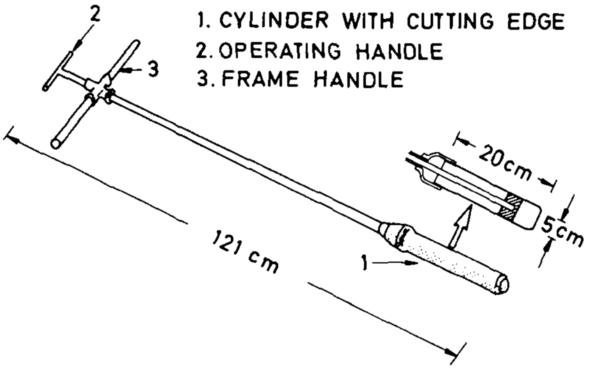


Figure 24. Piston type bed material hand sampler, US BMH-53.

c) The *clamshell* sampler (Figure 25). The jaws of the bucket are closed by an automatic spring system. The sampler may be mounted on a rod or suspended in a handline. It is used in quiescent water.

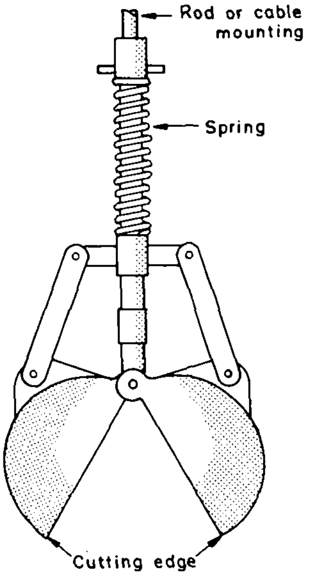


Figure 25. Clamshell type bed material sampler.

d) The US BMH-60 handline *rotary-bucket* sampler (Figure 26) weighs about 16 kg and is 55 cm long. The bucket capacity is 200 cm^3. The bucket is cocked in the open position. Then, when the sampler is rested on the bottom, the bucket is released and scoops up a 5 cm deep sample. The sampled material is enclosed and will not be washed out as the sampler is raised to the surface.

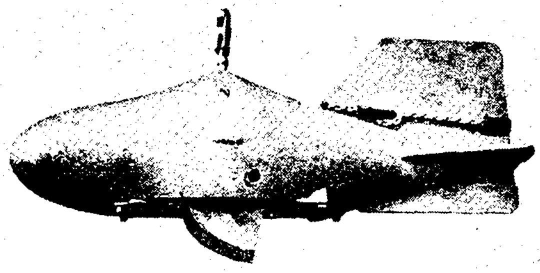


Figure 26. Handline spring-driven rotary-bucket bed material sampler, US BMH-60.

e) The US BM-54 sampler is similar to the US BMH-60 sampler. It weighs 45 kg and is used in large swift rivers with cable-and-reel suspension.

References [6], [7], [9], [10], [11].

5 SEDIMENT SAMPLING METHODS AND PROCEDURES

5.1 Suspended Sediment Sampling

The general procedure for taking sediment samples is similar to that for taking velocity measurements. Sediment samples are collected at depth verticals across the section to be sampled. Each vertical is sampled either by integration throughout its depth or by integration over a short period of time at representative points in the vertical.

5.1.1 The Depth-Integrating Method

Depth-integrating sampling requires that the sampler is lowered and raised uninterruptedly at a uniform transit rate through the range in depth of the sampling vertical. At the bed of the stream, the sampler must be reversed as quickly and smoothly as possible immediately it touches the bottom.

The method of depth-integrating is based on the assumption that, since the sampler is designed to admit the water-sediment mixture at a rate proportional to the velocity of the approaching flow and that in traversing the depth of a stream at a uniform speed, the sampler will receive at every point in the vertical a small instantaneous specimen whose volume is proportional to the local stream velocity. In this way, the collected sample will be representative of the mean concentration and particle size distribution in the vertical. In principle, one sample only is required from each vertical.

There are two different procedures for carrying out depth-integrating sampling, namely, 1) depth-integrated samples collected at stream verticals representing areas of equal water discharge in the cross-section, the *equal-discharge-increment* (EDI) procedure, and 2) depth-integrated samples collected at equally-spaced verticals in the cross-section, the *equal-transit-rate* (ETR) procedure.

5.1.1.1 The Equal-Discharge-Increments (EDI) Procedure

In the equal-discharge-increment procedure, the channel cross-section is divided into several segments of equal water discharge and depth-integrated samples are collected at their centroids. That is, the operator lowers and raises his sampler from the surface to the bottom and back at the centroid vertical at each equal discharge segment.

The transit rates of the sampler (rate at which the sampler is lowered or raised) need not be the same at each different vertical; also, the transit rate for the descending trip and the ascending trip need not be equal. However, the rate for each trip must be constant and uniform. This procedure will yield for each vertical a velocity-weighed sediment sample which gives the mean sediment concentration in each vertical. Thus, the discharge-weighed mean sediment concentration for the whole cross-section is equal to the average of the several vertical means. Also, provided all samples are of the same volume,

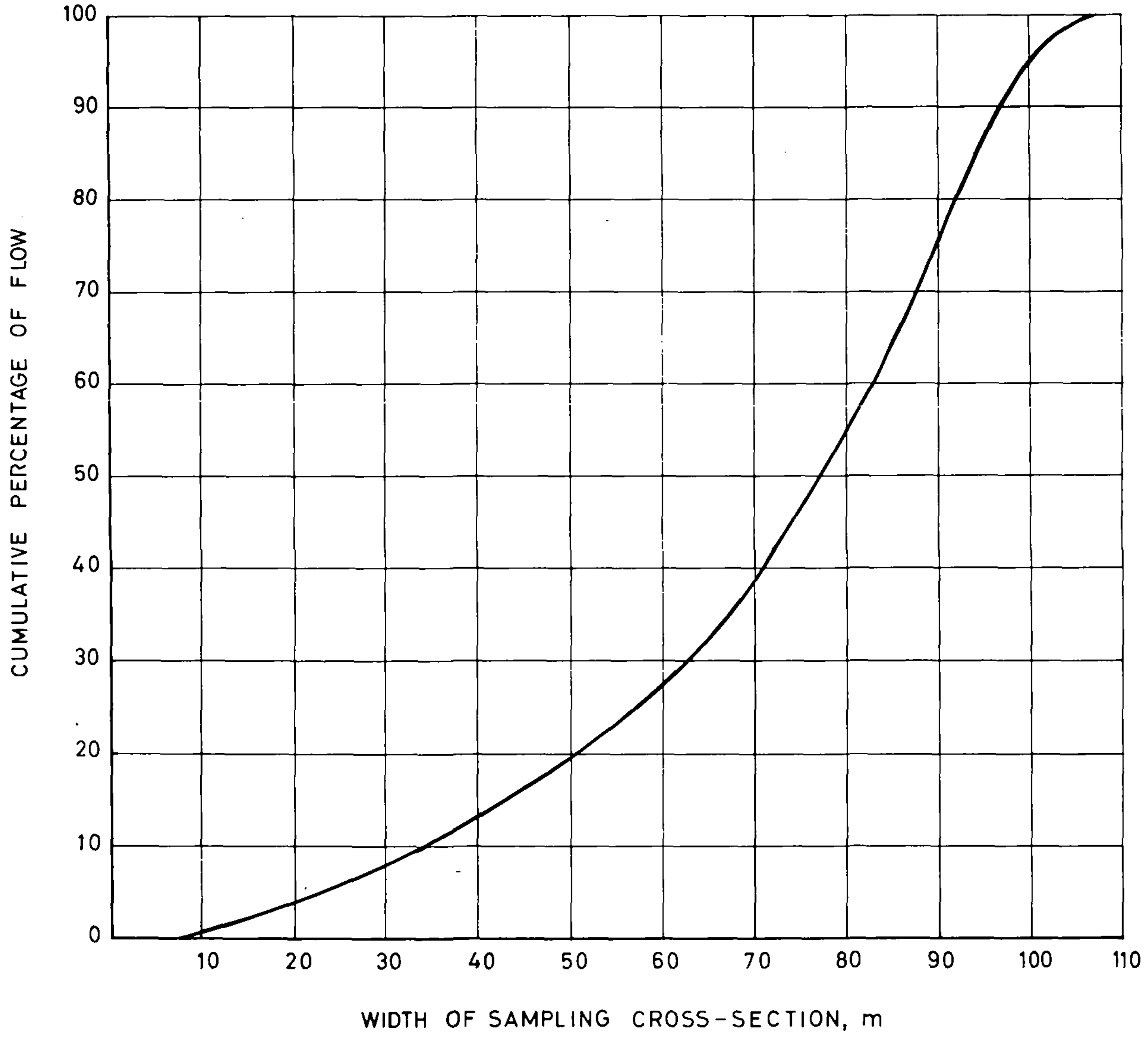


Figure 27. Plot of cumulative discharge in percent against distance from initial point.

the mean concentration for the cross-section is also equal to the concentration of the composited samples. (This means, as will be explained later, that samples collected by the EDI procedure for particle size analysis, must all be of the same volume).

The EDI procedure requires that the operator has prior knowledge of the streamflow distribution in the cross-section in order to select the sampling verticals. For sites with a stable stage-discharge relation, the following procedure is applicable. From a discharge measurement, a graph is plotted of cumulative discharge in percent of total discharge against distance from the initial point for the measurement. A decisison is then made of the number and location of the verticals required to define the sediment concentration in the cross-section (Figure 27). For example, if three sampling verticals are required, then the verticals would be located at the mid-point of each 33 1/3 percent increment in discharge. That is, the sampling verticals would be located at cumulative discharges of 17, 50 and 83 percent. Several graphs should be plotted representing various discharges.

For sites with a shifting stage-discharge relation, a water discharge measurement must precede the sediment measurement in order to determine the location of the sampling verticals. The procedure is illustrated in Appendix D.

In actual practice, the location of the sampling verticals is often approximated only. In such cases, the following rule of thumb may be used: When the cross-section to be sampled is fairly uniform, two methods may be used to select verticals so that they represent sections of approximately equal discharge. If the cross-section is wide, shallow and uniform, verticals selected at 1/6, 1/2 and 5/6 of the stream width will divide the cross-section into three subsections of equal discharge. If the cross-section is more or less U-shaped, V-shaped or nearly parabolic, a closer approximation to three areas of equal discharge can be made by selecting verticals at 1/4, 1/2 and 3/4 of the stream width.

The general practice, when sampling according to the EDI-scheme, is to collect two sample bottles at each vertical, thus obtaining two sets of cross-section samples. Laboratory time for analysis of the samples can be saved if the contents in each bottle have approximately the same volume, permitting the bottle contents of each cross-section set to be composited into one cross-section sample only.

The advantages of the EDI-scheme is that it requires comparatively few sampling bottles (samples) and that it is more adaptable than the more rigid ETR scheme.

As noted above, different transit rates can be used for the verticals, even the downward and upward transit rate for one and the same vertical need not be the same. If during sampling the bottom is reached sooner than expected, the raising rate may be slower than the lowering rate in order to give the correct sampling time. Similarly, if the lowering rate was too slow, the total time can be adjusted by raising the sampler at a slightly higher rate, though still uniform speed.

The number of verticals in an EDI measurement should not be less than three.

5.1.1.2 The Equal-Transit-Rate (ETR) Procedure

In the ETR procedure the verticals are equally spaced over the cross-section and one depth-integrated sample is collected at each vertical. The same transit rate must be used for all verticals, also, an equal rate for lowering and raising the sampler must be applied.

As the water-sediment mixture is admitted at a rate proportional to the local stream velocity at the intake and as the same transit rate is used for all the verticals, the sample from each vertical is automatically discharge-weighed. Therefore, the composite of all the samples will yield the correct mean concentration for the cross-section. Obviously, it is necessary to use the same nozzle for all verticals in a given measurement.

As previously noted, the maximum transit rate must not exceed 0.4 times the mean velocity in a given vertical; that is, the minimum transit rate must be sufficiently fast to prevent any of the sample bottles from overfilling. It follows that the transit rate to be used for all verticals is governed by the vertical representing the highest discharge per unit width; that is, the largest product of depth times velocity. Generally, the operator will soon acquire a "feel" for the location of this maximum vertical by sounding for depth and comparing the force of the current against the wading rod or an empty sampler. The transit rate required at the maximum vertical must be used at all the other verticals in the section. At verticals with less than half the flow of the maximum vertical, it is possible to sample two (and even more) verticals in one and the same bottle.

In slow-moving water, it is often impractical to use a very low transit rate, especially when wading. Under such circumstances, it is advisable to use a higher transit rate and make several trips in the vertical. In streams with sluggish flow, the sediment is generally of very fine material and the samples will not be affected if the transit rate should be somewhat faster than the theoretical limit.

ETR measurements are especially applicable to wide and shallow sand-bed streams where the distribution of the water discharge across the stream is not stable. The number of verticals to be used depends on the lateral variation of sediment concentration. For all but the very wide and shallow streams, 20 sampling verticals are considered sufficient.

An ETR measurement has some advantages over an EDI measurement:

1. No water discharge measurement has to precede an ETR measurement.
2. On the contrary, an ETR measurement makes it possible to compute the approximate stream discharge if the spacing of the verticals, the stream depth at each vertical, the length of time the sampler is under water and the volume of the sample is recorded. This is possible because the water enters the sampling bottle at the stream velocity and the sample volume is then proportional to the integrated velocity in the verticals.

   The mean velocity in the vertical can then be calculated by the equation:

   $$v = \frac{V}{\bar{A}t} \qquad (5.1)$$

   where
   v = mean velocity of flow (cm/sec)
   V = volume of the sample (cm^3)
   A = cross-sectional area of nozzle intake (cm^2)
   t = total transit time to obtain the sample (sec).

   In order to determine the velocity in this way, the transit rate must be less than 4/10 of the flow velocity.

   The stream discharge will be the summation of the velocity and area product for each sample segment of the stream.
3. Analysis time and work in the laboratory can be saved because all the samples can be composited to yield one single mean sample for the entire cross-section.
4. The ETR procedure is more easily taught to the local observers than the EDI procedure.
5. The ETR procedure gives the more accurate result.

An ETR measurement is illustrated in Appendix E.

5.1.1.3 General Sampling Procedure for the Depth-Integrating Methods

The operator places a clean sampling bottle in the sampler and checks that the bottle is sealed airtight and that there are no obstructions in the intake nozzle or in the exhaust tube. This is accomplished by blowing into the intake nozzle while closing the exhaust port with a finger; if air is passing, the seal is not airtight. Blowing into the intake nozzle with the exhaust port open will detect whether or not there are obstructions in the air passages.

The sampler is lowered to the water surface so that the intake nozzle is above the water and the vertical tail vane is in the water allowing the sampler to be properly oriented before it is submerged.

The depth-integrating is done by lowering the sampler to the streambed at a uniform and constant transit rate. When the sampler touches the bottom, it should be raised immediately, again at a constant rate.

In the EDI sampling scheme, the transit rates used at the different sampling verticals need not be the same. Neither does the downward transit rate need to be the same as the upward transit rate in a given vertical. But, in order to obtain a velocity-weighed sample, a given rate upward or downward, must be uniform.

In the ETR sampling scheme, on the other hand, only one and the same transit rate can be used for all the verticals in the sampling section.

The sampling bottle should be filled to between 300 and 440 ml, that is, to between 8 and 13.5 cm above base of bottle (Appendix C).

When a stream is shallow or the current is very slow, it is better to make the round trip from the surface to the streambed and back more than once, in order to obtain the sample.

During high water, when the depth exceeds the theoretical 4.5 metres limit, the operator should try to obtain a sample even if the recommended transit rate is exceeded. The practical sampling depth may be more than the theoretical if the velocity is not too high and especially if the suspended sediment consists mostly of fine materials such as clay and silt.

To avoid striking the nozzle into a dune or settling the sampler into a soft bed, a slow downward transit rate and a faster upward transit rate are recommended when sampling according to the EDI-scheme.

It is essential that the sampler is not left resting on the bed after touching it; the sampler must be raised immediately.

When sampling streams transporting heavy loads of sand, the operator should successively take two bottles, as close together in time as possible, at the same vertical. Each bottle is inspected visually just after the sampling by swirling the content and observing the quantity of sand settling at the bottom. If there is an appreciable difference in the amount of sand between the two bottles, then another sample (a new set of two bottles) should be taken.

If a bottle should be overfilled, that is, closer than 5 cm from the top, or if a spurt of water is seen coming out of the nozzle when the sampler is raised out of the water, then the sample should be discarded and a new sample taken. A clean bottle must be used for each sample.

The necessary information for laboratory and computation use is indicated in Appendix C. The data may be recorded on tags attached to the sampling bottle or written on an etched part of the bottle.

5.1.1.4 Sampling for Particle Size Analysis

It is to be noted that samples taken for particle size analysis should be depth-integrated samples, and that either the EDI or the ETR sampling scheme may be used.

There is no special method for taking samples for particle size analysis; they are taken in exactly the same way as those for concentration analysis. Generally, it is best to collect separate samples for particle size analysis and concentration analysis.

For accurate particle size analysis, the amount of sediment required is greater than what is usually contained in a 300–400 ml sample. Then, for size analysis, several samples have to be taken at each sampling vertical or sampling point. In general, the quantity needed for size analysis is as follows [12]:

Method	Quantity of sediment in grammes	
	Minimum	Optimum
Dry sieve	50	100
Wet sieve	.05	0.5–1.0
VA tube	.05	1.0–7.0
Pipette	.8	3.0–5.0
BW tube	.5	0.7–1.3

Figure 28 gives number of pint bottles required for one particle size analysis.

Samples collected for size analysis are usually composited. Only in special studies may there be a need to determine the size distribution in each individual vertical.

5.1.2 *The Point-Integrating Method*

The method of point-sampling is carried out by taking samples with a sampler kept stationary at a point in the vertical for a certain period of time. This method yields a sample which represents the mean concentration at the point, taking into account the fluctuations in concentration over the sampling period. It is thus a time-integrated sample.

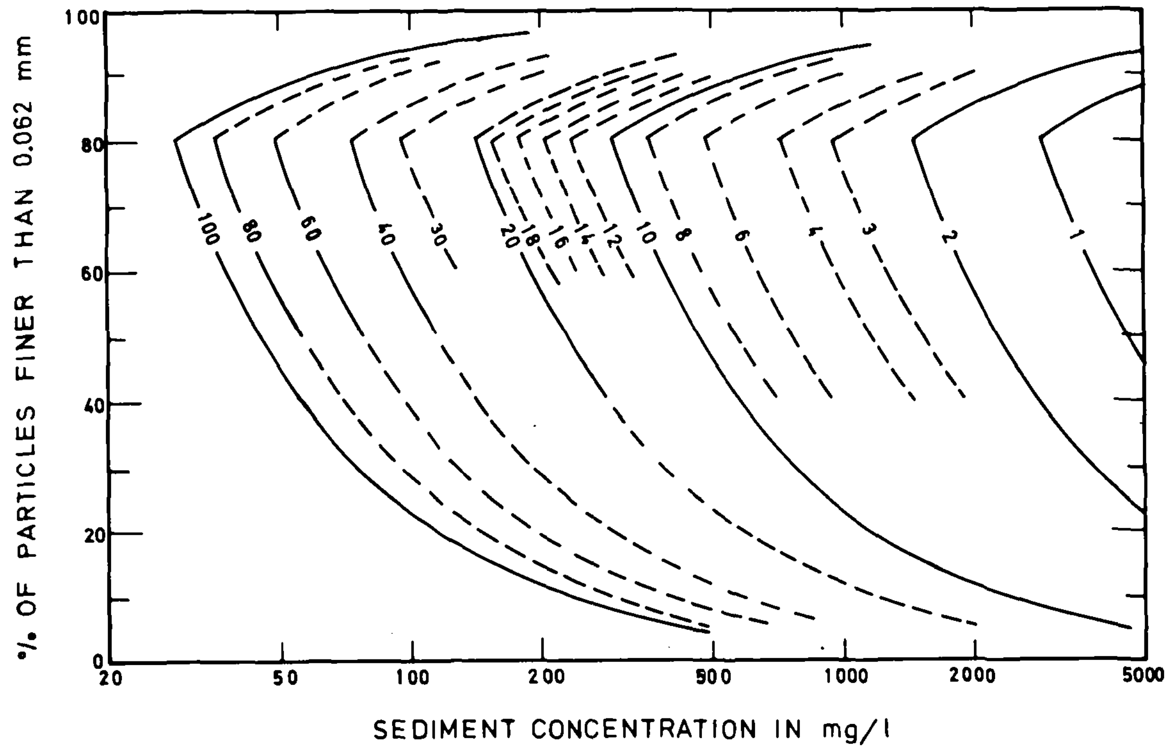


Figure 28. Minimum number of sample bottles to obtain sufficient sediment for particle size analysis [7].

Point-sampling is carried out at selected points in a vertical. The points selected for sampling are located either at 0.1, 0.4, 0.6 and 0.9 of the depth or at 0.2 and 0.8 of the depth. Using the 0.2/0.8 method, the mean concentration in the vertical is 3/8 of the concentration at 0.8 of the depth added to 5/8 of the concentration at 0.2 of the depth. This method was developed by Dr. L.G. Straub and bears his name. It is based on the assumption that the sediment concentration in a vertical is approximately linear. This assumption holds where the sediment consists mainly of fine material. By the same assumption, the mean concentration using the 0.1/0.4/0.6/0.9 method is calculated by:

$$c = 0.29 \times 0.1D + 0.36 \times 0.4D + 0.22 \times 0.6D + 0.13 \times 0.9D$$

In appendix F there is an explanation of how a velocity-weighed mean concentration for the sampling cross-section can be calculated. Also, a double graphical integration method for accurate calculation of the sediment discharge is explained.

Point-sampling is mostly used for precise measurements required in special investigations such as defining the distribution of the sediment in the cross-section. The verticals would then be equally spaced and quite numerous and many points in each vertical would be used. The work involved in analysis and computation of these precise measurements would be far too laborious for routine sampling.

Point samplers are used in streams too deep and swift for use of depth-integrating samplers. Stream depths as much as 9 metres can be depth-integrated in one direction at a time by a point-sampler, leaving the valve open. The sampler is first lowered to the streambed with the intake closed and the depth is recorded. Then a transit rate is estimated to give a proper sample volume. The upward integration must start immediately upon opening the intake nozzle. Two bottles should be obtained at each vertical, the first from bottom to surface and the second from surface to bottom. There is a slight difference in the intake ratios for the two trips; by sampling in opposite directions the difference will be eliminated.

Depths between 9 and 18 metres are sampled in four steps using four bottles. The first step consists of lowering the closed sampler to the bottom, noting the depth and estimating a transit rate. Then the nozzle is opened and the sampler raised immediately to about half the depth, at which point the nozzle is closed. The sampler is then raised to the surface and the bottle removed and labelled. Next, a clean bottle is inserted and the sampler is lowered to where the nozzle was closed on the first upward trip. At this point, the nozzle is again opened and the upper part of the vertical is sampled while raising the sampler at the same transit rate as used in the lower part of the vertical. The third and fourth steps would be to sample the upper, then the lower part of the vertical. For depths of more than 18 metres, more steps will have to be used. In addition to the usual information, the label on each bottle must indicate the segment sampled and whether it was taken on a downward or upward trip.

5.1.3 Surface and Dip Sampling

Surface or dip sampling may often be the only means of obtaining a sample under extreme conditions, such as: a) very high stream velocity, b) large floating debris carried by the flow and c) a sampler is not available.

In general, dip samples should be taken where stream water is turbulent. The operator should wade as far as possible into the stream and there keep the bottle under the water surface by hand until it is filled. At sites where the stream is flowing calm and steady, it is suggested that the cross-section with the highest velocity be chosen and that the sample is collected mid-stream at a depth of 0.6 of the total depth below the surface.

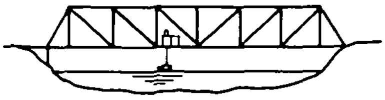
5.1.4 Routine Sampling at Daily Stations

Usually, at daily sediment stations, the routine sampling is done by local observers collecting samples at one (sometimes at two or more) fixed vertical in a stream cross-section and at one or more times a day. These local observers often need considerable supervision if they are to obtain reliable samples.

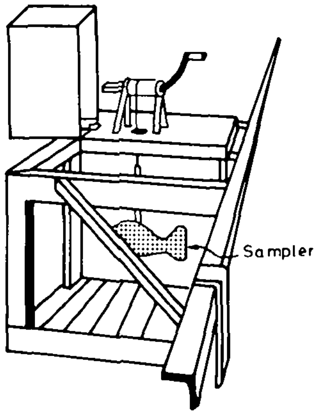
In addition to the routine sampling done by the local observers, it is necessary that a hydrographer from the field office visits the station periodically to make a complete sediment measurement in order to correlate and adjust the routine samples to the mean sediment concentration at the site. In this way, truly representative samples of the sediment concentration for the entire cross-section will be obtained from the routine samples.

5.1.4.1 The Fixed Sampler Method

A *fixed* or routine sampler, is merely a depth-integrating sampler permanently mounted on a bridge or operated by means of a cableway at a fixed vertical and where samples are taken regularly at prescribed times by a local observer (Figure 29).



Location on bridge



Platform and mounting

Figure 29. Fixed sampler installation.

The best location in the cross-section of the fixed sampling vertical is determined by trial. In this respect, a complete sediment measurement is carried out by either the EDI or the ETR multi-vertical schemes. By use of these procedures, the average sediment concentration in the sampling cross-section and the sediment concentration distribution across the section are obtained. The mean concentration in each vertical is then plotted against its corresponding distance from the initial point and from the plot a vertical is located that will give a concentration most nearly equal to the average concentration in the cross-section. This will be the fixed vertical. It should be at least 3 metres away from any obstructions such as bridge piers, etc.

A correction coefficient for adjusting the fixed sampler to the mean concentration in the cross-section is obtained by comparing the routine samples taken by it with the results of the complete EDI of ETR measurements. The correction coefficient is equal to the ratio of the average concentration of cross-section samples to the average concentration of the single-vertical samples. The correction coefficient may not be the same for the low discharges as for the high discharges, however, it generally varies systematically with discharge. Thus, different coefficients may have to be determined and applied depending on the magnitude of the flow. As a rule, coefficients within five percent of unity are not applied unless they are consistently high or low for long periods of time.

During the first few months of sampling at a new station, complete sediment measurements should be taken frequently by professional field personnel in order to establish the correction coefficient. In order to detect changes in the correction coefficient, frequent detailed measurements are necessary only during and after high water periods when major changes in the stream channel geometry may have occurred.

When establishing the correction coefficient, two samples should be collected at the fixed vertical, both before and after the complete sediment measurement. The average concentration of these four routine samples is to be compared with the mean concentration of the complete measurement. The two pairs of routine samples must be taken by the local observer in his usual way.

For streams with a stable bed and a uniform lateral suspended sediment distribution, sampling at a single vertical will usually be adequate. However, the distribution of sediment concentration across a sand-bed stream often varies markedly with distance across the stream and with time, as pointed out before. Therefore, a realistic daily sampling programme may require sampling at several routine verticals. Location of these fixed sampling verticals can be determined in the same manner as described for the single-vertical location or they may be located at the centroids of equal increments of stream discharge. As the streamflow changes with the seasons, it may be necessary to move the sampling verticals to other locations from time to time.

5.1.4.2 Automatic Pumping Sampling

Automatic pumping equipment has been developed in recent years and has been used on a limited scale.

Mostly, the intake in this method has been mounted at one fixed point with the sampling nozzle mounted at right angles to the flow. However, in a few instaces, intakes have been mounted on floating supports to obtain samples at or near the approximate centroid of discharge. Concentrations obtained from a single-point pumping sampler must be related to the mean concentration in the sampling vertical and the cross-section of flow before they can be used to compute a representative sediment discharge. The correlation coefficient and the sampling efficiency are highest for the sediment fraction finer than 0.062 mm. For the sediment fraction coarser than 0.20 mm, random errors are usually excessive. EDI or ETR samples must be obtained periodically to determine the relation between the pumped at-a-point samples and the mean concentration in the cross-section. This relation may be quite variable, but may vary systematically with stage or discharge. As in the case of single-vertical samples, representative cross-section samples will be necessary more frequently during periods of high flow, particularly when rapid rises in stage occur. [10].

5.1.5 Recording of Suspended Sediment Sampling Data.

Complete records must be made when sampling so that there is the least possible chance of information being lost or of the sampling bottles being mixed-up. For this purpose, every bottle must be provided with a label showing the name of the river, location, date and time, gauge height, depth of vertical, number of vertical, number of bottle and temperature of water, as indicated in Appendix C.

In addition, all pertinent data must be recorded on a standard Sediment Sampling Data form (Figure 30) which must accompany every set of samples. It is important that full details of the samples be given on this form as listed:

SUSPENDED SEDIMENT SAMPLING DATA

River .... Location .... Station No. .... Date ....

Discharge measurement taken: Yes .... No .... Discharge .... m^3/sec Gauge Height .... m

Observer .... Sampler type ....

Sampling Method .... Nozzle size ....

	Time	G.H.	Mean G.H.
Start			
Finish			

Serial No. of sample	Distance from Initial Point	Depth of vertical	Depth of sampling	Sampling time	Velocity at sampling point	FOR ENTRY AT LABORATORY											
						Conc. of susp. sediment, ppm	Particle sizes, ppm										

Remarks .... Analysed and Results entered by .... Date ....

.... Sediment Load Computed by .... Date ....

Figure 30. Note Sheet for Suspended Sediment Sampling Data.

1. Name of stream, location, and No. of station.
2. Date.
3. Preceding discharge measurement (if any).
4. Name of observer.
5. Type of sampler, size of nozzle, and method of sampling (routine vertical, EDI or ETR procedure, point sampling).
6. Time and gauge height at beginning of sampling.
7. Serial No. of sampling bottle.
8. Location of vertical, i.e., distance from Initial Point.
9. Depth of vertical.
10. Depth of sampling (in case of point sampling).
11. Sampling time (in case of point sampling).
12. Time and gauge height at end of sampling.

5.1.6 Handling and Transport of Samples

In order to avoid confusion, handling and transport of samples must follow set procedures. The duty of overseeing this should be allocated to special officers. The following procedure is proposed:

1. As soon as a sampling bottle has been filled, it must be properly labelled. The label may be attached to the bottle with tape, secured to the bottle by a string or written directly on a frosted part of the bottle.
2. The bottle must be properly capped in order to prevent evaporation.
3. When all the bottles for a measurement have been completed, the Sediment Sampling Data form must be filled in in triplicate.
4. To avoid growth of algae, 4–5 pipette drops of formaldehyde may be added to the bottles after sampling.
5. The samples are brought to the Regional Office. The officer responsible will take care of the samples, check the condition of the bottles and see that all required data have been recorded.
6. When one box for transport of sampling bottles to and from the Head Office has been filled, the officer-in-charge will label the box and send it to the Head Office for analysis. Two copies of the standard sediment sampling data form for each sampling must be included in the box. The third copy of the sampling form has to be filed at the Regional Office.
7. At the Head Office, the officer-in-charge of the sediment sampling programme will check the bottles to see if all required data are included. He then sends the box to the laboratory for analysis.
8. The results of the analysis are to be entered on the sampling form, the bottles are to be cleaned and the box containing the bottles returned to the officer-in-charge. One copy of the sampling form is to be filed at the laboratory.
9. The officer-in-charge files the remaining copy and returns the box with the empty bottles to the Region as soon as possible.

References [1], [6], [7],[9], [10], [11].

5.2 Bedload Sampling

5.2.1 Sampling by Bedload Samplers

The rate of bedload transport is measured by placing the bedload sampler on the streambed for a fixed time interval. The sampler is held in position by a suspension cable from a boat, from a bridge or from a cableway spanning the river. The number of measuring points in a cross-section should generally be from three to ten. The sampler should be kept on the streambed until one third of its total capacity has been filled. The time required is measured by a stop watch. The sediment collected in the sampler is dried and weighed. The dry weight, when divided by the time taken for the measurement and the width of the sampler, gives the rate of bedload transport per unit width of the stream at the sampling point.

A continuous record of bedload transport can be obtained by relating bedload transport to stream discharge. Measurements are made at various stream discharges so that a rating curve can be prepared giving the relation between water discharge and bedload transport. During flood stages, however, measurements of bedload transport are not only difficult, but impossible, in particular on large rivers.

Because of the difficulties involved in direct measurement of bedload as previously discussed (refer Section 4.8), bedload is commonly estimated by formulas based on theory and experiments, see Section 7.3.2.

Fortunately, bedload transport is usually a small fraction of the total sediment load in streams where sediment transport is of special interest. Thus, even if the estimation of the bedload fraction may be wide off the mark, the total error will not be, in general, very significant.

5.2.2 Volumetric Method

The method consists in principle of a) measuring the suspended sediment transport at a cross-section, b) measuring total deposited sediment in a lake, reservoir or a large pit just downstream from the measuring section. By subtracting a) from b), the bedload transport past the measuring section is obtained. Proper corrections may have to be applied. In this connection information on particle size distribution of the suspended sediment will be needed. The volumetric method seems to give accurate results for small streams under uniform flow conditions.

5.3 Bed Material Sampling

The purpose of sampling material from the streambed is to determine the particle size distribution of the material, information that is required in order to compute the bedload transport by formulas. The method is applicable to sand-bed streams only. The objective is to collect samples of the upper layer of the moving sand-bed without disturbing it too much or burrowing too deeply into it.

Bed material is sampled in lakes and reservoirs in order to determine the density of the deposited sediment, information needed for predicting the rate of silting up of planned water reservoirs.

Samples of bed material can be obtained by simply scooping some of it into a container. This may be done by hand in shallow water and by using a bed material sampler in deeper water.

The selection of a suitable bed material sampler is dependent primarily on stream depth and velocity. Where a stream can be waded, the most practical is a standard hand sampler, say the BMH-53. By use of a boat, this sampler may be used for depths of up to 1 1/4 metres. For deep water, the clamshell type sampler may be used for depths of up to 4 metres.

In deep and swift streams, use of the BMH-60 or BM-54 is recommended. The 16 kg BMH-60 is suitable for velocities less than 1 metre per second and depths less than 3 metres. The 45 kg BM-54 is for higher velocities and greater depths.

A bed material sample is a composite sample of the material comprising the top layer of the streambed at a given cross-section or over a short reach of channel. A sufficient number of samples must be collected to yield a representative sample of the distribution of particle sizes in the channel bed. The number of individual samples collected may vary from 3 to 15 depending on channel width, characteristics of the bed material and the operator's judgement and experience. For most purposes, only the upper 5 cm of material nearest the surface of the streambed is desired or needed in an analysis.

5.4 Measurement of Total Sediment Discharge

Standard integrating suspended sediment samplers do not collect a sample of the total suspended sediment transport in a stream. An *unsampled zone* about 10 cm thick exists near the streambed. The term *measured concentration* is therefore often used to indicate that the samples collected do not represent the total suspended sediment concentration. Samples of the total sediment load can be obtained by the so-called *contraction* method which applies usually to small streams only.

5.4.1 The Contraction Method

Streams having a natural contraction of the channel causing a high degree of turbulence may be utilized for sampling total sediment transport. In such sections, the whole sediment load is often thrown into suspension and is measured easily by standard suspended sediment samplers. The method is particularly applicable where the turbulent section consists of erosion-resisting material such as bedrock.

Turbulent flumes or special weirs can also be used to bring the total load into suspension.

References [6], [7], [9], [10].

6 LABORATORY METHODS AND PROCEDURES FOR SEDIMENT ANALYSIS

6.1 General

The principal function of the sediment laboratory is to determine the concentration and particle size distribution of the collected sediment samples.

6.2 Determination of Suspended Sediment Concentration

Concentration of suspended sediment samples may be determined by either *evaporation* or *filtration*. The evaporation method consists of allowing the sediment to settle in the sample bottle, decanting the supernatant liquid, washing the sediment into an evaporating dish and drying it in an oven at a temperature between 90° and 95°C. The filtration method consists of filtering the sample through an appropriate filter and oven-drying the filter together with the filtered sediment. This method usually utilizes a Gooch crucible and either an asbestos mat or commercially available glass-fibre disks.

After the sediment in the evaporating basin or crucible is dried, the weight of sediment is determined to the nearest 0.0001 grammes (g), i.e. 0.1 milligrammes (mg).

Suspended sediment concentrations should be reported in terms of dry weight of sediment per litre of sample (water-sediment mixture), in milligrammes per litre (mg/l).

Because of convenience in the laboratory, the concentration is calculated by dividing the weight of dry sediment by the weight of the sample and expressing the result in parts per million (ppm). If, for example, the sample weighs 400 grammes and the amount of dried sediment is 0.02 grammes, the concentration of sediment would be 0.02 grammes in 400 grammes which is the same as 50 grammes in 1,000,000 grammes or 50 ppm. Parts per million are calculated as one million (10^6) times the ratio of the dry weight of sediment in grammes to the weight of the sample in grammes.

Then, the conversion from ppm to mg/l is done by applying the conversion factor C given in Table 4 to the ppm values as follows:

$$\text{mg/l} = C \times (\text{ppm})$$

Table 4. Factor C for converting sediment concentration from parts per million to milligrammes per litre [12]

(The factors are based on the assumption that the density of water is 1.000, plus or minus 0.005, the range of temperature is $0^\circ - 29^\circ$C, the specific gravity of sediment is 2.65, and the dissolved solids concentration is less than 10,000 parts per million)

Ratio	C	Ratio	C	Ratio	C
0– 15,900	1,00	234,000–256,000	1.18	417,000–434,000	1.36
16,000– 47,000	1.02	257,000–279,000	1.20	435,000–451,000	1.38
47,000– 76,000	1.04	280,000–300,000	1.22	452,000–467,000	1.40
77,000–105,000	1.06	301,000–321,000	1.24	468,000–483,000	1.42
106,000–132,000	1.08	322,000–341,000	1.26	484,000–498,000	1.44
133,000–159,000	1.10	342,000–361,000	1.28	499,000–513,000	1.46
160,000–184,000	1.12	362,000–380,000	1.30	514,000–528,000	1.48
185,000–209,000	1.14	381,000–398,000	1.32	529,000–542,000	1.50
210,000–233,000	1.16	399,000–416,000	1.34		

It is seen from Table 4 that for concentrations less than 16,000 parts per million, parts per million equal milligrammes per litre for all practical purposes.

It is recommended that sediment concentration is reported to the nearest 0.1 mg/l up to 9.9 mg/l, for values ranging from 10 mg/l up to 999 mg/l the concentration should be reported to the nearest 1 mg/l, for higher values three significant figures should be used. These recommendations are based on the assumption that the net sediment can be weighed to the nearest 0.1 mg and the water-sediment mixture to the nearest 1 gramme.

The accuracy of sediment computations depends to a large degree on the accuracy and reliability of the laboratory work. Too small a quantity of sediment in the samples tends to magnify errors caused by weighing or transfer from one container to another. On the other hand, samples with too large a quantity of sediment sometimes cause problems in drying and weighing. For samples containing colloidal clay, it is often difficult to separate the sediment from the native water.

6.2.1 The Evaporation Method

The advantage of this method is its simplicity of equipment and technique. The sediment is allowed to settle to the bottom of a container, the supernatant water decanted, the sediment is washed into an evaporating basin and then dried in an oven.

The method works well if the sediment settles readily to the bottom of the container. However, for samples containing dispersed clay, the settling time is too long, making the method impractical unless some flocculating agent is used to reduce the settling time.

The supernatant fluid must be carefully decanted or siphoned off, so that none of the sediment is removed from the bottom of the settling container. The remainder is washed into an evaporation basin and dried in an oven at a temperature from 5° to 10°C below the boiling point; at a higher temperature sediment may be lost from the basin by "spattering". After all moisture has evaporated, the temperature should be raised to 110°C for about one hour. The evaporating basins must be kept in a dry state before weighing.

After decantation, the naturally dissolved solids (i.e. salts) in the remaining water are retained with the dried sediment. If the dissolved solids concentration is high, the weight of this material must be subtracted in order to obtain the weight of the dried sediment. As a rule of thumb, if the dissolved solids concentration in the natural water is about equal to the suspended sediment concentration, the fraction of the dissolved solids material in the dried sediment will be about 5 percent of the total weight of the material in the evaporating basin.

6.2.2 The Filtration Method

In the filtration method, a common Gooch crucible fitted to an aspirator system for vacuum filtration is usually used. The Gooch crucible is a small porcelain cup of about 25 ml capacity with a flat perforated bottom which is covered with a filtering medium during the filtering operation. The sample may be either filtered while in a dispersed state or the sediment may be first allowed to settle to the bottom of the sample bottle, the supernatant water siphoned off and the remainder filtered. Then the crucible is dried in an oven, cooled in a desiccator and weighed.

A commercially available glass-fibre filter (such as the Corning No. 934-AH) is quite satisfactory for most sediments.

If glass-fibre filters are not available, then an asbestos filter can be prepared. This is done by making a slurry of shredded asbestos in distilled water and pouring a little of the slurry into the crucible while vacuum is applied. The resulting mat is rinsed with distilled water while under vacuum, the crucible is dried in an oven at 110°C for one hour, cooled in a desiccator and finally tare-weighed.

To save time, the same asbestos mat may be used several times, especially for coarse sediment of low concentration. The gross weight of the prior use then becomes the tare weight for the next.

Often, better results may be obtained for fine sediments by using a glass-fibre filter disk in conjunction with the asbestos mat.

The filtration method has some advantages over the evaporation method as follows: a) less oven and desiccator space is needed, b) its tare weight is less likely to change during weighing due to sorption of moisture from the air and c) dissolved solids pass through the crucible thus eliminating the dissolved solids correction.

In addition, the filtration method is faster than the evaporation method, that is, as long as the sediment content in the sample is not too high. The upper limit for the filtration method is about 2000 mg/l of sediment that is mostly clay, and about 10,000 mg/l when mostly sand. Thus, the filtration method is best for the lower sediment concentrations.

If the filtration becomes too slow with the Gooch crucible, on account of clogging of the filter, the ordinary sedimentation, decantation and evaporation procedure must be used.

6.2.3 General Procedure for Concentration Analysis

1. Inspect the general condition of the sample bottles as they arrive at the laboratory from the field. Clean dirty bottles and fasten loose caps.
2. If storage is necessary before samples can be analysed, store samples in a cool dark room to retard evaporation and growth of organisms.
3. Arrange samples from a given station in chronological order when bringing them in for weighing.
4. Check and record the information from the sample labels on to the appropriate data forms as necessary.
5. Weigh the sampling bottles and record the gross weight to the nearest gramme.
6. Leave the weighed bottles undisturbed on a table or rack for the sediment to settle. This may take from one to several days.

   If the sample contains much naturally dispersed clay which does not readily settle, special procedures must be used such as adding a flocculating agent to reduce the settling time. In these cases, the filtration method for analysis should be used. The samples can be filtered when in a dispersed or semi-dispersed state.
7. Siphon off about 9/10 of the clear water taking care not to disturb or remove sediment. If required, keep this water in order to determine the amount of dissolved salts in it.
8. Using distilled water, wash the remainder into a previously tare-weighed evaporating basin or a prepared and tare-weighed Gooch crucible. During this operation, the Gooch crucible is fitted to the aspirator bottle by use of a rubber adapter and vacuum applied by use of a vacuum pump or a water suction pump connected to the water tap.
9. Clean the sample bottles and air dry. Determine the tare weight by weighing to the nearest gramme. Cap the bottles and pack them in carrying cases for reuse.
10. Dry the evaporating basins or Gooch crucibles at 90° to 95°C in an oven. After loss of all visible moisture, heat at 110°C for one hour. The water-sediment mixture must be dried at a temperature below the boiling point in order to prevent loss of sediment from the containers by spattering caused by boiling action.
11. Cool the containers (evaporating basins or Gooch crucibles) in a desiccator at room temperature.
12. Weigh the containers to the nearest 0.1 mg on an analytical balance. The tare weight of the evaporating basins and of the crucibles with filtering mat should be determined before each use.
13. Compute the net weight of the sediment in the containers and deduct the weight of the dissolved solids in the evaporation method if necessary.
14. Calculate the concentration in parts per million as:

$$\text{ppm} = \frac{\text{Dry weight of sediment (g)}}{\text{Weight of sample (g)}} \times 10^6$$

SEDIMENT CONCENTRATION NOTES, DEPTH INTEGRATED SAMPLES (Short form)

Stream and location ____________________ Computed by __________ Checked by __________

Date											
Time											
Gage height											
Sampling Sta.											
Temp. and Spec.Cond.		/	/	/	/	/	/	/	/	/	/
Remarks											
WEIGHT OF SAMPLE	Gross										
	Tare										
	Net										
Container no.											
WEIGHT OF SEDIMENT	Gross										
	Tare										
	Net										
	D.S. Corr.										
	Net										
Conc. (ppm)											

Date											
Time											
Gage height											
Sampling Sta.											
Temp. and Spec.Cond.		/	/	/	/	/	/	/	/	/	/
Remarks											
WEIGHT OF SAMPLE	Gross										
	Tare										
	Net										
Container no.											
WEIGHT OF SEDIMENT	Gross										
	Tare										
	Net										
	D.S. Corr.										
	Net										
Conc. (ppm)											

Figure 31. Laboratory form. Sediment Concentration Data, Depth-Integrated Samples [12].

15. Convert ppm into mg/l as:

$$mg/l = C \times (ppm)$$

The factor C is obtained from Table 4.

A slightly different procedure is given in Appendix G for the evaporation method to be used when the naturally dissolved salts content is high.

Figure 31 shows a Laboratory Sediment Concentration Notes form for depth-integrated samples. The form is to be used in the laboratory for recording data and for computation of suspended sediment concentrations.

6.3 Determination of Particle Size Distribution

The methods for determination of the particle size distribution of sediment fall into two classes: 1) direct measurements and 2) sedimentation methods, that is, methods based on the settling time of different sized particles in water.

Direct measurements include measurement of diameter and circumference of boulders and cobbles in the field and semi-direct measurement of diameters by use of sieves. Sedimentation methods in general use today include the *pipette* method, the *bottom-withdrawal (BW) tube* method and the *visual-accumulation (VA) tube* method.

Samples having particle sizes covering a wide range must be analysed by a combination of methods as a given method is best applicable to a specific limited range. For example, the coarse material in a sample is analysed by use of sieves, the medium-sized material by the visual-accumulation tube and the fine material by the pipette or the bottom-withdrawal tube method.

Table 5 below is a guide as to the particle size analysis concentration and the quantity of sediment desired for each method of analysis.

Table 5. Guide for selection of analysis method [12]

	Size range (mm)	Analysis concentration (mg/l)	Quantity of sediment (g)
Sieves	0.062–32		< 0.05
VA tube	0.062–2.0		0.05–15.0
Pipette	0.002–0.062	2,000–5,000	1.0 – 5.0
BW tube	0.002–0.062	1,000–3,500	0.5 – 1.8

6.3.1 Sieving

The division between fine and coarse sediment is set at 0.062 mm, the finer material consists of silt and clay and the coarser of sand and larger material such as gravel. Before sieving, the sediment sample must be prepared and split into a fine material fraction, silt and clay, and a coarse material fraction, sand and larger. Then, the coarse material fraction is analysed by sieving while the fine material is analysed by the pipette or the BW tube method.

The sample for particle size analysis consists generally of the composite of two or more standard pint sampling bottles. The sample preparation and sieving procedure would be as follows:

1. The number of bottles selected for size analysis and their gross weight together with other pertinent data are recorded on an appropriate form, such as shown in Figure 32.

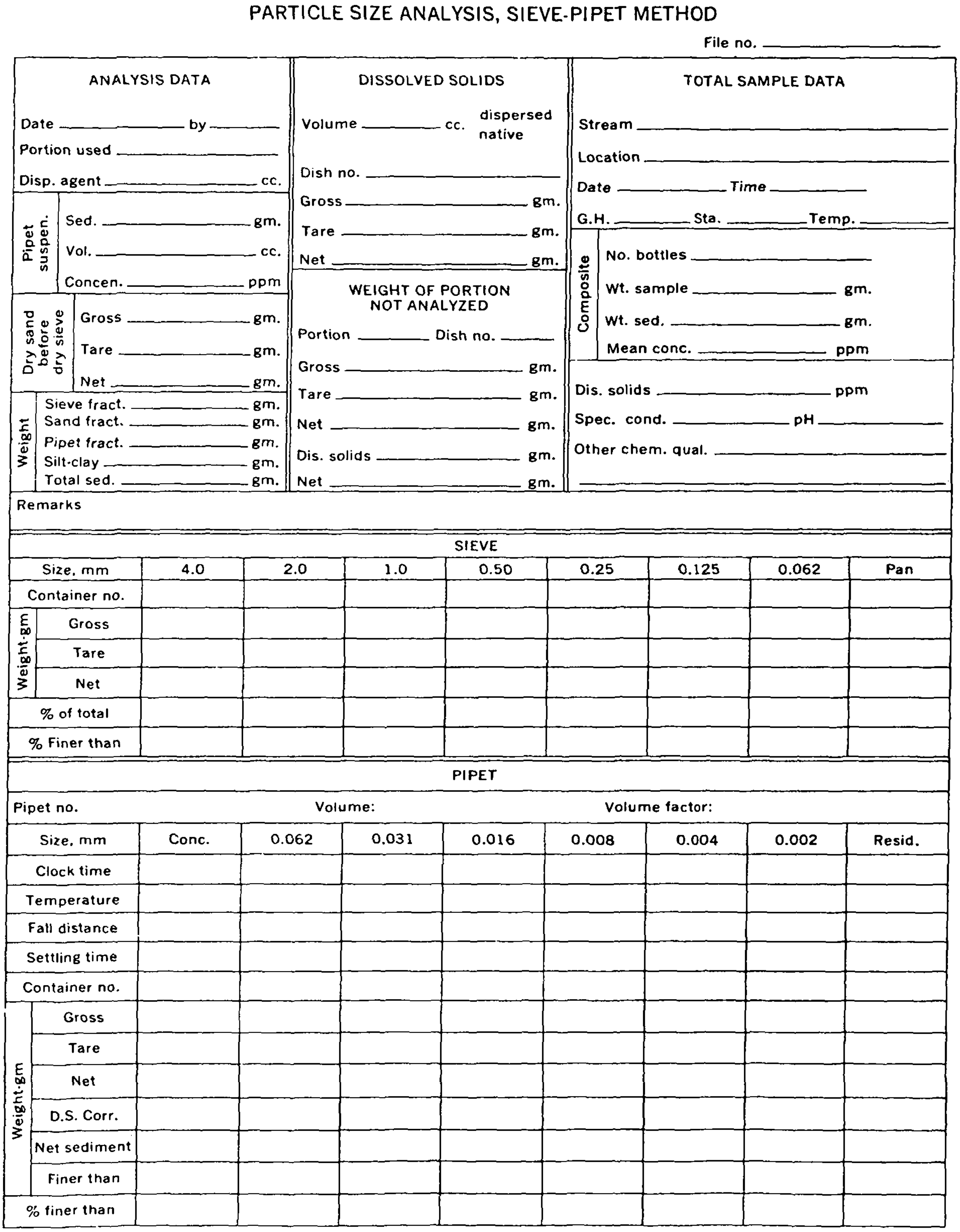
2. After the sediment has settled in the bottles, siphon out as much clear water as possible. The material remaining in the bottles is then composited. Record the net weight of the composited sample and the tare weight of the bottles.

3. The composited material is placed in a soil dispersion cup and diluted to about 300 ml with distilled water. The sample is then mixed for 5 minutes with a common milk-shake mixer (about 10,000 rpm without load).

4. Immediately following the mechanical dispersion in step 3, the sediment is wet-sieved using the 0.062 mm sieve and distilled water for washing the fine material through the sieve, the sieve is rotated and tapped gently to facilitate the operation.

   The fine material passing through the 0.062 mm sieve is stored temporarily in a suitable beaker before being further analysed by, for example, the pipette method, see Section 6.3.2 below.

5. The sand fraction remaining in the 0.062 mm sive is washed into an evaporating basin and dried in an oven, see Section 6.2.3.



PARTICLE SIZE ANALYSIS, SIEVE-PIPET METHOD

File no. ________

ANALYSIS DATA

Date ________ by ________
Portion used ________
Disp. agent ________ cc.

Pipet suspen.
Sed. ________ gm.
Vol. ________ cc.
Concen. ________ ppm

Dry sand before dry sieve
Gross ________ gm.
Tare ________ gm.
Net ________ gm.

Weight
Sieve fract. ________ gm.
Sand fract. ________ gm.
Pipet fract. ________ gm.
Silt-clay ________ gm.
Total sed. ________ gm.

DISSOLVED SOLIDS

Volume ________ cc. dispersed native
Dish no. ________
Gross ________ gm.
Tare ________ gm.
Net ________ gm.

WEIGHT OF PORTION NOT ANALYZED

Portion ________ Dish no. ________
Gross ________ gm.
Tare ________ gm.
Net ________ gm.
Dis. solids ________ gm.
Net ________ gm.

TOTAL SAMPLE DATA

Stream ________
Location ________
Date ________ Time ________
G.H. ________ Sta. ________ Temp. ________

Composite
No. bottles ________
Wt. sample ________ gm.
Wt. sed. ________ gm.
Mean conc. ________ ppm

Dis. solids ________ ppm
Spec. cond. ________ pH ________
Other chem. qual. ________

Remarks

SIEVE

Size, mm		4.0	2.0	1.0	0.50	0.25	0.125	0.062	Pan
Container no.									
Weight-gm	Gross								
	Tare								
	Net								
% of total									
% Finer than									

PIPET

Pipet no. Volume: Volume factor:

Size, mm		Conc.	0.062	0.031	0.016	0.008	0.004	0.002	Resid.
Clock time									
Temperature									
Fall distance									
Settling time									
Container no.									
Weight-gm	Gross								
	Tare								
	Net								
	D.S. Corr.								
	Net sediment								
	Finer than								
% finer than									

Figure 32. Laboratory form. Particle-Size Analysis, Sieve-Pipette Method [12].

6. After drying and cooling, the sand is brushed into a nest of 6–10 cm diameter sieves to separate it into fractions finer than 4, 2, 1, 0.50, 0.25, 0.125 and 0.062 mm. The sieves are shaken for 10 minutes on a shaker. The sand remaining on each sieve is weighed and recorded on the form.

   The sediment passing through the 0.062 mm sieve, called the pan material, is added to the fine material stored in the beaker after the separating operation in step 4.

If clay is adhering to the sand particles after the separation in step 4, wet-sieving should be used instead of dry-sieving in step 6. A simple procedure is to wash the finer material through the nest of sieves by means of a gentle jet of distilled water. This method is sufficient when the sand fraction is less than 20 percent of the total weight of sediment, which is usually the case. If the percentage is higher, more elaborate methods may have to be used.

6.3.2 *The Pipette Method*

The pipette method is used for clay and silt in the size range 0.002–0.062 mm and concentration range 2000–5000 mg/l.

The method consists essentially of withdrawing a small sample of suspension at a fixed point in a sedimentation cylinder after a certain period of time. The time and depth of withdrawal are predetermined on the basis of Stokes law. Table 6 gives recommended times and depths of withdrawal to determine concentrations finer than each of six size increments from 0.002 mm to 0.062 mm for a range of water temperatures. For example, after thorough stirring at 27°C with pipette tip at 10 cm depth and 26 minutes and 2 seconds elapsed time since end of stirring, all particles coarser than 0.008 mm would have settled below the pipette tip.

Thus, a pipette withdrawal made under such conditions would be representative of the particle size fraction finer than 0.008 mm in the sedimentation cylinder. The quantity of sediment in the pipette withdrawal is determinded by the usual drying and weighing procedure.

For calculating the results, the total weight of the sediment in the sample is required. The weight is obtained from the mean concentration and volume of the settling suspension. The concentration is obtained by making a *concentration withdrawal* with the pipette at the start of the analysis. The weight may also be determined by adding the dry weight of the sediment remaining in suspension after the completion of the pipetting and the dry weight of sediment in each pipette withdrawal.

In both cases, the dry weight of the sand fraction has to be added if the sample was split before the pipette analysis, see Section 6.3.1, step 4.

Table 6. Time of pipette withdrawal for given temperature, depth of withdrawal and diameter of particles [12]

(The values in this table are based on particles of assumed spherical shape with an average specific gravity of 2.65, the constant of acceleration due to gravity = 980, and viscosity varying from 0.010087 at 20°C to 0.008004 at 30°C)

Diameter of particle mm	0.062		0.031				0.016		0.008		0.004		0.002			
Depth of withdrawal..........cm	15	10	15		10		10		10		5		5		3	
Time of withdrawal.....	(sec)	(sec)	(min)	(sec)	(min)	(sec)	(min)	(sec)	(min)	(sec)	(min)	(sec)	(hr)	(min)	(hr)	(min)
Temperature (°C):																
20..............	44	29	2	52	1	55	7	40	30	40	61	19	4	5	2	27
21..............	42	28	2	48	1	52	7	29	29	58	59	50	4	0	2	24
22..............	41	27	2	45	1	50	7	18	29	13	58	22	3	54	2	20
23..............	40	27	2	41	1	47	7	8	28	34	57	5	3	48	2	17
24..............	39	26	2	38	1	45	6	58	27	52	55	41	3	43	2	14
25..............	38	25	2	34	1	42	6	48	27	14	54	25	3	38	2	11
26..............	37	25	2	30	1	40	6	39	26	38	53	12	3	33	2	8
27..............	36	24	2	27	1	38	6	31	26	2	52	2	3	28	2	5
28..............	36	24	2	23	1	35	6	22	25	28	50	52	3	24	2	2
29..............	35	23	2	19	1	33	6	13	24	53	49	42	3	19	1	59
30..............	34	23	2	16	1	31	6	6	24	22	48	42	3	15	1	57

The pipetting procedure would then be:

1. Transfer the split-off silt and clay fraction of the sample to the settling cylinder, add distilled water as appropriate.
2. Record the temperature of the suspension, the depth of withdrawal, the settling time, the tare weights of numbered evaporating basins for each withdrawal and other pertinent data on a form such as the one illustrated in Figure 32.
3. Stir thoroughly with a plunger type hand stirrer. Remove stirrer and immediately make a concentration-withdrawal. When pipette is filled (after about 10 seconds), empty the pipette into an evaporating basin, add one rinse (distilled water) of the pipette.
4. Stir for 1 minute with hand stirrer and start the stop watch when the stirrer is removed.
5. Make withdrawals with the pipette at depths of, for example, 15, 15, 10, 10, 5 and 5 cm as given in Table 6. The pipette is emptied into a separate evaporating basin and one rinse of the pipette is added each time.
6. Dry the material in the evaporating basins and cool in a desiccator, weigh the basins and enter the weights on the form.

The dry weight of sediment in each pipette-withdrawal when multiplied by the volume ratio, i.e. total volume of suspension divided by volume of pipette withdrawal, gives the weight of sediment in the suspension finer than the particle corresponding to the time and depth of withdrawal. This value, divided by the dry weight of the total sediment in the sample, gives the fraction or percentage of total sediment finer than the given size.

Equipment: Settling cylinder of 5 cm diameter and 500–1000 ml capacity. General purpose pipette of 10–15 ml capacity with pipette filler. Evaporation basins of 50 ml capacity.

In place of the pipette filler, a rubber tube for suction may be slipped on the top of the pipette. The pipette is held with both hands, tip at the proper level and an even suction is applied by the mouth. When the pipette is filled, the end of the rubber tube is clamped by the teeth and the content transferred to the evaporation basin.

6.3.3 The Bottom-Withdrawal (BW) Tube Method

The bottom-withdrawal tube method also operates as a dispersed sedimentation system where all particles begin to settle from an initially uniform dispersion. The apparatus consists of a transparent tube 122 cm long with inside diameter 25 mm. The lower end of the tube is contracted to a short section of small tube with inside diameter 7 mm on which is slipped a short piece of rubber tube which can be opened and closed with a pinch-clamp (Figure 33).

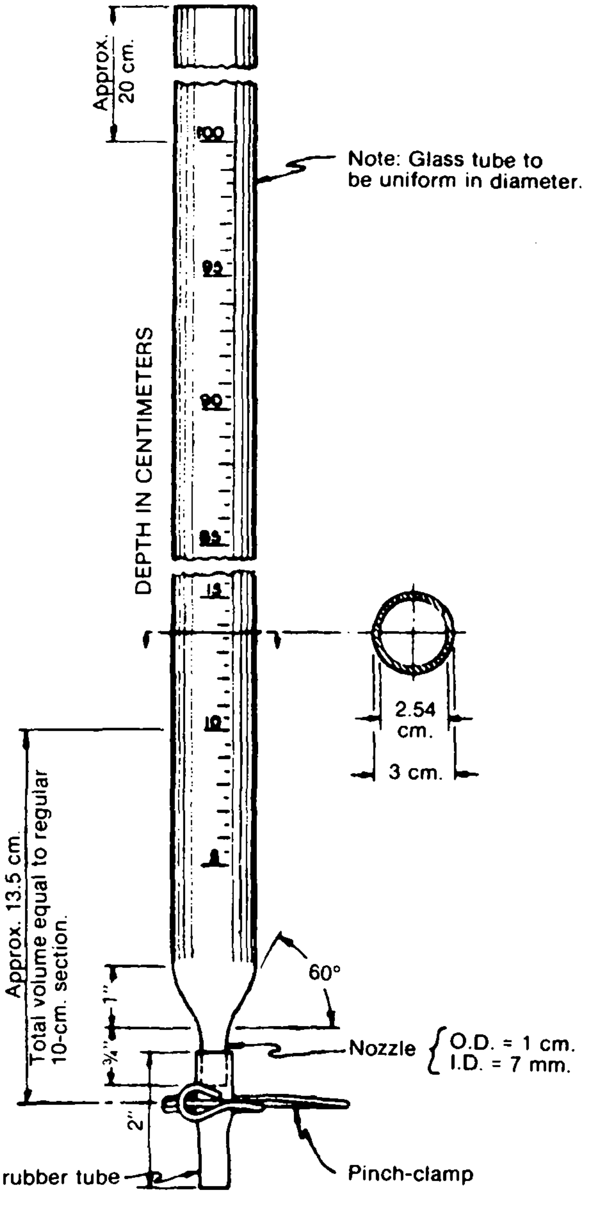


Figure 33. The standard Bottom Withdrawal Tube.

Predetermined volumes are withdrawn through the rubber tube at set time intervals. The quantity of sediment in each withdrawal is determined by drying and weighing. The method requires considerable calculation work. A detailed analysis procedure can be found in US Inter-Agency Report No. 7 of series *A Study of Methods used in Measurement and Analysis of Sediment Loads in Streams* [15]. The procedure is reproduced in Appendix H.

The BW tube method is based on the *Oden theory*. From a dispersed suspension of sediment particles in distilled water, the particles begin to settle. The accumulation of particles at the bottom of the settling tube will at any time *t* consist of all particles with fall velocities great enough to fall the entire length of the tube during time *t*, and in addition, some smaller particles which had a shorter distance to fall. An accumulation curve can be plotted as shown in Figure 34 with time as abscissa and percentage by weight of material remaining is suspension as ordinate. This is the so-called *Oden curve*.

Draw tangents to the curve at two points corresponding to time t_1 and t_2, let the tangents intersect the ordinate axis at W_1 and W_2, then the difference between the percentage W_1 and W_2 will represent the percentage of material in a size range with limits corresponding to the settling times t_1 and t_2.

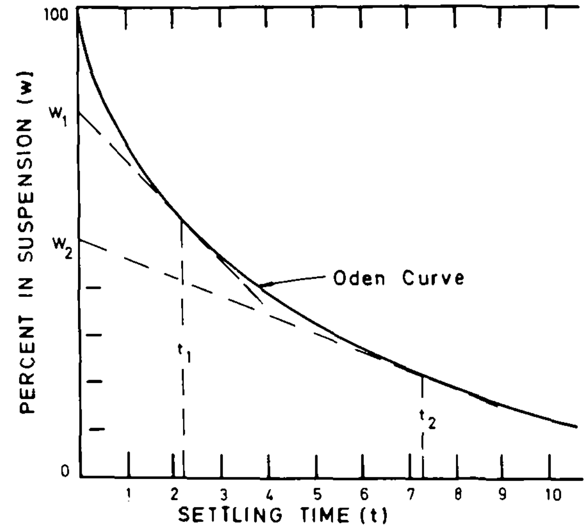


Figure 34. The Oden curve. The intercept of a tangent to the curve with the ordinate axis represents the percentage of sediment remaining in suspension after a specific time of fall.

6.3.4 The Visual-Accumulation (VA) Tube Method

The visual-accumulation tube method operates on the stratified sedimentation system. In the stratified system, the particles start settling from a common source and become stratified at the bottom according to their settling velocities. At a given instant, the particles coming to rest at the bottom of the tube are of one particular size, finer than those already settled and coarser than those still remaining in suspension.

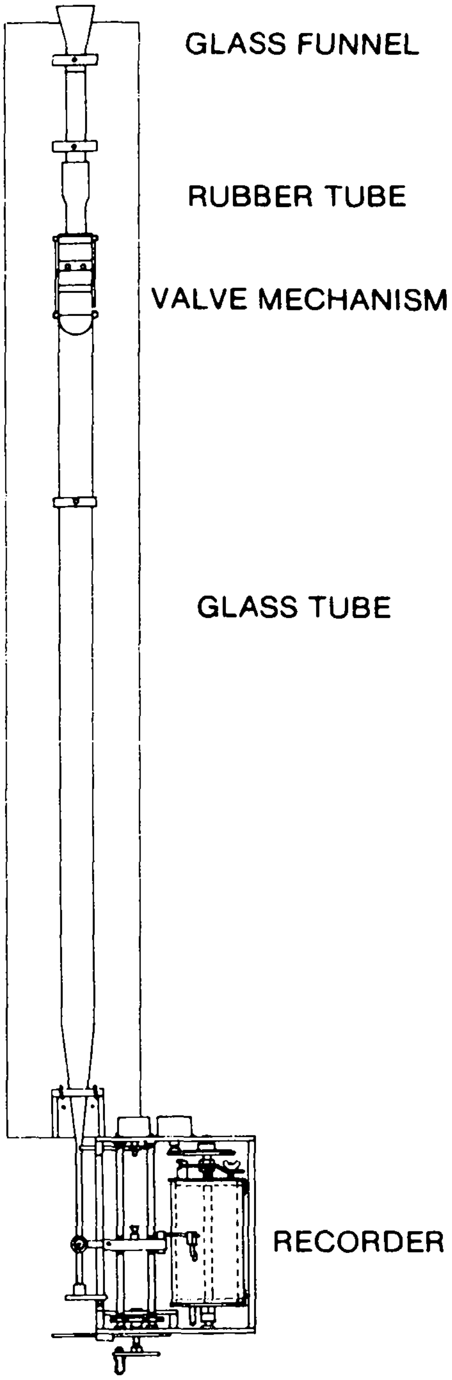
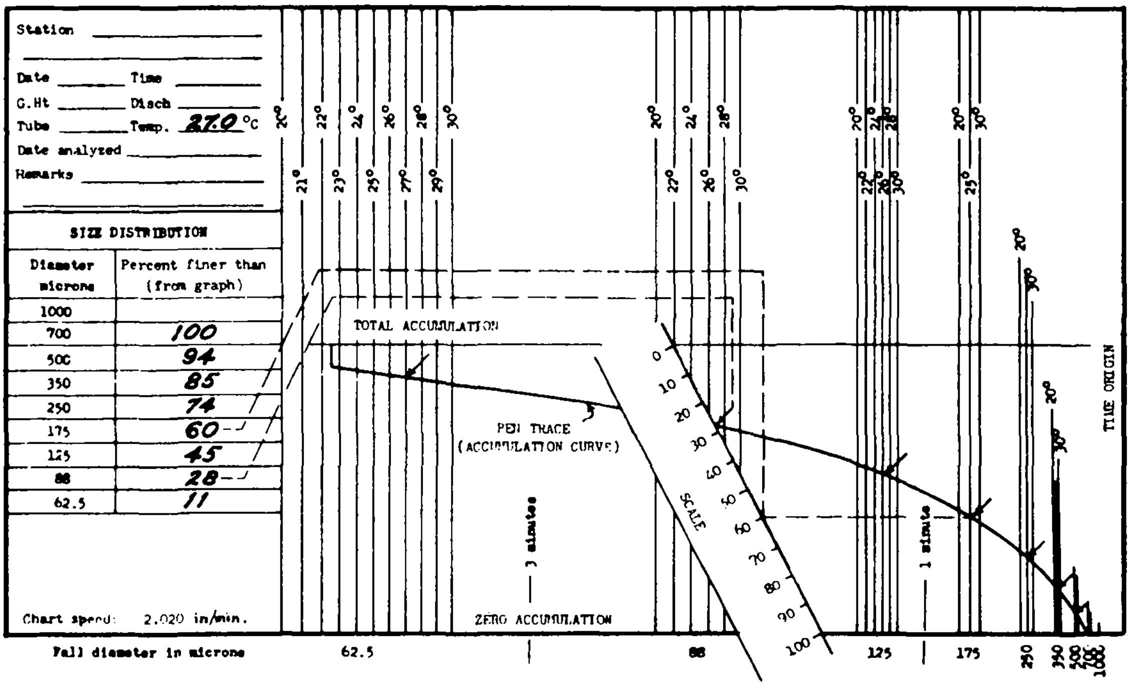


Figure 35. The Visual-Accumulation-Tube Sand Size Analyser.



Station ______

Date ______ Time ______

G.Ht ______ Disch ______

Tube ______ Temp. 27.0 °C

Date analyzed ______

Remarks ______

SIZE DISTRIBUTION

Diameter microns	Percent finer than (from graph)
1000	
700	100
500	94
350	85
250	74
175	60
125	45
88	28
62.5	11

Chart speed: 2.020 in/min.

Fall diameter in microns

Figure 36. Recorder Chart for the Visual-Accumulation-Tube Sand Size Analyser showing method of reading the size distribution, 120 cm long tube.

The VA tube analyser (Figure 35) consists essentially of a 120 cm long glass settling tube, a funnel with a valve mechanism at the top and a recorder. To make an analysis, the sample is introduced through the funnel into the water-filled tube (distilled water). The particles are separated according to size as they settle through the water. As the sediment accumulates in the settling section of the tube, the top of the column is tracked manually and a particle size grading curve is automatically and simultaneously traced on a chart. The relative amount of each particle size, in terms of percent finer than a given size in the sample, is read from this graph. (Figure 36). A clear and concise operator's manual is furnished with each analyser by the manufacturer.

The VA tube sediment size analyser provides a fast and economical means of determining the size distribution of sediment samples. It is especially suitable for analysis of samples composed mainly of sand in the range 0.062–1.0 mm. By use of a 180 cm long tube (on special order), the size range can be extended upward to 2.0 mm. It is not practicable for finer materials, as the settling time for silt and clay is too long. For samples with particles greater than 0.062 mm, an analysis can be done in less than 10 minutes.

References [12], [13], [14], [15].

7 COMPUTATION OF SEDIMENT DISCHARGE RECORDS

7.1 Mean Suspended Sediment Concentration for the Sampled Cross-Section

A velocity-weighed mean suspended sediment concentration in a vertical is obtained by depth-integrated sampling because depth-integrated samples are automatically velocity-weighed.

A velocity-weighed mean sample for a vertical can also be obtained from a composite of point samples if all the samples were taken for an equal period of sampling time at a sufficient number of sampling points in the vertical.

Compositing is the practice of mixing all the samples into one container. The mean concentration of a composite sample is the ratio of the total weight of the sediment to the total weight of the water-sediment mixture.

The EDI sampling scheme yields individual discharge-weighed samples because equal discharge increments are sampled. Then , the discharge-weighed mean concentration for the sampled cross-section is obtained by a simple averaging of the individual concentrations at each vertical. Also, in the EDI scheme, a discharge-weighed mean concentration for the sampled section can be obtained from the composited samples, provided all the samples were of equal volume.

The ETR sampling scheme, that is, equally spaced verticals and equal transit rate at all verticals, yields a sample of the discharge-weighed mean concentration for the sampled cross-section when all the individual samples are composited.

Then, samples that are composited are those collected by the ETR-scheme, and those collected by the EDI-scheme when all the samples are of the same volume.

Samples analysed individually are those collected by the EDI-scheme when the samples for the several verticals are not of equal volume and point samples when the objective is to define the lateral and vertical sediment distribution in a cross-section.

In the laboratory, sediment concentrations are determined as parts per million and later converted to milligrammes per litre, see Section 6.2. The concentration in mg/l should be reported as illustrated in Table 7 below.

Table 7. Significant Figures for Sediment Concentration [16]

mg/l	Significant figures
< 0.5	report 0 mg/l
0.5–1	report 1 mg/l
1 –9	report 1 significant figure
10 –90	report 2 significant figures
>100	report 3 significant figures

References [12], [16].

7.2 Computation of Suspended Sediment Discharge

The general methods used in computing sediment discharge depend on the accuracy and frequency of the sediment sampling and on expected use of the computed sediment discharge. Often, a combination of methods is used. The general procedure will be discussed separately for computations that are based on frequent sediment sampling and for computations based on infrequent and occasional sampling.

7.2.1 The Temporal Concentration Graph Method

When sufficient sampling data of suspended sediment concentration are available, as at daily sampling stations, the temporal concentration graph method will give accurate results and is to be recommended. The procedure is to plot the mean sediment concentration, as sampled at a cross-section, together with the hydrograph for the water discharge at the section. A continuous curve is then drawn through the plotted data points and a daily mean value of the concentration determined from it. Similarly, a daily mean value of the water discharge from the hydrograph is determined. Then, multiplying together the daily mean concentration, the daily mean water discharge and a conversion factor, the daily mean sediment discharge is obtained in tonnes per day according to the formula given below.

$$Q_s = kQ_w C_s \qquad (7.1)$$

where

Q_s = sediment discharge (tonnes/day)

Q_w = daily mean water discharge (m^3/sec)

C_s = daily mean concentration of suspended sediment (mg/l)

k = 0.0864, a conversion factor assuming a specific weight of 2.65 for sediment

The procedure for a few days of actual water discharge and sediment concentration is illustrated in Table 8 and Figure 37.

Table 8. Computation of Daily Mean Suspended Sediment Discharge

Day	Discharge	Concentration	Sediment discharge Computed	Sediment discharge Reported as
	m^3/sec	mg/l	tonnes/ day	tonnes/ day
1	1450	250	31320	31300
2	1700	300	44064	44100
3	4300	600	222912	223000
4	9600	1300	1078272	1080000
5	10850	1600	1499904	1500000
6	8500	1600	1175040	1180000
7	6600	1400	798336	798000
8	4900	1100	465696	466000
9	3450	850	253368	253000
10	2500	700	151200	151000
11	1900	600	98496	98500

Significant figures should be reported as illustrated in Table 9.

Table 9. Significant Figures for Daily Sediment Discharge [*16*]

Tonnes/day	Significant figures
<0.005–	report 0 tonnes
0.005–0.01	report 0.01 tonnes
0.01 –0.09	report to nearest 0.01 tonnes
0.10 –99	report 2 significant figures
>100	report 3 significant figures

The mean values of sediment concentration and water discharge are usually determined by a graphical method. This is accomplished by a simple device consisting of a thin sheet of clear plastic, 15 cm x 7 cm, with an index line etched along the major axis. The average value is determined by placing the index line over the intersection of the graph and the vertical line representing the beginning of the time interval considered. The index line is rotated around the point of intersection and area A visually balanced against area B, the average value is read at the intersection of the index line and the vertical mid-line of the time interval (Figure 38).

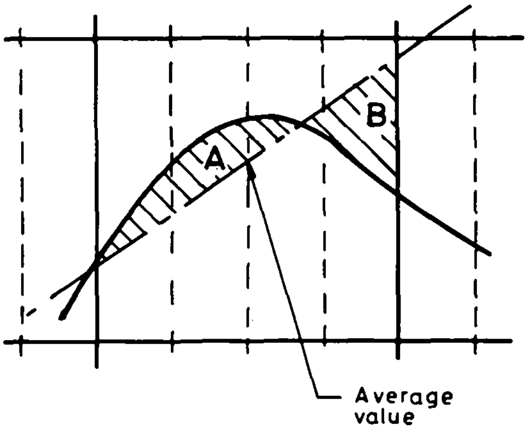


Figure 38. Determination of average value by graphical method.

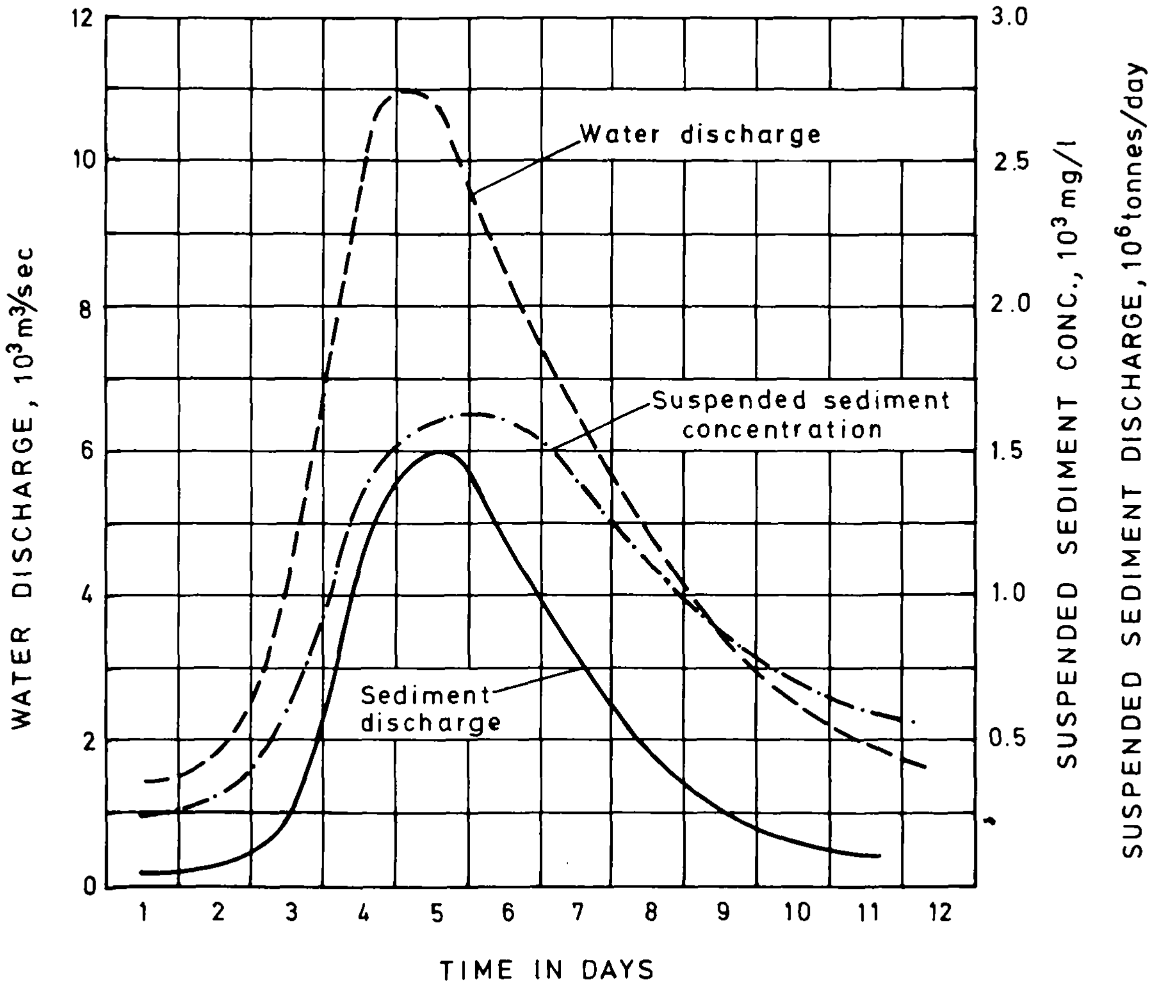


Figure 37. Water discharge, suspended sediment concentration and sediment discharge.

If the water discharge and the sediment concentration are reasonably constant during the day, the average values can be determined quite accurately. However, if the flow and concentration change considerably within short periods of time (Figure 39), the day must be subdivided into shorter intervals in order to obtain correct daily mean values of the suspended sediment discharge. Figure 40 can be used as a guide in deciding when subdivision is necessary. The day must be subdivided into identical intervals for both the water discharge and for the sediment concentration. [16].

When the temporal-concentration-graph method is used to compute sediment discharge for stations where the time period between each sediment sampling is longer than a day or where samples are missing for a period, the temporal-concentration-graph must be based on all pertinent information available and on the judgement of the computer. A sediment rating curve (see next section) for the site is very helpful in estimating missing data. Also, some typical sediment concentration values plotted against time, during storm events, should be prepared and be available for a sampling station for estimation of missing data. Further, useful information and data for estimating missing sediment concentration data and filling in gaps in records may include theoretical considerations, study of past records for the station, comparison with records of upstream and downstream stations, data on storm distribution and intensity, soil conditions, vegetal cover, etc.

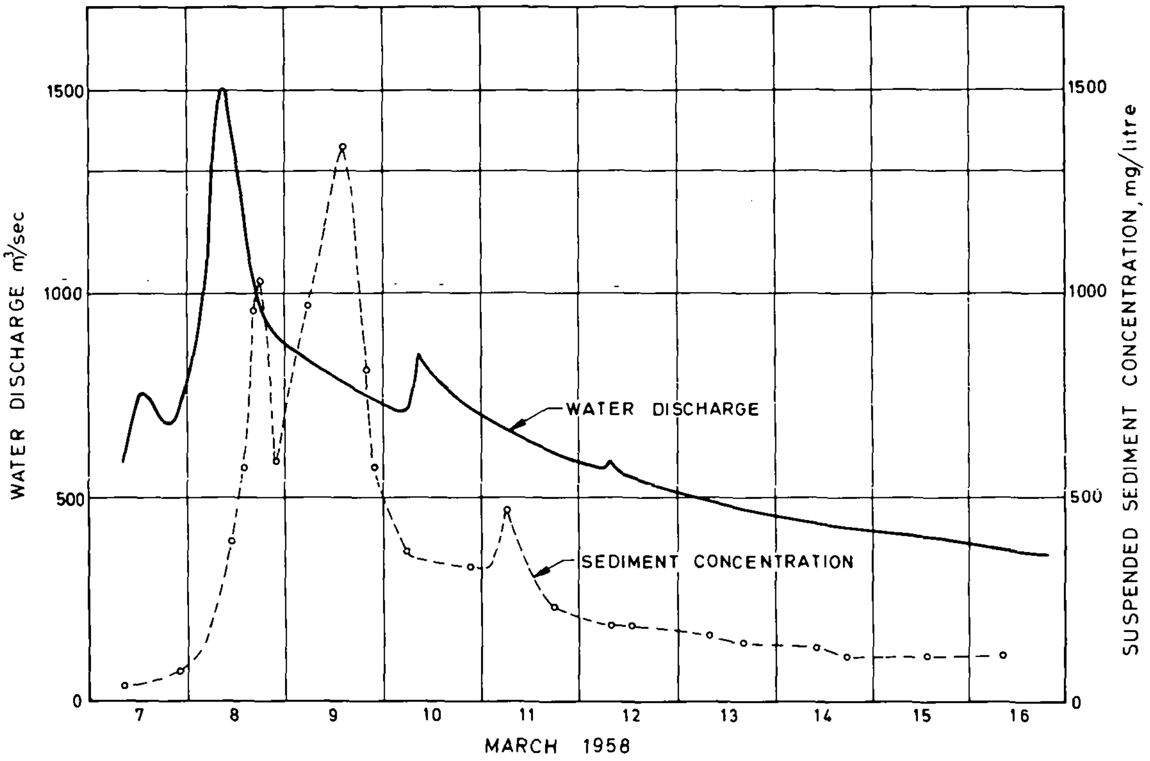


Figure 39. Water discharge and suspended sediment concentration.

7.2.2 The Flow Duration Sediment Rating Curve Method

This method is used when only infrequent and occasional sediment sampling data are available. The data should cover the usual range of flow at the station. The sediment discharge in tonnes/day or concentration in mg/l is plotted against the water discharge at the time of sampling. Thus, an average sediment discharge or sediment concentration curve for the station may be defined (Figure 41).

A plot on log-log paper will often be a straight line with an equation:

$$S = kQ^n \qquad (7.2)$$

where S is rate of sediment movement, Q is water discharge and k and n are empirical constants. Usually, individual points scatter widely from such a curve.

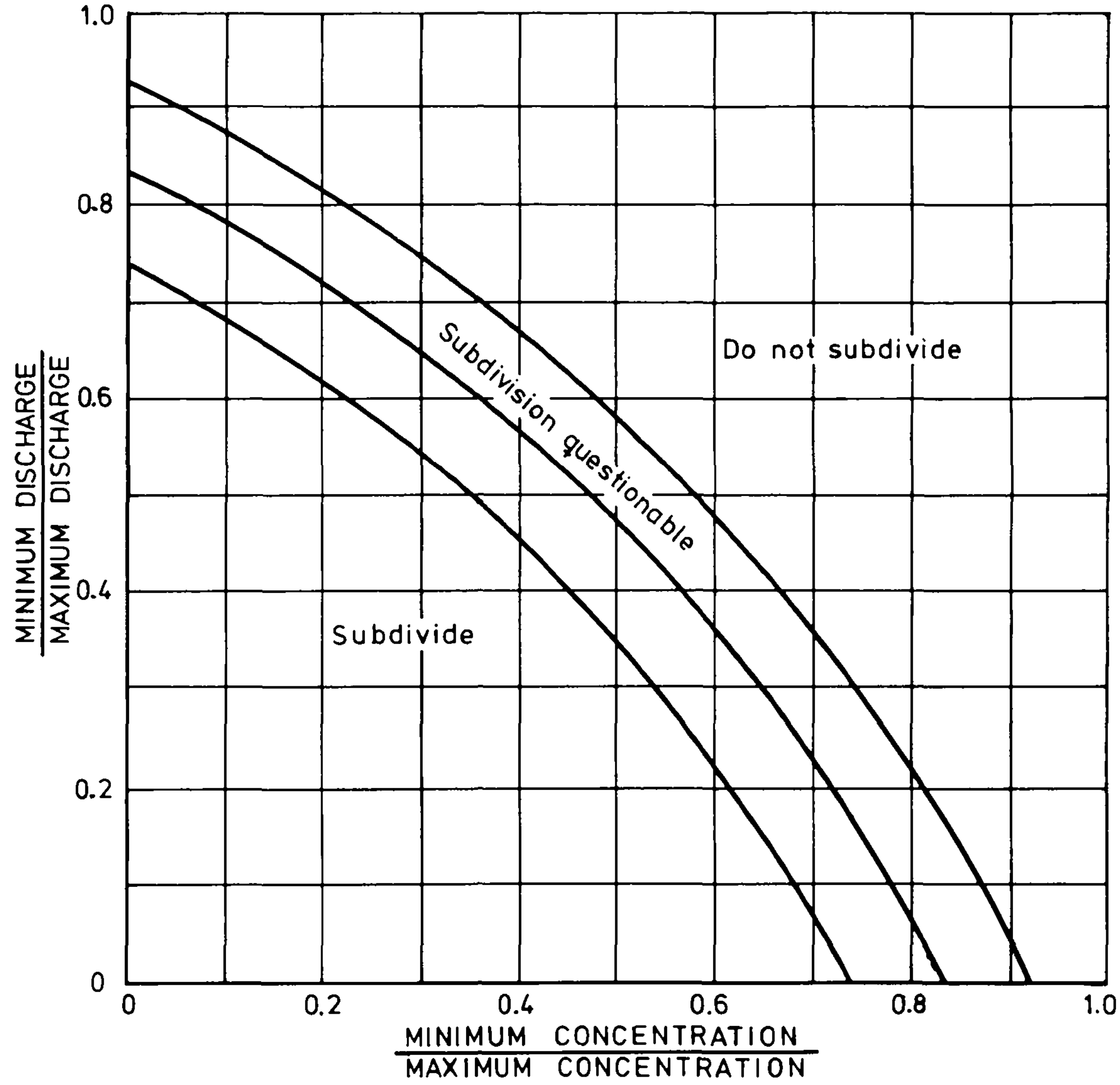


Figure 40. Guide to determine whether subdivision is required, assuming an accuracy of about 5 per cent [16].

The second step is to develop a long-time water flow duration curve for the station. The sediment rating curve is then applied to the flow duration curve, the resulting computation gives a long term average sediment yield. The procedure is outlined in reference [1], of which an extract is reproduced in Appendix I.

Actually, there is little reason to expect a simple relation between streamflow and sediment load. A sediment rating curve does not necessarily represent the transport capacity of the stream, but represents rather the sediment production capability of the drainage area (refer Section 2.2). The streamflow-sediment load relation often changes with type of runoff and should be subdivided into more than one curve corresponding to the different seasons of the year. In determining the average long-term sediment load, the major part is carried by the less frequent high water discharges. The extrapolation of the sediment rating curve through this discharge range can give unreliable results because of incomplete sampling data.

An investigation with these objections in view was carried out by the *US Bureau of Reclamation* [18]. An extract of the conclusions arrived at is reproduced in the following.

> ”From the results of the study, it may be concluded that often poor correlations between sediment load and water discharge may be greatly improved by a more searching analysis into the sources and types of run-off. Run-off from snowmelt very often is found to have a much smaller

sediment concentration than run-off from other sources. A correlation can be obtained by separating the run-off for an average snowmelt season. It may be noted that periods of transition occur at the beginning and end of the snowmelt season. During this period the curves of relationship show trends from one curve to the other depending upon ratio of each type of run-off making up the total flow. This period is usually of short duration and not always predictable; hence it was found

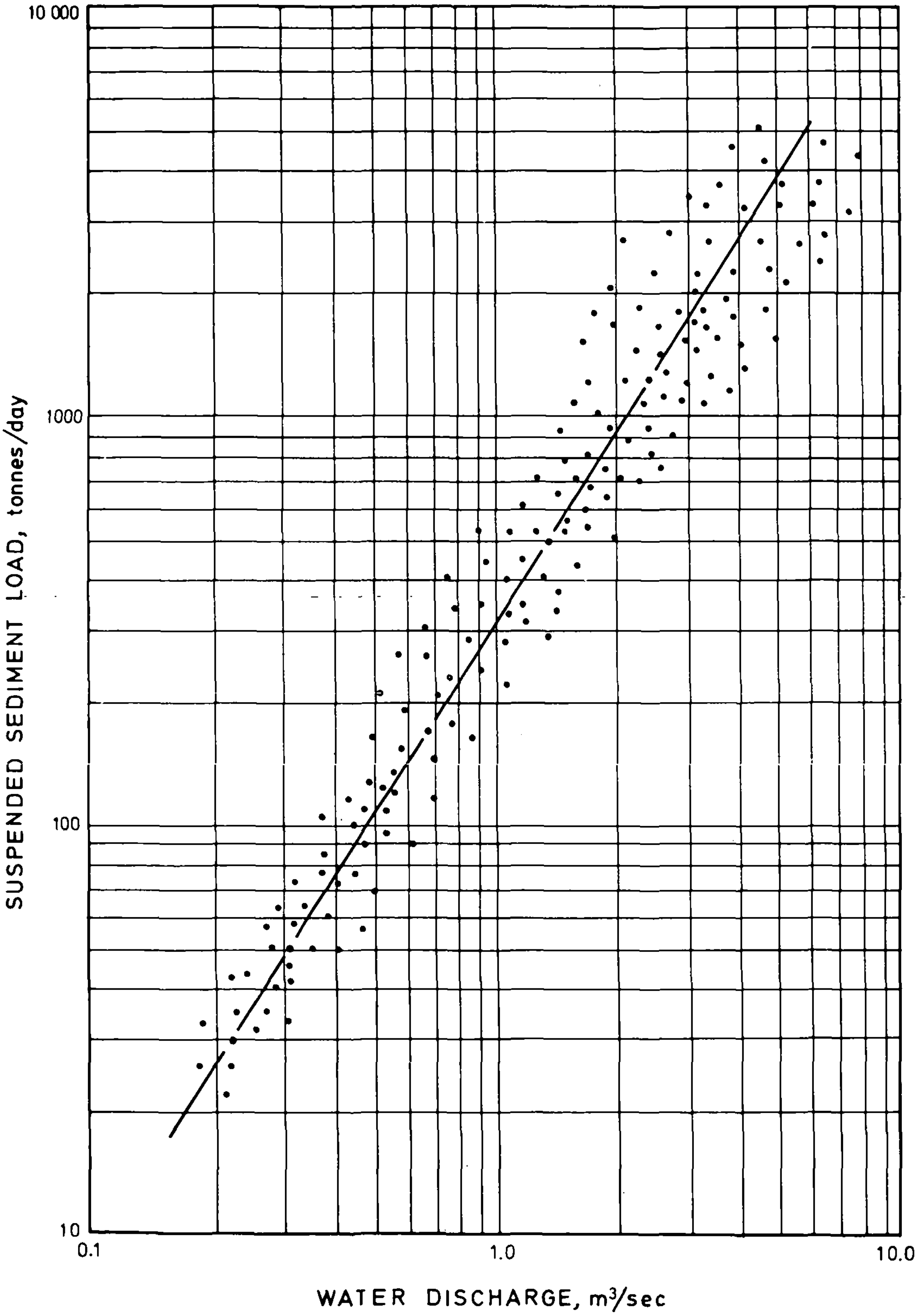


Figure 41. Sediment rating curve plotted on log-log graph paper.

best to divide this period and average the data between seasons.

There appear to be some cases where the run-off types are not restricted to any one season. The sediment yields from snowmelt and base-flow run-off will correlate very well. Storm run-off sediment yields, however, are usually much higher; and while they will correlate fairly well as a group, they do not correlate with other run-off types. It is necessary to separate the individual cases of storm run-off since they may occur during any season of the year. This measure can best be accomplished from an examination of the hydrograph and precipitation records.

In plotting sediment data, it is best to assign different symbols to represent different months, periods or seasons, in order that any trends will be more readily distinguished. It is also a good scheme to study the characteristics of the drainage area and associate run-off trends, that usually show up on hydrographs, with particular pecularities of the drainage area. Very often, such knowledge may lead to the isolation of run-off by types or sources and allow a better correlation to be developed.

The sediment-rating curve, flow-duration curve method of estimating sediment yield appears to be sufficiently accurate for practical application.

However, the use of a sediment record for one year in estimating a long-period sediment yield for a drainage area should be done with full knowledge of the possible limitations. It should be understood that a relationship of discharge and sediment load as derived in this study is a pattern for estimating the adjustment of short-term records to mean values, rather than a precise mathematical theorem applicable to every case.

Although a definite correlation between discharge and sediment load may seem to appear, it cannot be used indiscriminately for computing the mean sediment load on the basis of one year of sediment record, since there is no way of determining whether the year in question will follow the general trend or will have "abnormal" tendencies.

> Additional points of interest regarding the computation, while not an objective of the study, came out during the progress of the study. It was found that the unit-weight to be used in the sediment-load computations should be carefully determined. A unit weight greater than the actual results in an underestimation of the sediment load; whereas, a unit weight smaller than actual will result in an overestimation. This becomes increasingly important when the computed sediment load is to be used in determining the space allocation necessary for sediment in a reservoir."

It appears that sediment rating curves should be used with caution. They should, where possible, be applied to small and comparatively homogeneous drainage areas.

References [1], [16], [19].

7.3 Estimation and Computation of Bedload Discharge

The fraction of total suspended sediment transport that can not be sampled due to the design of the sampler, i.e. about 10 cm at the bottom of the vertical (Figure 11), is included in the bedload. Generally, bedload may be estimated when it is a small fraction of the total load. When the bedload fraction is relatively high, one should attempt to measure it or calculate it.

7.3.1 Estimation of Bedload

Estimates of the bedload are usually based on a correction added to the measured suspended load. As a guide in this estimation, the following general relationships may be stated [20]:

Firstly, there are three major variables which affect the amount of bedload a stream may carry:

1. The size of the bed material.
2. The slope of the stream.
3. The nature of the channel such as depth, size, shape and roughness.

Secondly, there are a number of criteria which are useful in the evaluation of the effect which these variables have on the bedload:

1. The smaller the concentration of the suspended load, the higher the percentage of bedload will usually be.
2. The smaller the difference in the particle sizes of the bedload and of the suspended load, the higher the percentage of bedload will be.
3. The ratio bedload to suspended load tends to be larger for low or medium stages than it is for high stages. Thus, a stream in which the flow does not fluctuate greatly, is likely to carry a higher percentage of bedload. This criterion does not necessarily apply to very steep mountain streams which move boulders at flood stages. In such cases, the bedload ratio may increase with an increase in discharge.
4. Streams with wide shallow channels carry a higher proportion of sediment as bedload than streams with deep narrow channels.
5. Stream channels with a high degree of turbulence tend to have a smaller amount of bedload.

The following table serves as a guide in estimating the amount of bedload correction to apply and although it takes into account only a portion of the variables mentioned, those omitted can be given consideration in determining the part of the suggested bedload range to adopt.

References [1], [12], [16], [18], [19], [20].

7.3.2 Computation of Bedload

In sand-bed streams the bedload transport is always equal to the transporting capacity of the stream. A too small bedload would immediately involve local erosion from the bottom or the banks, and a too heavy bedload would cause deposition. The flow will never be unsatiated with sand material and variation in transporting capacity will immediately result in scour or deposition.

Many formulas for computation of bedload have been developed over the years by various workers in this field, such as *Einstein* [21], *Schoklitsch* [22]. *Kalinske* [23], and *Meyer-Peter and Muller* [24]. The classical concept on which many bedload formulas are based, states that the capacity of a stream to transport sediment along its bed varies with the difference between the shear stress acting on the bed particles and the critical shear stress for

Table 10. Maddock's Classification for Determining Bedload [*20*]

Concentration of suspended load, in parts per million (1)	Type of material forming the channel of the stream (2)	Texture of the suspended material (3)	Bedload discharge, in terms of suspended sediment discharge as a percentage (4)
Less than 1000	Sand	Similar to bed material	25 to 150
Less than 1000	Gravel, rock or consolidated clay	Small amount of sand	5 to 12
1000 to 7500	Sand	Similar to bed material	10 to 35
1000 to 7500	Gravel, rock or consolidated clay	25% sand or less	5 to 12
Over 7500	Sand	Similar to bed material	5 to 15
Over 7500	Gravel, rock or consolidated clay	25% sand or less	2 to 8
Any concentration	Clay and silt unconsolidated	Silt and clay	Less than 2

initiation of the particle motion. These formulas are mostly empirical, that is, mathematically derived from measured relationships and include the Schoklitsch, the Kalinske, and the Meyer-Peter and Muller formulas. The Einstein formula, on the other hand, is based largely on statistical and probability theory relying on experimental results for evaluation of the various constants and indices.

It is commonplace that application of different bedload formulas to a given situation yields different answers. Thus the practicing engineer should have some knowledge of the data, methods, derivation, and limitations of the various bedload formulas before they are applied to a particular situation. The several formulas that apply to a given situation should be used and the results compared. In this way the limitations and variance of each is developed by experience. Although, there are limitations to the use of bedload formulas , they are adaptable to changing hydraulic conditions in the stream channel and can be used to estimate loads for a variety of problems associated with project development and planning.

There are indications that the empirical formulas in use over-estimate the sand-transporting capacity of tropical rivers in the order of 10–15 per cent. Probably, this is due to the decrease in viscosity caused by the relatively high water temperature of these rivers.

The Schoklitsch Formula

The Schocklitsch formula was developed for coarse materials on European streams and was verified by meausrements on these streams. The formula correlates the bedload, channel slope, discharge and particle size of the bed material. For material of specific weight 2.65 g/cm³, the Schoklitsch formula will read [25]

$$g_s = 7000\, S^{3/2}\, D_{50}^{-1/2}\, (q - q_c) \qquad (7.3)$$

where

g_s = bedload transport per unit stream width (kg/sec/m)
S = channel slope (m/m)
D_{50} = median particle size of bed material (mm)
q = water discharge per unit stream width (m³/sec/m)
q_c = $1.94 \cdot 10^{-5}\, D_{50}\, S^{-4/3}$, where, q_c is the critical water discharge, per unit stream width, initiating the movement of the bedload (m³/sec/m)

The Schoklitsch formula is valid for homogeneous sand material, but also for unsorted sand and gravel when each size fraction is computed separately.

The Kalinske Formula

Kalinske assumed that bedload discharge g_s (kg/sec/unit width) must equal the product of particle volume ($\pi D^3/6$), average number of particles in movement per unit streambed area ($p/(\pi D^2/4)$), effective specific weight of particles ($w_s - w_v$), and mean particle velocity (v_s), or

$$g_s = (\pi D^3/6)\,(4p/\pi D^2)\,(w_s - w_v)v_s \qquad (7.4)$$

This formula can be rearranged to [25]

$$g_s = 7.3 \cdot 10^{-3}\, p\,(gT_0/w_v)^{1/2}\, D w_s \cdot f(T_c/T_0) \qquad (7.5)$$

where

g_s = bedload transport per unit stream width (kg/sec/m)
p = a factor indicating the proportion of the streambed area covered by moving particles at any instant, generally taken as 0.35
g = acceleration due to gravity, 9.8 m/sec²
R = hydraulic radius (m)
S = channel slope (m/m)
D = particle diameter (mm)
w_v = specific weight of water , 1 g/cm³
w_s = specific weight of sediment, generally taken as 2.65 g/cm³
T_0 = total shear stress at boundary of streambed (g/m²)
T_c = critical shear stress at which bedload transport begins (g/m²)

The function $f(T_c/T_0)$ depends on the intensity of the flow turbulence. When the ratio T_c/T_0 is known, the value of the function is given in Table 11 [23].

The critical shear stress T_c is computed by the formula [25]

$$T_c = 192\,D \qquad (7.6)$$

The total shear stress T_o is computed by the relation [3]

$$T_o = w_v\,RS \qquad (7.7)$$

The Kalinske formula is developed for homogeneous sand material. The transport of unsorted sand should be integrated through the range of particle sizes. However, a single computation using the median particle diameter seems to give a reasonable approximation.

Table 11. Values of the Function $f(T_c/T_o)$ for Given Values of the Ratio T_c/T_o [23]

T_c/T_o	$f(T_c/T_o)$
0.0	2.40
0.2	1.40
0.4	0.90
0.6	0.60
0.8	0.40
1.0	0.25
1.2	0.16
1.4	0.087
1.6	0.048
1.8	0.026
2.0	0.013
2.2	0.006
2.4	0.002

The Meyer-Peter and Muller Formula

The Meyer-Peter and Muller formula is based on a large number of laboratory experiments with slopes ranging from 0.04 to 2% and particle sizes ranging from 0.4 to 30 mm in unsorted material. For wide streams and material of specific weight 2.65 g/cm³, the formula will read [25]

$$g_s = 600\left(\frac{1}{n\,k_r}\right)^{3/2} dS - 0.048\,D_{50} \qquad (7.8)$$

where

g_s = bedload transport per unit stream width (kg/sec/m)
n = Manning's roughness coefficient (roughness of streambed)
k_r = roughness of particles
d = depth of flow (m)
S = channel slope (m/m)
D_{50} = median particle size of bed material (mm)

The roughness of the streambed may be computed using the Manning formula for the mean velocity of flow

$$v = \frac{1}{n} R^{2/3} S^{1/2} \qquad (7.9)$$

The particle roughness is computed by the formula [25]

$$k_r = 8.2 D_{90}^{-1/6} \qquad (7.10)$$

In formula (7.10), D_{90} is the particle size for which 90 per cent of the bed material is finer.

The Modified Einstein Procedure

Essential data for application of the Modified Einstein procedure at a particular time and location are as listed:

1. Stream width, average depth and mean velocity.

2. Average concentration of suspended sediment from depth-integrated samples.

3. Size analysis of the suspended sediment included in the average concentration.

4. Average depth of the verticals where the suspended-sediment samples were collected.

5. Size analysis of the bed material.

6. Water temperature.

Actually, the Modified Einstein procedure is a comprehensive computational method which results in an estimated total sediment load. The method uses the sampled concentration of suspended sediment and expands or integrates the suspended load the full stream depth in order to determine also that part of the total load moving in the unsampled zone. Separate computations of bedload and suspended load may be carried out instead of a comprehensive total load computation. The computations are lengthy and involved. The application of the modified Einstein procedure is explained in detail in reference (21).

References [20], [21], [22], [23], [24], [25].

REFERENCES

1. Kutena, F. Z.
   1963: Sediment Sampling. – Lecture Notes for Hydrologic Training Course, Ministry of Water Development and Power, Dar es Salaam.

2. Colby, B. R.
   1963: Fluvial Sediments – a Summary of Source, Transportation, Deposition, and Measurements of Sediment Discharge. – United States Geological Survey Bulletin 1181-A, 47 p.

3. Chow, V.T.
   1964: Handbook of Applied Hydrology. – McGraw-Hill Book Co., New York.

4. Guy, H. P.
   1970: Fluvial Sediment Concepts. – Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter Cl, 55 p.

5. World Meteorological Organization
   1965: Guide to Hydrometeorological Practices. – WMO Secretariat, Geneva.

6. UNITED NATIONS – Economic Commission for Asia and the Far East.
   1953: The Sediment Problem. – Bankok, 92 p.

7. Guy, H.P. and Normann, V.W.
   1970: Field Methods for Measurements of Fluvial Sediment. – Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter C2, 59 p.

8. Tilrem, Ø. A.
   1978: Operation of Stream Gauging Stations. – Manual on Procedures in Operational Hydrology, Vol. 2. Norwegian Agency for International Development (NORAD), Oslo.

9. Task Committee on Preparation of Sediment Manual
   1969: Sediment Measurement Techniques, A. Fluvial Sediment. – Journal of the Hydraulics Division, ASCE, Vol. 95, No.HY5, Proc. Paper 6756, September 1969, p. 1477 –1514.

10. U.S. Geological Survey
    1972: Recommended Methods for Water-Data Acquisition. – Preliminary Report on Designation of Standards for Water Data Acquisition. United States Department of the Interior.

11. Witzigman, F. S.
    1963: A Summary of the Work of the Inter-Agency Sedimentation Project. – Paper No. 25 in Proceedings of the Federal Inter-Agency Sedimentation Conference 1963, United States Department of Agriculture, p. 166–177.

12. Guy, H.P.
    1969. Laboratory Theory and Methods for Sediment Analysis. – Techniques of Water-Resources Investigations of the United States Geological Survey, Book 5, Chapter Cl, 58 p.

13. Task Committee on Preparation of Sediment Manual
1969: Sediment Measurement Techniques, F. Laboratory Procedures. – Journal of the Hydraulics Division, ASCE, Vol. 95, No. HY5, Proc. Paper 6757, September 1969, p. 1515–1543.

14. U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation
1941: Methods of Analyzing Sediment Samples, Report 4. – St. Paul U.S. Engineer District Sub-Office, Hydraulic Laboratory, University of Iowa.

15. U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation
1943: A study of New Methods for Size Analysis of Suspended Sediment Samples, Report No. 7. – St. Paul U.S. Engineer District Sub-Office, Hydraulic Laboratory, University of Iowa.

16. Porterfield, G.
1972. Computation of Fluvial-Sediment Discharge. – Techniques of Water-Resources Investigations of the United States Geological Survey, Book 5, Chapter C3, 66 p.

17. Searcy, J.K.
1959: Flow-Duration Curves. – United States Geological Survey Water-Supply Paper 1593, 33 p.

18. Miller, C. R.
1951: Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield. – United States Bureau of Reclamation, 55 p.

19. Campbell, F.B. and Bauder, H. A.
1940: A Rating-Curve Method for Determining Silt Discharge of Streams. – Amer. Geophys. Union Trans. 2, p. 603–607.

20. Shepard, J.R.
1963: Methods and Their Suitability for Determining Total Sediment Quantities. – Paper No. 32 in Proceedings of the Federal Inter-Agency Sedimentation Conference 1963, United States Department of Agriculture, p. 272–287.

21. Colby, B. R. and Hubbell, D.W.
1961: Simplified Methods for Computing Total Sediment Discharge with the Modified Einstein Procedure. – United States Geological Survey Water-Supply Paper 1593, 17 p.

22. Shulits, S.
1935: The Schoklitsch Bedload Formula. – Engineering, London, 644 pp.

23. Kalinske, A. A.
1947: Movement of Sediment as Bedload in Rivers. – Amer. Geophys. Union Trans. 28 (4), p. 615–620.

24. Meyer-Peter, E. and Muller, R.
1948: Formulas for Bedload Transport. – International Assoc. for Hydraulic Structures Res., 2nd Meeting, Appendix 2, 39 pp.

25. Nordseth, K.
1974: Sedimenttransport i norske vassdrag. – (Sediment Transport of Norwegian Rivers), Geographical Institute, Oslo University, Oslo, 177 p. (in Norwegian).

APPENDIX A

OPERATING INSTRUCTIONS FOR DH-48 SUSPENDED-SEDIMENT HAND SAMPLER

OPERATING INSTRUCTIONS FOR DH-48 SUSPENDED-SEDIMENT HAND SAMPLER

The hand sampler, DH-48, was designed for depth-integration of suspended-sediment samples in shallow streams. With this instrument, the operator takes the sediment samples while wading in the stream or, if more convenient, by operating from a low bridge. The sampler consists essentially of a streamlined aluminum casting, 13 inches long and weighing approximately 3 1/2 pounds, which incloses the sample container. Specific details of the instrument are illustrated on the attached drawing. The sampler is supported on the standard one-half-inch round wading rod used in stream gaging. Any alternate rod or pipe of desired size may be utilized to support the sampler provided appropriate end fittings are incorporated. A brass nozzle, threaded to permit hand assembly to the streamlined head, projects upstream and provides the intake passage for the sample.

Round pint bottles are used for sample containers. Pressure from a spring-tensioned operating rod, which is rotated by hand to bear upon the base of the sample bottle, holds and seals the bottle against a rubber gasket within the sampler head. The operating rod assembly can be removed from the recess provided at the rear of the sampler casting, and the pressure exerted by the operating rod can be adjusted by increasing or decreasing the compression on the operating spring. The axis of the sample container is inclined at an angle of 72 1/2 degrees to the vertical which permits sampling to within 3 1/2 inches of the stream bed. With the instrument oriented into the direction of flow (nozzle horizontal and pointed upstream) a continuous stream filament is discharged into the sample bottle during the period of submergence. The air displaced by the sample is ejected through the air escape vent tube projecting from the instrument alongside the head and oriented to discharge downstream. A fixed static head differential of 11/16 inch between the intake and air exhaust facilitates sampling in low stream velocities and slack waters. Hand samplers are usually equipped with only the quarter-inch-diameter nozzle. However, nozzles with smaller bore may be employed if desired.

A clean bottle should be used for each separate sediment sample. At least one suspended-sediment sample is taken at each stream vertical selected in the cross section. In sampling operation, the intake nozzle is oriented upstream, directly into the current, and held in a horizontal position while the sediment sampler is lowered into the stream. Submerged obstruction directly upstream or adjacent to the sampler should be avoided to preclude interference with the stream filament approaching the intake nozzle. The sampler should be lowered at a uniform rate from the water surface to the bottom of the stream, instantly reversed, and then raised again to the water surface at a uniform but not necessarily an equal rate. Each filled sample bottle, when removed from the instrument, should be capped immediately and appropriately marked.

The hand sampler continues to take its sample in flowing water, throughout the time of submergence, even after the bottle is completely filled. If the bottle becomes entirely full, the sample may not be representative and it should be discarded. Although the capacity of the sample container is about 470 cc., the tilt of the bottle is such that any sample containing more than 440 cc., or 5 inches of a water-sediment mixture in the bottle, may be in error. In order to provide sufficient sample for a laboratory analysis, the length of time the instrument remains submerged should be adequate to produce a sample volume greater than 375 cc., but not to exceed 440 cc. It is generally preferable to save an initial sample smaller than 375 cc., but larger than 300 cc., than to discard the sample on the spot and resample into the same bottle. Moreover, if the initial sample volume is considerably less than 300 cc., the stream vertical may be integrated a second time, or even a third time, each being additive to the same sample bottle. A minimum sample of 350 cc. or 3 inches is suggested. However, sufficient latitude in minimum sample volumes should be permitted to obviate retaking a large number of samples.

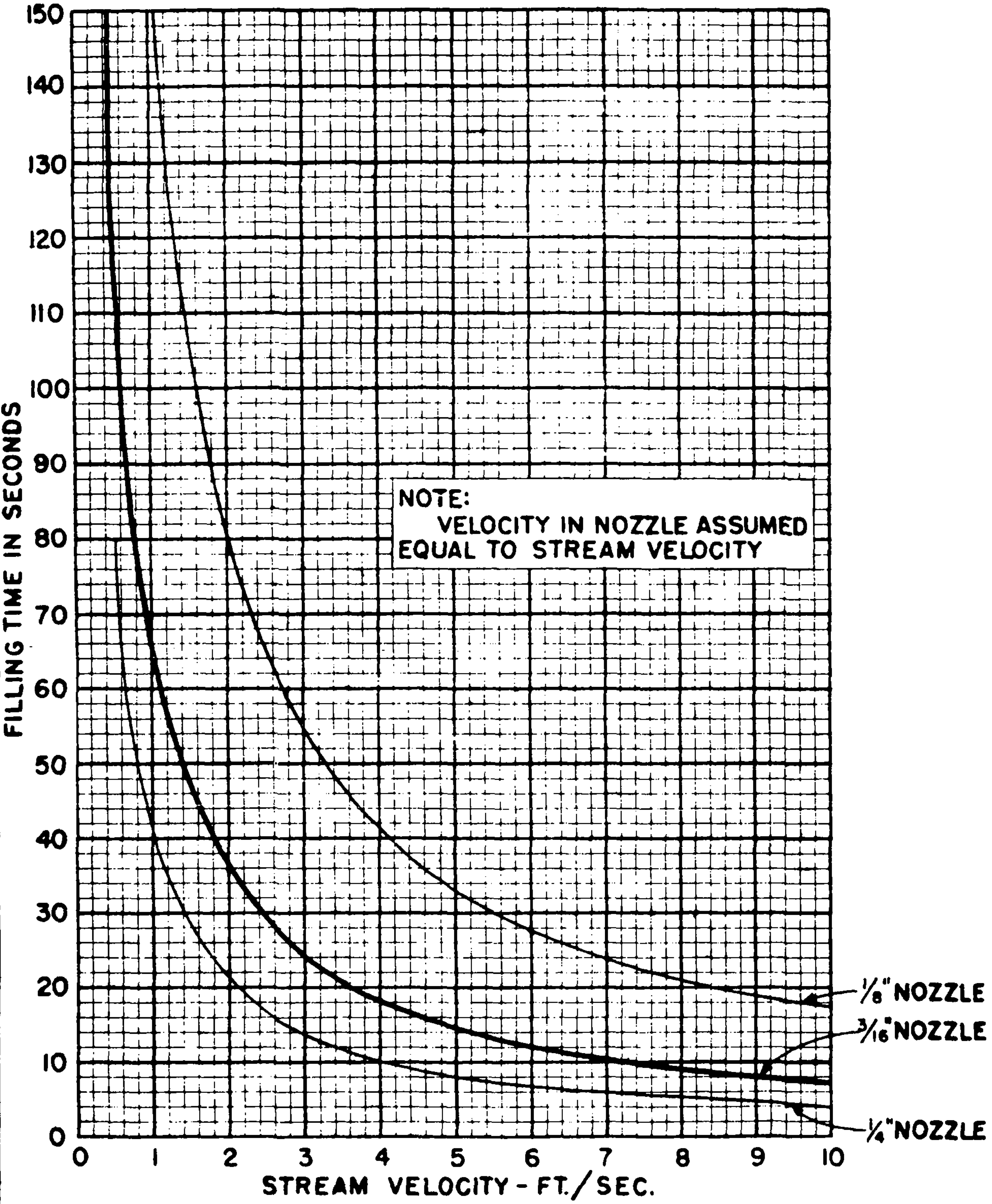
The volume of sample collected throughout any stream vertical is dependent primarily upon the mean stream velocity in that vertical, the size of the intake nozzle, and the time of submergence of the instrument. The operator must regulate the size of the sample accumulated by establishing the appropriate time period over which the sample is to be taken. Thus, the volume of the sample may be increased or decreased by varying correspondingly the sampling time. The attached graph shows the relation between stream velocity and filling time to produce samples 400 cc. in volume for three different nozzle sizes. The volume, 400 cc. between the maximum and minimum sample suggested above, was arbitrarily selected for this illustration as permitting the greatest latitude in estimation stream velocities and depths. The filling time in seconds represents the total time of submergence of the instrument and includes the time involved in traversing the stream vertical in both the downward and upward direction. For example, if the mean velocity of flow in a stream vertical is 4 feet per second, the graph shows that a sediment sampler equipped with a quarter-inch diameter intake nozzle will accumulate a sample 400 cc. in volume in 10 seconds of submergence. If the sampler is lowered from the water surface to the stream bed at a uniform rate in 5 seconds, it should be raised at a uniform rate so as to break the water surface at the expiration of the next 5 seconds. The time of traversing the stream vertical need not be the same in both directions of travel. However, the rate at which the sampler moves vertically must remain uniform in each direction of travel. Thus, in the above example, the stream vertical could have been traversed at a uniform rate downward in 4 seconds and the sampler raised at a uniform rate upward to clear the water surface in 6 seconds, the total submergence period still being 10 seconds.

Adequate information and data to identify the sample and to satisfy the purposes of the investigation should be recorded at the time of sampling. The following items are suggested:

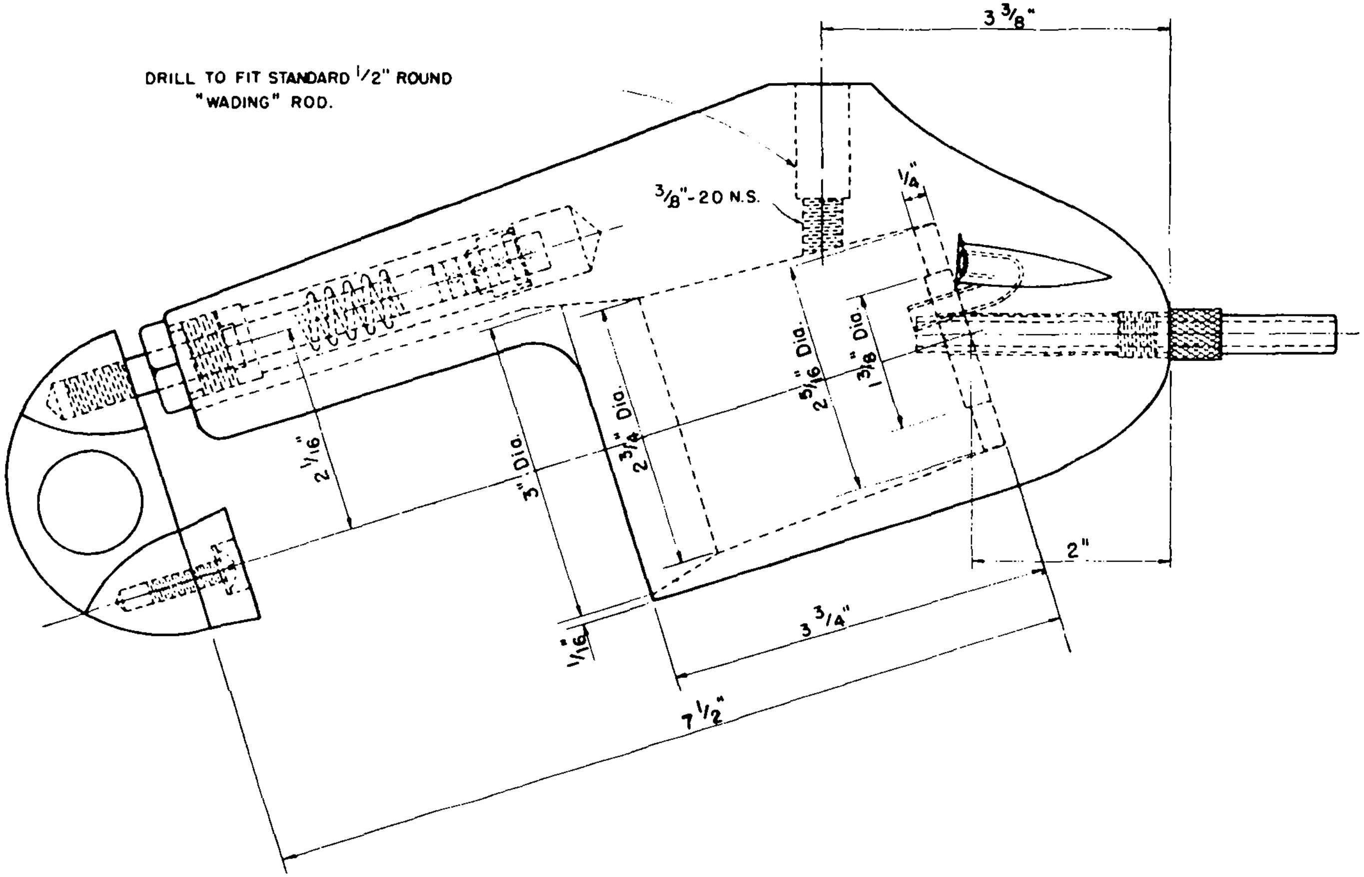
Name of stream
Location of the cross section
Location of the vertical
Stream depth covered by the sample
Stage of the stream
Date
Time of day
Identification of personnel
Sampling time
Water temperature
Serial number of sample

A portion of the exterior face of the glass bottle may be etched or otherwise treated to provide a surface suitable for marking and for recording the essential information regarding each sample. Before the bottles are re-used, they should be washed clean inside and outside to avoid contamination of future samples and to remove data referring to previous samples.

Reference: U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, Report J, 1965.



FILLING TIME
FOR SAMPLE OF 400 c.c.



DEPTH-INTEGRATING SUSPENDED-SEDIMENT WADING-TYPE HAND SAMPLER, USDH-48

APPENDIX B

OPERATING INSTRUCTIONS FOR DEPTH-INTEGRATING SUSPENDED-SEDIMENT SAMPLERS D-49 AND DH-59

OPERATING INSTRUCTIONS FOR DEPTH-INTEGRATING SUSPENDED-SEDIMENT SAMPLERS D-49 AND DH-59

The D-49 and DH-59 suspended-sediment samplers are depth-integrating instruments designed for use in streams not more than about 15 feet in depth. The samplers have streamlined bodies weighing about 62 and 24 pounds, respectively, which are recessed to accommodate round one-pint bottle sample containers. Tail vanes to orient the instruments into the direction of flow and air escape passages are cast integrally. The heads of the samplers are drilled and tapped to receive the intake nozzles. The D-49 head is hinged, permitting access to the sample bottle cavity by releasing the catch and swinging the head downward, away from the hanger bar support. Nine Brass nozzles, three each with 1/4-inch, 3/16-inch, and 1/8 inch diameter bore, threaded for hand assembly to the head, are supplied with each D-49 instrument. Five Brass nozzles, two each with 1/4-inch and 3/16-inch diameter bore, and one 1/8-inch diameter bore, threaded for hand assembly to the head, are supplied with each DH-59 instrument. In the sampling operation, the head is oriented upstream with the nozzle pointing directly into the current, and the sampler is lowered from the water surface to the stream bed and then raised to a position above the water surface. During the period of submergence, a continuous filament of stream flow is collected in the sample bottle. Air displaced from the bottle while the sample accumulates is discharged through the air escape passage which points downstream. A fixed static head differential of 1/2-inch between the intake and exhaust facilitates sampling in low stream velocities and slack waters.

Selection of sampling locations requires evaluation of local conditions, a procedure which will not be discussed here. After the sediment sampling station or cross section has been selected, sediment samples are usually taken at verticals that represent equal fractions of stream discharge. One or more samples may be taken at each sampling vertical.

Depth-integrating suspended-sediment samplers accumulate a sample of the water-sediment mixture throughout the period of submergence. However, if the container becomes completely filled during a sampling operation, the sample will not be representative and must be discarded. Clean bottles must be used and after sampling they should be covered with suitable caps to prevent contamination or loss of the sample. The capacity of the sample bottle is about 470 cc. However, because the axis of the bottle is inclined to the vertical, any sample containing more than 440 cc. may be in error due to circulation of the water-sediment mixture. The period of submergence should be sufficient to produce a sample volume less than 440 cc., but greater than 375 cc. in order to obtain a sample large enough for laboratory analysis. It is generally preferable to retain an initial sample of less than 375 cc., but greater than 300 cc., rather than to discard the sample and resample into the same bottle. If the initial sample volume is considerably less than 300 cc., the stream vertical may be integrated a second time, or even a third time, each being additive to the same sample bottle. A minimum sample of 350 cc. is suggested but sufficient latitude in minimum sample volume should be permitted to avoid re-taking a large number of samples.

The D-49 suspended-sediment sampler should normally be used in stream depths of 15 feet or less, but depths of 20 feet can be sampled if necessary. These depths presume that sampling occurs throughout both the descending and ascending trips in the stream vertical. In general, the largest diameter nozzle that can be used within the operational limits of the equipment and personnel should be selected. However, a nozzle size which would require transit rates that are too great to be handled conveniently should not be selected. A transit rate which will produce a sample of not less than 350 cc. and not more than 440 cc. should be used for stream depths less than 10 feet. Similarly the sample obtained should approximate 380 to 440 cc. for stream depths of 10 to 15 feet., and 400 to 440 cc. for stream depths greater than 15 feet but not greater than 20 feet.

The volume of sample collected at a vertical is dependent primilarly upon the local stream velocity and the duration of submergence of the instrument. Because the operator has no control over the stream velocity and depth encountered, he must regulate the volume of the sample by selecting a nozzle of appropriate size or by varying the sampling time (total time of submergence of the instrument).

A chart showing the relation between stream velocity and corresponding filling time (time of submergence of the sampler) to produce samples 400 cc. in volume for the three standard nozzle diameters is attached. The filling time in seconds represents the total time of submergence of the instrument , that is, the time involved in traversing the stream vertical in both the downward and upward directions. Use of these filling time curves will provide acceptable sample volumes and will permit minor variations in the total time of submergence without invalidating the sample. Enter the sampling time curve with the stream velocity and determine the sampling time to secure a sample volume of 400 cc. for the respective nozzle sizes. Then select the largest diameter nozzle that can be traversed conveniently throughout the depth of the stream in the time indicated, at a uniform rate through each direction of travel.

If the estimated mean velocity of flow in a stream vertical is 4-feet per second, a sediment sampler equipped with a 1/4-inch diameter intake nozzle will accumulate a sample of 400 cc. in 10 seconds of submergence. The sampler must be lowered from the water surface to the stream bed at a uniform rate in 5 seconds and raised from the bed of the stream at a uniform rate to break the water surface at the expiration of the remaining 5 seconds. The time used in traversing the stream vertical need not be the same in both directions of travel. However, the rate at which the sampler moves vertically in any one direction must remain uniform. Thus, in the above example, the stream vertical could be traversed at a uniform downward rate in 6 seconds and at a uniform rate upward to clear the water surface in 4 seconds, a total submergence period of 10 seconds. If the 1/4-inch diameter nozzle requires a vertical transit rate greater than allowable for the stream depth, then a smaller diameter nozzle should be used.

A clean bottle must be used for each separate sediment sample; at least one suspended-sediment sample is taken at each sampling vertical in the cross section. When a filled sample bottle is removed from the sampler it is immediately capped to prevent contamination and appropriately marked. Pertinent information for every sample should be recorded to include the following:

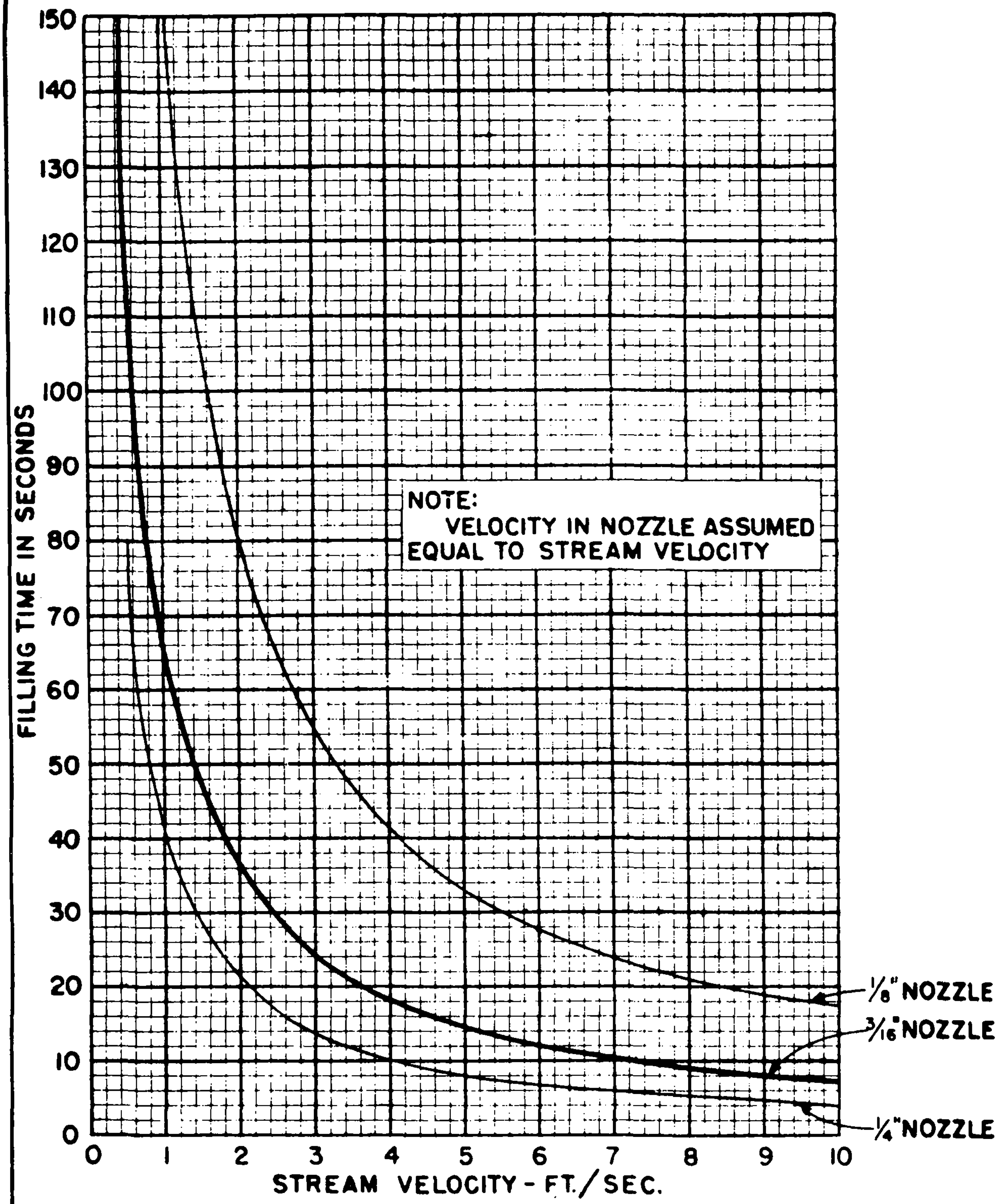
Name of stream
Precise location on stream (vertical)
Location of the cross section
Stream depth covered by the sample
Stage of the stream (gage height)
Date
Time of day
Identification applied to sampling personnel.

In addition to the above, the following information may be useful also:

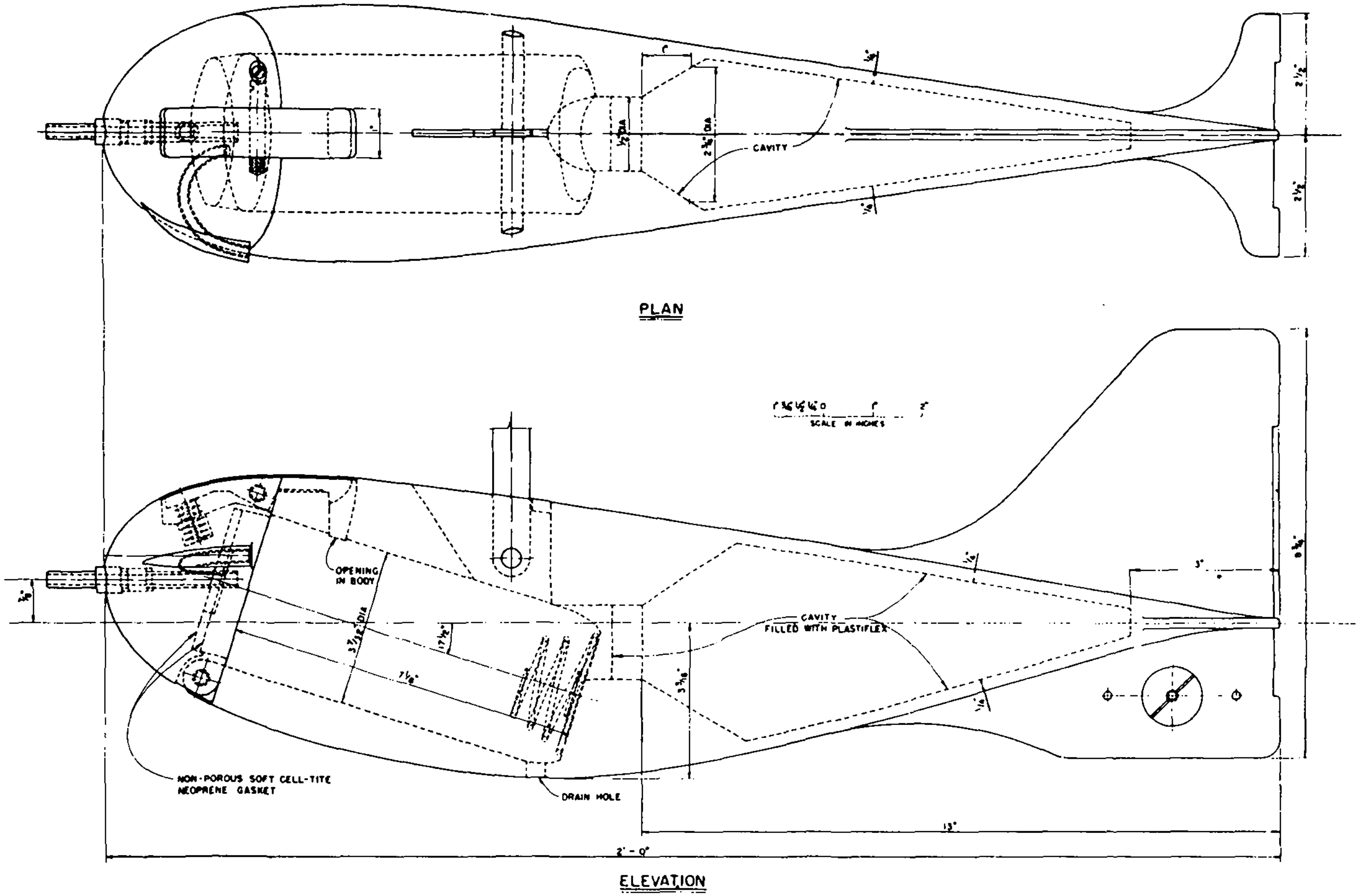
Sampling time (sampler submergence time)
Water temperature
Coordination with sample groups
Individual identifying sample number.

A portion of the exterior of the glass bottle may be etched or otherwise treated to provide a surface suitable for recording all the essential information for each sample.

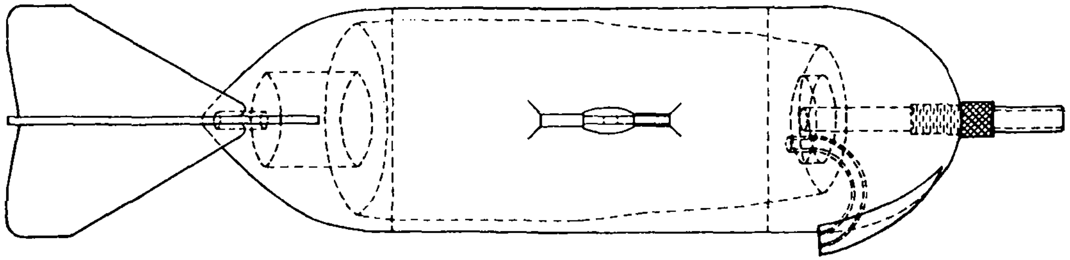
Reference: U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation, Report 0, 1965.



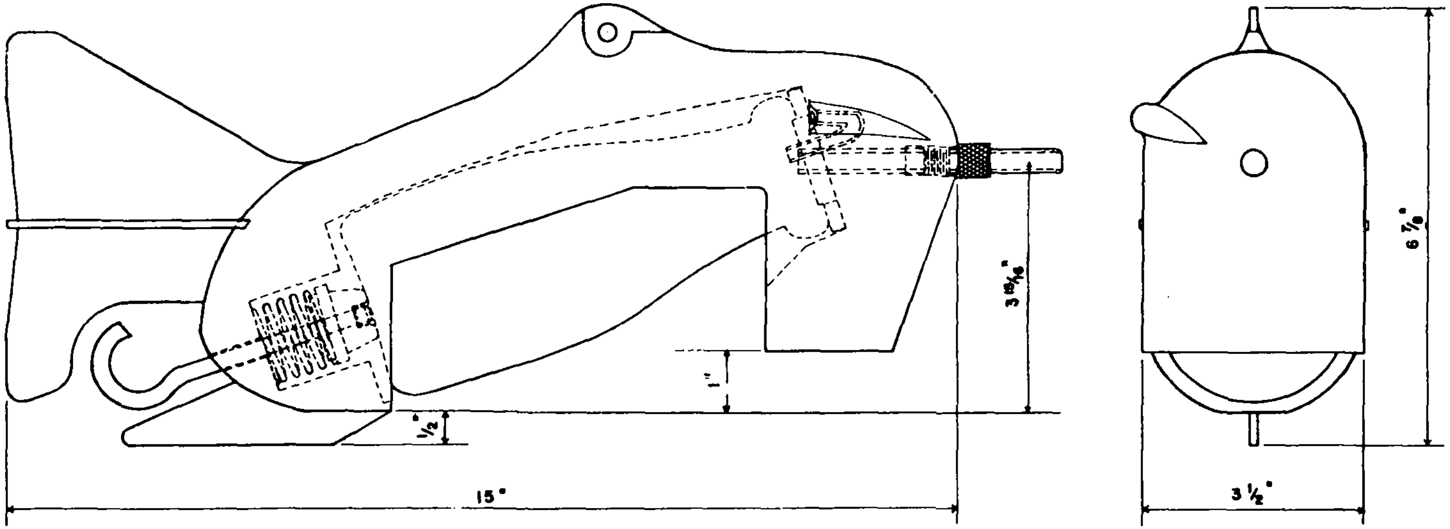
FILLING TIME
FOR SAMPLE OF 400 c.c.



DEPTH-INTEGRATING SUSPENDED-SEDIMENT SAMPLER, USD-49



PLAN



ELEVATION

FRONT

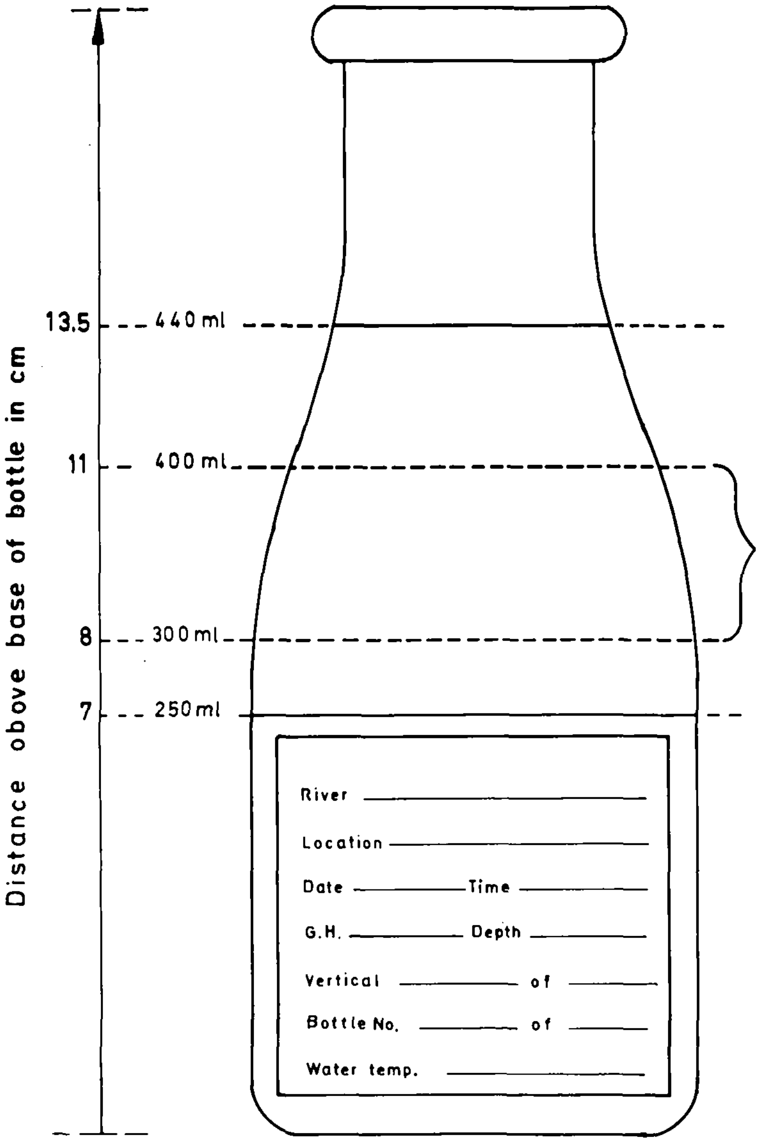
SUSPENDED-SEDIMENT SAMPLER, U S DH-59
HAND LINE SUSPENSION

APPENDIX C

SAMPLING CONTAINER

PINT-SIZE GLASS MILK BOTTLE

SAMPLING CONTAINER
PINT-SIZE GLASS MILK BOTTLE



Maximum amount of sample. More water-sediment mixture causes over-filling of the sample bottle resulting in an inaccurate sample.

A sample level in this range gives the best laboratory results.

Minimum amount of sample. Less water-sediment mixture may be an inaccurate sample.

APPENDIX D

PROCEDURE FOR THE EDI SCHEME

PROCEDURE FOR THE EDI SCHEME

Three equal increments of discharge are to be used:

1. Make a discharge measurement and compute it (Figure D.1).

2. Find the mid-points (centroids) of three increments of equal discharge. Using the discharge measurement notes of Figure D.1 the following are obtained:

   a) Divide the total discharge into three equal parts:
   380 m^3/sec ÷ 3 = 127 m^3/sec (all numbers rounded).

   b) Add the partial discharges in the last column to the right until the sum is closest to the number 127:

   0+ 1.3+2.8 + 4.8 + 6.3 + 7.6 + 8.4 + 9.3 + 10.4+ 11.1 + 11.8+ 11.8 + 13.0+ 12.8+ 12.3 = 123.7

   By adding one more partial discharge, the sum would become 137.4, therefore 127 m^3/sec is flowing in the stream between vertical at 5 metres (left edge of water) and about vertical at 66 metres (since the number 127 is closer to 123.7 than to 137.4). The mid-point of the first 127 m^3/sec increment is at (5 + 66) ÷ 2 = 36 metres. Therefore, a vertical at 36 metres is at the centroid of the first increment.

   c) Continue summing up the partial discharges, beginning with the next value:

   13.7 + 15.8 + 17.6 + 19.3 + 17.6 + 14.6+ 15.1+ 15.6 = 129.3

   This shows that 127 m^3/sec is flowing between vertical at 66 metres and about vertical at 86 metres. The mid-point of the second increment of 127 m^3/sec is at (66 + 86) ÷ 2 = 76 metres. Therefore, a vertical at 76 metres is at the centroid of the second increment.

   d) The sum of the remaining partial discharges is found to be 127.2 m^3/sec, then 127.2 m^3/sec is flowing between vertical at 86 metres and vertical at 109 metres (right edge of water). The mid-point is at (86 + 109) ÷ 2 = 98 metres. Therefore, a vertical at 98 metres is at the centroid of the third increment.

   e) As a check against the summing up, the three parts of nearly equal discharge should total 380.2 m^3/sec, which was the original discharge computed:

   123.7+ 129.3+ 127.2 = 380.2

   Thus, the summation is proved correct.

   Therefore, the three centroids at which the sediment samples will be collected are located 36, 76 and 98 metres from the initial point situated on left bank (Figure D.2).

3. When taking samples from a bridge, from a boat or from a cable-car, the DH-59 or the D-49 sampler can be used. When wading, the DH-48 sampler is used. In this example, suppose the D-49 sampler is being used from a bridge. The procedure for taking a depth-integrated sample in a vertical is as follows:

   a) Place a clean sampling bottle in the sampler and close the head. Be sure that the rubber gasket is in place in the head of the sampler and that the seal is airtight. To check for adequate seal: With bottle in proper position and air exhaust port closed with a finger, try to blow through the nozzle. This should not be possible. To check for blockage: Repeat as above but with air exhaust port open. The air should now pass freely.

   b) Estimate the length of time required to fill a sampling bottle to desired volume by use of the filling time curve for the nozzle size being used; a standard filling time curve is provided with each instrument. Rate of sampler movement is obtained by dividing the double depth by the desired sampling time.

   Usually, with practice in the field, the operator will quickly get a "feel" of the transit rates to be used without actually having to calculate them.

c) At the vertical through the first centroid, lower the sampler until the bottom barely touches the water surface. The vertical tail-fin will now orient the sampler head in an upstream direction. Do not allow the nozzle to become submerged before the sampler is in the correct position.

d) When the sampler is in the correct position, lower it to the streambed at the predetermined uniform rate. The sampler should not be allowed to rest on the streambed. Raise the sampler towards the surface immediately, again using a constant transit rate.

e) When the sampler has cleared the water surface, it can be raised at a somewhat faster rate up to the bridge for approval of the sample.

f) Carefully remove the bottle from the sampler and place a cap firmly on the top of the bottle.

g) Record all the required information on the bottle or on a bottle label (Appendix C).

h) Repeat the procedure at the two remaining centroids. The transit rate may be different at each centroid.

i) When the measurement has been completed, record all pertinent data on the Suspended Sediment Sampling Data form (Section 5.1.5).

4. A few suggestions which will be helpful in order to obtain good samples:

a) If the transit rate has been too fast and the content in the bottle is substantially less than the required minimum of 250 ml as shown in Appendix C, the same bottle can be replaced into the sampler being careful not to spill any water and once again lowered to the streambed and raised. Another sample is thereby added to the bottle at the same centroid by using a transit rate that will fill the bottle to the proper level. If in doubt as to the accuracy of the sample, a new sample should be taken at a slower transit rate and the first sample discarded.

b) Whenever debris is found on the nozzle, a new sample should be taken. If debris is found inside the nozzle, it is ususally cleared by blowing through it.

c) If water is seen to drain out from the nozzle when the sampler is raised from the water surface, it means that the bottle is overfilled. The sample should be discarded and a new sample taken at a faster transit rate.

d) If more water than usual is draining from the sampler when it is raised from the water surface, it may mean that the bottle was placed improperly in the sampler and that some of the sample has leaked out around the gasket. In this case, the sample is thrown out and a new sample taken.

e) The maximum theoretical sampling depths are as previously noted:

2.5 m for 1/4 inch nozzle
4.3 » » 3/16 » »
4.6 » » 1/8 » »

The best sample is obtained with the largest nozzle which can be used in a given situation.

GAUGING STATION.. No.............................. SHEET No......1/3.......

DATE.................................. MEAN GAUGE HEIGHT...............................

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
LEW	1445															Per cent
5	0												0	0	0	0
7	1.0			.6		10	46	0.51			0.51		2.5	1.3	1.3	0.3
10	1.2			.6		10	40	0.58			0.58		4.8	2.8	4.1	1
15	1.4			.6		20	67	0.69			0.69		7.0	4.8	8.9	2
20	1.6			.6		20	58	0.79			0.79		8.0	6.3	15.2	4
25	1.8			.6		20	54	0.85			0.85		9.0	7.6	22.8	6
30	1.9			.6		20	52	0.88			0.88		9.5	8.4	31.2	8
35	2.0			.6		20	49	0.93			0.93		10.0	9.3	40.5	11
40	2.2			.6		20	48	0.95			0.95		11.0	10.4	50.9	13
45	2.2			.6		20	45	1.01			1.01		11.0	11.1	62.0	16
50	2.3			.6		20	40	1.13			1.13		10.4	11.8	73.8	19
54	2.4			.6		30	55	1.23			1.23		9.6	11.8	85.6	22
58	2.4			.6		30	50	1.35			1.35		9.6	13.0	98.6	26
62	2.5			.8		30	52	1.29			1.46		8.8	12.8	111.4	29
				.2		30	41	1.64								
65	3.0			.8		30	49	1.38			1.58		7.8	12.3	123.7	32
Totals				.2		40	50	1.79								

Computed.. *Date*.. *Checked by*.. *Date*..

Figure D.1. Illustration showing a water discharge measurement.

GAUGING STATION... **No.**.............................. **SHEET No.** 2/3

DATE..................................... **MEAN GAUGE HEIGHT**..................................

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	Velocity					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
68	3.0			.8		30	46	1.47			1.69		8.1	13.7	137.4	36
				.2		40	47	1.91								
71	3.0			.8		30	43	1.56			1.82		8.7	15.8	153.2	40
				.2		40	43	2.08								
74	3.0			.8		30	40	1.68			1.96		9.0	17.6	170.8	45
				.2		40	40	2.23								
77	3.0			.8		40	50	1.79			2.08		9.3	19.3	190.1	50
				.2		50	47	2.38								
80	2.5			.8		40	48	1.87			2.20		8.0	17.6	207.7	55
				.2		50	44	2.55								
82	2.0			.8		40	47	1.91			2.28		6.4	14.6	222.3	58
				.2		50	42	2.65								
84	2.0			.8		40	46	1.95			2.36		6.4	15.1	237.4	62
				.2		50	40	2.78								
86	2.0			.8		40	45	1.99			2.44		6.4	15.6	253.0	66
				.2		60	46	2.90								
88	2.0			.8		40	44	2.03			2.54		6.4	16.3	269.3	71
Totals				.2		60	44	3.04								

Computed.. *Date*.................................... *Checked by*.. *Date*..

Figure D.1. Illustration showing a water discharge measurement.

GAUGING STATION.. **No.**........................... **SHEET No.**....3/3.........

DATE.................................... **MEAN GAUGE HEIGHT**...............................

Distance from initial point	Sounded depth	Angle	Revised depth	Unrevised depth of obs.	Revised depth of obs.	Revs.	Time	VELOCITY					Area of section	Discharge in section	Discharge accum.	Remarks
								Vel. at point	Multiplier		Mean vel. in vert.	Mean vel. in section				
90	2.0			.8		40	44	2.03			2.60		6.6	17.2	286.5	75
				.2		60	42	3.18								
92	2.0			.8		40	44	2.03			2.60		6.6	17.2	303.7	80
				.2		60	42	3.18								
94	2.0			.8		40	44	2.03			2.57		6.4	16.4	320.1	84
				.2		60	43	3.11								
96	2.0			.8		40	45	1.99			2.48		6.0	14.9	335.0	88
				.2		60	43	2.97								
98	2.0			.8		40	46	1.95			2.36		5.4	12.7	347.7	92
				.2		50	40	2.78								
100	2.0			.8		40	48	1.87			2.20		5.0	11.0	358.7	94
				.2		50	44	2.53			2.53					
102	2.0			.6		40	45	1.99			1.99		4.6	9.2	367.9	97
104	2.0			.6		40	52	1.72			1.72		3.8	6.5	374.4	98.5
106	2.0			.6		30	49	1.38			1.38		3.0	4.1	378.5	99.6
108	1.5			.6		20	47	0.97			0.97		1.8	1.7	380.2	100
109	0.5												0			
Totals	REW	1600													380.2	100

Computed.. *Date*................................. *Checked by*.................................... *Date*....................................

Figure D.1. Illustration showing a water discharge measurement.

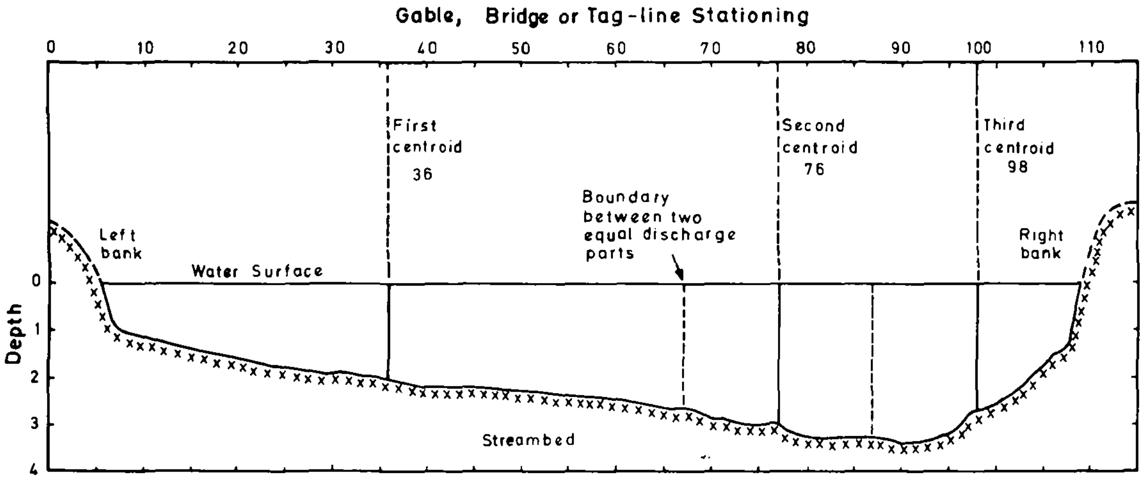


Figure D.2. Diagram of a stream cross-section (same as in Figure D-1) with the location of three centroids and boundaries between parts of equal discharge in the EDI sampling method.

APPENDIX E

PROCEDURE FOR THE ETR SCHEME

PROCEDURE FOR THE ETR SCHEME

In the ETR scheme, a single uniform transit rate is used for all sampling verticals. The transit rate must be one that causes the bottle used in the maximum vertical (vertical where the product of depth and velocity is greatest) to be filled to the proper level. It is desirable at a new sampling station to make initially a few water discharge measurements at various levels in order to gain information about depths and velocities.

The ETR procedure is as follows:

1) Select 10 to 20 equally spaced sampling verticals over the cross-section (Figure E.1).

2) Select the transit rate to be used. Assume that a water discharge measurement has been made and that the deepest vertical also has the highest velocity, say a depth of 1.5 metres and a mean velocity of 1 m/sec.

   At a depth of 1.5 metres, the sampler must travel a total distance of 3 metres (1.5 metres down and 1.5 metres up). Table 3 shows that about 23 seconds are required to fill a sample bottle to the proper level in water flowing at 1.00 m/sec if the 3/16-inch nozzle is used; if the 1/4-inch nozzle is used, the time required would be about 13 seconds. The transit rate can now be calculated by the formula

$$\text{Transit rate} = \frac{\text{Depth in deepest section x 2}}{\text{Filling time for sample bottle}}$$

   For the 3/16-inch nozzle:

$$\text{Transit rate} = \frac{1.5 \text{ x } 2}{23} = 0.13 \text{ m/sec}$$

   For the 1/4-inch nozzle:

$$\text{Transit rate} = \frac{1.5 \text{ x } 2}{13} = 0.32 \text{ m/sec}$$

   If the deepest vertical and the vertical having the highest mean velocity are not one and the same, the transit rates have to be calculated for both of them and the highest rate selected.

   The above example shows the proper method for calculating the transit rate for different nozzles. Three points should be considered in selecting which nozzle to use:

   Firstly, the 1/4-inch nozzle should be used wherever possible because it gives more accurate samples than the smaller nozzles. The 1/8-inch nozzle should be used only when a correct sample can not be obtained with the larger nozzle, because coarse sand may not enter the 1/8-inch nozzle in the right proportion.

   Secondly, a transit rate must be selected that the operator can manage and still obtain an accurate sample. The transit rate that can be managed varies with different operators according to the experience they have in taking samples.

   Thirdly, a transit rate should be selected that is less than 4/10 of the mean velocity of the flow in the vertical having the highest velocity. This is because at a faster rate than 4/10 of the flow velocity, the effective velocity of the water entering the nozzle is significantly reduced and a representative sample can no longer be obtained.

   If a small part of the flow, for instance near the banks, is very slow compared to the major part of the flow, the slow portion should be ignored when the 4/10 velocity rule is applied.

3) Place a bottle in the sampler making sure that the gasket is in place in the head of the sampler.

4) Using the transit rate selected, take a sample at the first vertical. If it is possible to do so without overfilling, use the same bottle taking a sample at the second vertical.

5) Continue sampling across the stream at the preselected sampling verticals, changing bottles only when necessary in order to prevent overfilling. It is generally possible to use a single bottle at two or three verticals in the slower and shallower parts of the stream, while in the deeper and faster parts only one bottle will be used per vertical. Follow the instructions given in Appendix D as applicable to the ETR scheme.

6) Enter the required information on the labels of all bottles. The bottles should all be marked "ETR" and numbered in the following manner: if there are six bottles used for the total set of samples, they should be marked 1/6, 2/6, 3/6, 4/6, 5/6 and 6/6 indicating that the bottle 2/6, for instance, is bottle number 2 in a set of six bottles.

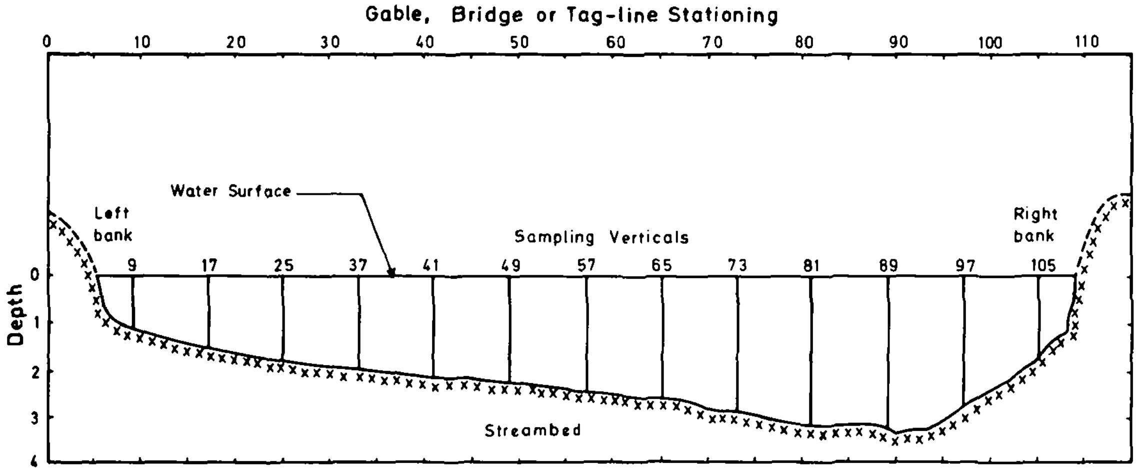


Figure E.1. Diagram of a stream cross-section with 13 equally-spaced sampling verticals in the ETR sampling method.

APPENDIX F

POINT SAMPLING, CALCULATION OF A VELOCITY WEIGHED MEAN CONCENTRATION

POINT SAMPLING. CALCULATION OF A VELOCITY-WEIGHED MEAN CONCENTRATION.

Taking c_i and v_i as the concentration and velocity at each sampling point, the mean concentration $\bar{c}$ is calculated as:

$$\bar{c} = \frac{\Sigma c_i v_i}{\Sigma v_i}$$

That is, the mean of the concentrations is weighed with respect to the velocities according to the following theory:

There are a corresponding concentration c_i and a velocity v_i for each of the 6 points at A, B, C, D, E, F, (Figure F.1). The total cross section is assumed divided into six equal segments A_i, c_i and v_i being the mean concentration and velocity respectively in each segment.

Then the weight of sediment transported per second is:

$$P = \Sigma A_i v_i c_i = A_i v_i c_i + \cdots\cdots\cdots + A_6 v_6 c_6$$

The mean stream discharge in the cross section is:

$$Q = \Sigma A_i v_i = A_1 v_1 + \cdots\cdots\cdots\cdots + A_6 v_6$$

The mean sediment concentration is:

$$\bar{c} = P/Q = \frac{\Sigma A_i v_i c_i}{\Sigma A_i v_i}$$

As $A_1 = A_2 = A_3 = A_4 = A_5 = A_6 = A/6$, it follows that:

$$\bar{c} = \frac{A/6\ \Sigma v_i c_i}{A/6\ \Sigma v_i} = \frac{\Sigma v_i c_i}{\Sigma v_i}$$

The sampling points A, B, C, D, E, F are positioned in the centre of the subsections as indicated in Figure F.1.

The velocity at a sampling point is obtained as follows:

$$\bar{v} = \frac{V}{At}$$

where

$\bar{v}$ = mean velocity of flow (cm/sec)
V = volume of sample (cm^3)
A = cross-sectional area of nozzle intake (cm^2)
t = filling time (sec)

In lieu of using the velocity at each sampling point for weighing the concentrations, record the sampling time for each sample and use the weight of the sample collected per second in order to weigh the concentrations.

A more accurate result can be obtained by a double graphical integration as follows: The product obtained by multiplying concentration by velocity at each sampling point is plotted against depth of the corresponding vertical and a curve drawn through the points. The area bounded by the curve, the vertical and the water's surface is then plotted against its lateral position in the stream cross-section and a curve drawn through these points. The area bounded by this curve and the width of the cross-section represents the total sediment discharge through the cross-section.

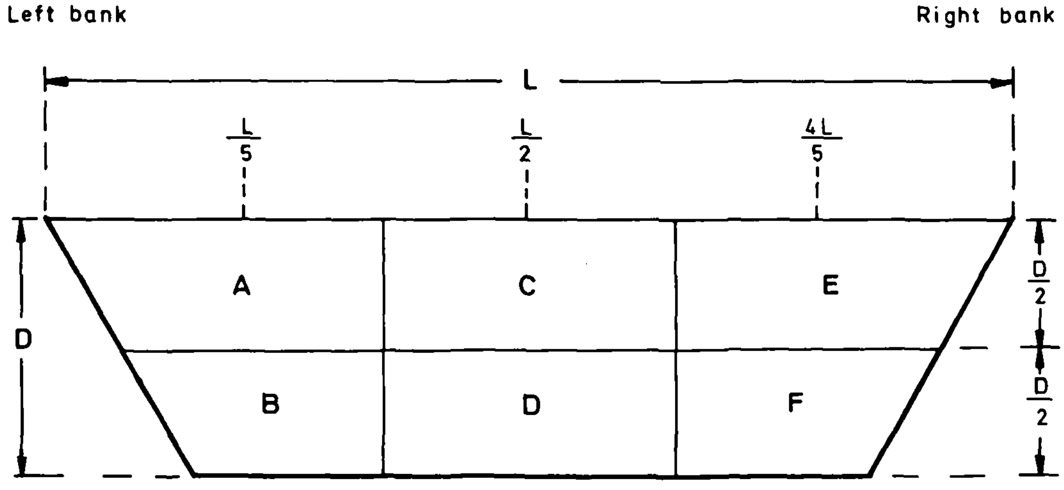


Figure F.1. Diagram of a stream cross-section with the location of six sampling points in the point sampling method.

APPENDIX G

PROCEDURE FOR THE EVAPORATION METHOD WHEN DISSOLVED SOLIDS CONTENT IS HIGH

PROCEDURE FOR THE EVAPORATION METHOD WHEN DISSOLVED SOLIDS CONTENT IS HIGH

The sample is washed in distilled water as follows:

1. Weigh the sampling bottles with the samples to the nearest gramme.
2. Leave the samples to settle in their bottles.
3. When all the sediment has settled and the water is clear (this may take one or more days), siphon off about 9/10 of the clear water. Keep this water in order to determine the concentration of the dissolved solids (i.e. salts) in the natural water if required.
4. Pour the remainder into a glass evaporation basin and rinse the sampling bottle out with distilled water as thoroughly as possible at least four or five times. This water is also poured into the evaporation basin which should contain 400 to 500 ml of water by the end of the operation.
5. Clean the sample bottles and air dry them. Determine the tare weight by weighing to the nearest gramme. Cap the bottles and pack them in carrying cases for reuse.
6. Leave the basins until all the sediment in the water has settled and the water is completely clear. Then siphon off about 9/10 of the clear water.
7. Heat the basins with the remaining water-sediment mixture to 90–95°C. When all visible moisture has evaporated, raise the temperature to about 110°C for one hour.
8. Cool the evaporation basins in a desiccator at room temperature.
9. Weigh the basins to the nearest 0.1 mg on an analytical balance.
10. After weighing, wash out the basins and dry them and weigh them empty.

To find the weight of salts in solution, evaporate a known quantity of the water siphoned off in step 3 above.

With this procedure, if the concentration of salts in solution in the natural water is equal to the sediment concentration, the fraction of the dried material consisting of salts will be about 0.6 percent of the total weight of the material in the evaporating basin.

One additional advantage of this procedure is that the sediment is more completely washed out of the sampling bottle and into the evaporation basin. This is important when sediment tends to adhere to the inner surface of the sampling bottle (which may be the case with plastic bottles) and when the sediment concentration is low.

APPENDIX H

DETAILED ANALYSIS PROCEDURE FOR THE BOTTOM WITHDRAWAL TUBE

DETAILED ANALYSIS PROCEDURE FOR THE BOTTOM WITHDRAWAL TUBE

A complete list of equipment and a comprehensive and detailed description of the test procedure and computations necessary is given below for determining the size grading of a sediment sample, together with notes and observations designed to aid in obtaining a correct analysis. The test procedure is based upon the analysis of suspended sediment samples submitted to the laboratory in pint bottles and containing, approximately 400 cc.

Equipment

Beakers, capacity 400 cc
Drying oven
Desiccators
Analytical balance, sensitivity 0.1 mg., capacity 200 gm
Evaporating dishes, pyrex, capacity 100 cc
Graduates, capacity 100 cc
Distilled water
Bottom withdrawal tubes, similar to that shown in Fig. 10
Stop watch or timer
Thermometer, 1° subdivisions, −10° to + 110°C
Rubber tubing, 5/16 in. bore
Stand for holding bottom withdrawal tube during test
Bottle brush
Pinch-clamps
Corks, size No. 9

Step by step procedure

a. If samples are to be stored in the laboratory for a period of several weeks before analysis they should be placed in a dark room or in subdued light in order to retard the growth of algae, or a few drops of formaldehyde may be added to prevent growth of algae. Samples in which algae have grown or which give off a strong odor of decaying organic matter or of hydrogen sulfide probably should be discarded.

Discussion: It is strongly recommended that samples be taken to the laboratory as soon as possible after being secured and the analysis run immediately in order to simulate actual stream conditions. If this is done it is believed that the turbulence set up in bringing the suspension to a uniformly dispersed condition, as described in step c, will probably more nearly approach the condition found in natural streams. If a sample is stored over a prolonged period of time before an analysis is made, and it appears that some additional mechanical dispersion is necessary, caution should be observed in determining the severity of the mixing process. Conglomerates or clusters of particles which appear in the natural stream should not be broken down if a true picture of sedimentation is to be obtained.

b. Pour the sample into the bottom withdrawal tube and note the height of water column in order that the volume of the sample may be determined and recorded. Wash the sample bottle into the tube with a stream of clear native water and bring the suspension to the 100 cm height.

c. In the 2 or 3 min. required to transfer the sample into the tube, all of the particles of 1/8 mm diameter or greater will have had time to collect at the bottom of the tube. Placing one hand over the open end, or with a cork closing the open end, raise the tube to an inclined position so that the bottom of the tube is at a slightly higher elevation than the top end. With the tube in this position execute a backward and forward motion to wash the coarser particles out of the constricted or bottom end and continue this motion until it is observed that the coarser particles are distributed quite uniformly over the total length of the tube. The coarser particles can be seen by the eye along the bottom of the tube if it is held before a light. When this has been accomplished the tube will still be in an inclined position with the air bubble at the constricted end. Place the tube in an upright position. Invert the tube from end to end, allowing the air bubble to travel the full length of the tube (this takes about 5 sec.) before each inversion. Uniform dispersion is obtained when the suspension has become uniform in color throughout. This may take from 2 to 5 min. The tube is held vertical in both the upright and inverted positions. Once the inverting of the tube is started the process should be continuous. Should a break in the dispersion procedure occur, a fresh start should be made with the tube in an inclined position as described above. After uniform dispersion is obtained the stop watch is started when the tube is inverted to an upright position preparatory to placing in the stand. At this instant the air bubble is at the bottom of the tube. The tube is then securely fastened in the stand in a vertical position. If a cork is used it must be removed before the first fraction is withdrawn.

Discussion: This method of dispersion and the time for starting the stop watch differs somewhat from the procedure used in the preliminary tests. It is based upon further study of the behavior of the coarser particles made as a result of suggestions received from the cooperative agencies in reviewing the preliminary report and represents a refinement in the test procedure. It is felt that these improvements will result in a better analysis.

d. In this investigation, ten equal volume fractions were withdrawn for each test. Time intervals were chosen in such a way as to accurately define the Oden curve. Since the tube was 100 cm in length, each fraction corresponded to a column height of 10 cm. The first fraction had a total fall of 90 cm. A 1.0 mm particle will fall 90 cm in about 6 sec. and a 1/16 (0.0625 mm) particle will fall that distance in a little less than 5 min. In the former case the first fraction would have to be withdrawn in from 6 to 10 sec. but in the latter case it need not be withdrawn until after about 5 min. have elapsed. In general, for material containing particles as coarse as 1.0 mm, the withdrawal times used were at 10 sec., 30 sec., 1, 3, 7, 16, 40, 80 and 120 min. For samples containing particles in the neighborhood of 1/16 mm or smaller the time intervals were spaced at 4, 15, 40, 54, 69, 82, 97, 110 and 124 min. The last fraction had a fall of 10 cm and particles as fine as 0.0039 mm were caught in a total elapsed time of 120 min. Deviations from any certain set time will do no harm if the actual time of withdrawal is noted.

e. About 1.0 sec. before the chosen withdrawal time, the pinch-clamp is quickly opened to full width and then closed slowly as the last of the sample is being withdrawn. A full opening is required at the start in order that the rush of water will clear the cone of any deposited sediment. Once this has been accomplished the pinch-clamp may be closed as slowly as desired in order to gage the sample height more accurately. With a little practice one becomes quite expert at withdrawing fractions. It must be remembered, however, that the total elapsed time is not taken at the time the pinch-clamp is opened, but at the time that it is closed. The method is entirely flexible in that fractions of any desired depth and volume may be withdrawn as long as the particle size range is covered and enough points are obtained to accurately define the Oden curve. Seven is probably the minimum for satisfactory results. The column height must be read after the withdrawal of each fraction.

f. Samples are withdrawn into a 100 cc graduate in order to eliminate the possibility of losing any of the sample from splashing. They are then poured into the evaporating dishes, the graduate being washed with a stream of distilled water. Each evaporating dish should be numbered and the tare weight determined frequently. Preference was given to pyrex evaporating dishes rather than porcelain because the glass containers are lighter in weight. Care should be taken in cleaning the tubes, evaporating dishes, and graduates before each test. This is especially important when light concentrations are being analyzed.

g. The evaporating dishes are placed in the oven to dry overnight at a temperature of from 105° to 110°C.

h. The evaporating dishes are transferred directly from the oven to a desiccator and allowed to cool about 40 min. to room temperature. They are then weighed to 0.1 mg. The desiccator should remain closed except when removing a sample.

i. Using ordinary precautions in maintaining a constant room temperature, a temperature determination of the suspension at the middle or latter part of the test has been taken as the average for the entire test. If there is considerable temperature variation more frequent readings will be necessary.

j. A sample of the clear water from one of the pint bottles evaporated to dryness should give the amount of dissolved solids present. For the sake of the time saved, it is recommended that one or more dissolved solids determinations be made in this manner for each set of sediment samples so that it will not be necessary to filter through filter paper or Gooch or alundum crucibles. Experience should dictate the number of determinations necessary. Having determined the weight of dissolved solids per cc of suspension, a correction can be made to each fraction withdrawn according to its volume.

k. The recorded data together with the computation required to obtain the coordinates of the Oden curve are shown in Table 4. Columns 1 to 6, inclusive, are recorded during the analysis. The weight of sediment in each fraction is obtained by subtracting the tare from the gross and is recorded in Column 7. Column 8 is the net weight of sediment after subtracting the proportionate weight of dissolved solids from the weights in Column 7. By adding the net weights cumulatively, as is done in Column 9, the total sediment weight in suspension above each indicated depth is obtained. A depth factor is then computed in Column 10 by dividing the observed column heights in Column 3 into the total depth of 100 cm. Applying this factor to the weights in Column 9 reduces them to the weight that would obtain in a 100 cm depth at the same average density. In Column 12 these weights for a 10 cm depth are expressed in percentages of the total sediment weight. Column 13 is the result of applying the depth factor to the elapsed time in Column 2 and is the time required for the average density above each observed height in Column 3 to be reached at 100 cm. In effect, then, these computations reduce the observed times of settling and weights in suspension to a constant depth of 100 cm.

l. The Oden curve is plotted on rectangular coordinate paper as shown in Fig. 25. The lower curve of Fig. 25 is the complete curve plotted from Columns 12 and 13 of Table 4. The upper curve is the upper portion of the complete curve plotted to an enlarged horizontal scale to facilitate the determination of the grading of the coarser particles. The choice of horizontal scales is arbitrary so long as smooth curves are drawn through the plotted points. Points of tangency are located from the temperature of the suspension (26°C) and the use of Table 1. It will be noted that the "square root of two" grade scale is used. Once the Oden curve is defined any grade scale may be used, because as many or as few grade points as desired may be determined by merely drawing tangents at the proper points and reading the tangent intercepts on the vertical axis.

Discussion: The construction of the Oden curve and the drawing of tangents is a matter of vital importance in the analysis of sediment samples. In order to better show the method of drawing the curve, several typical examples are given in Appendix B. In suspended sediment samples where sedimentation takes place from a uniformly dispersed condition, the settling of particles will continue for several hours or even days before all particles have completely settled out of suspension. Since the Oden curve as here used shows the amount of sediment remaining in suspension with respect to time it is evident that the slope of the curve will probably never become zero over the period of time covered by the size analysis test. Furthermore, the curve will never have a negative slope. These facts are used as a guide in drawing a curve such as that shown on Fig. 30, Appendix B. No involved or refined method was used in arriving at smooth average curves or in the drawing of tangents. Curves and tangents were drawn with the aid of french curves, ship curves, and triangles. No study was made of the extent of error to be expected as a result of the variation in drawing of tangents by the same or different workers.

A tangent at a point is difficult to draw on a curve having too flat or too steep a slope. The horizontal scales used have been chosen in such a way that this difficulty is minimized. It may be desirable to change scales to fit different materials. If it is felt that the tangent intercept for the 0.0039 mm fraction is too indefinite on Fig. 26, Appendix B, for instance, the curve can be redrawn to a horizontal scale of 200 min. to the cm instead of the 100 min. to the cm as shown. This would increase the slope of the curve and make the drawing of the tangent more positive. Any of several different french and ship curves may be used for drawing the curves, but particular use was made of a ship curve similar to Dietzgen catalogue No. 2217–48 in drawing the flatter portion of the curves. It becomes difficult to maintain continuity with the use of ordinary french or ship curves if the horizontal scale is expanded much beyond that used in the curves shown in this report.

This recommended test procedure differs in some respects from that used in the testing of the bottom withdrawal tube. It was not practicable to attempt to obtain actual suspended sediment samples with the desired size range from nearby rivers. Oven dry material was used instead, because any desired concentration and volume of suspension could easily be made up. The dry material was weighed, placed in a beaker, covered with distilled water, a deflocculant added if necessary, and allowed to soak overnight. The sample was then washed into a dispersion cup, placed in a milk shake mixer, and dispersed for 10 min. The dispersion cup and machine were similar to those specified in A.S.T.M. Designation D422–38T. The suspension was then ready to be transferred to the bottom withdrawal tube and the step by step procedure followed as outlined above. Since distilled water was used, no correction was necessary for dissolved solids.

In the tests the fractions were withdrawn into a 100 cc glass graduate and then transferred to an evaporating dish, since some of the water would splash out if taken directly into the evaporating dish. In order to eliminate the necessity of making this transfer, and to speed up the analysis, it is believed that a way can be found of taking the fraction from the tube directly into the vessel in which it is evaporated.

Test results of a few analyses made on actual suspended sediment samples emphasize the likelihood that concentrations as light as 100 ppm may be handled with the bottom withdrawal tube with an accuracy comparable to the field conditions under which they are usually taken. Test results of one field sample of higher concentration is shown in Table 4 and Fig. 25.

The foregoing procedure is not entirely based upon extensive experience, as it was necessary to complete the project before many actual suspended sediment samples were analyzed. It can no doubt therefore be improved upon as the result of further experience.

Care should be exercised in attaching the scale to the bottom withdrawal tube. The scale should cover only the cylindrical portion of the tube and the volume below the lowest reading on the scale down to the pinch-clamp should be the same as would exist if the cylindrical portion of the tube was extended down to, and the tube ended at, the zero of the gage. Thus, if the lowest reading on the scale is 10 cm, the volume of the tube below this graduation down to the pinch-clamp should be the same as in any 10 cm section of the cylindrical portion of the tube above the 10 cm mark.

Reference [15]

TABLE 1

BOTTOM WITHDRAWAL SEDIMENTATION TUBE ANALYSIS

TIME TABLE TO BE USED WITH THE ODÉN CURVE

Time in min. required for spheres having a specific gravity of 2.65 to fall 100 cm. in water at varying temperatures. Terminal fall velocity for particles 0.00195 to 0.0625 mm. computed according to Stokes' Law; terminal fall velocity for coarser particles taken from curves prepared at The California Institute of Technology.

Temp. °C.	Particle Diameter in mm.														
	1.00	0.50	0.25	0.125	.0625	.0442	.0312	.0221	.0156	.0110	.0078	.0055	.0039	.00276	.00195
10	0.115	0.243	.592	1.73	6.22	12.4	24.9	49.7	99.6	200	399	802	1594	3182	6380
11	0.114	0.240	.577	1.68	6.03	12.1	24.2	48.3	96.9	195	388	780	1551	3095	6206
12	0.113	0.237	.568	1.65	5.87	11.7	23.6	46.9	94.2	189	377	758	1507	3007	6031
13	0.112	0.233	.562	1.62	5.72	11.4	22.9	45.7	91.6	184	367	737	1466	2927	5868
14	0.111	0.232	.552	1.59	5.57	11.1	22.3	44.5	89.2	180	357	718	1428	2850	5715
15	0.110	0.228	.543	1.56	5.42	10.8	21.7	43.3	86.9	175	348	698	1391	2776	5566
16	0.109	0.227	.538	1.53	5.27	10.6	21.2	42.2	84.6	170	339	681	1354	2703	5421
17	0.108	0.225	.528	1.50	5.15	10.3	20.6	41.1	82.5	166	330	664	1320	2969	5285
18	0.107	0.222	.522	1.48	5.02	10.0	20.1	40.1	80.5	162	322	647	1288	2570	5154
19	0.107	0.220	.515	1.45	4.88	9.77	19.6	39.1	78.5	158	314	631	1256	2507	5026
20	0.106	0.218	.508	1.41	4.77	9.53	19.2	38.2	76.6	154	306	616	1225	2445	4904
20.5	0.106	0.217	.505	1.40	4.72	9.43	19.0	37.8	75.8	153	303	609	1212	2418	4849
21	0.105	0.217	.503	1.39	4.67	9.32	18.7	37.3	74.9	151	299	602	1198	2391	4794
21.5	0.105	0.215	.500	1.38	4.61	9.21	18.5	39.9	74.0	149	296	600	1179	2362	4736
22	0.104	0.213	.497	1.37	4.56	9.10	18.3	36.4	73.0	147	292	587	1168	2332	4675
22.5	0.104	0.213	.492	1.35	4.50	8.99	18.1	36.0	72.2	145	289	580	1155	2306	4621
23	0.104	0.212	.488	1.34	4.45	8.88	17.8	35.5	71.3	143	285	574	1141	2277	4566
23.5	0.104	0.210	.487	1.33	4.39	8.78	17.6	35.1	70.5	142	282	567	1128	2251	4514
24	0.103	0.210	.485	1.32	4.33	8.67	17.4	34.7	69.6	140	279	560	1114	2225	4461
24.5	0.103	0.210	.480	1.31	4.29	8.58	17.2	34.3	68.9	139	276	554	1102	2200	4411
25	0.103	0.208	.478	1.30	4.25	8.48	17.0	33.9	68.1	137	273	548	1090	2175	4361
25.5	0.102	0.208	.475	1.29	4.20	8.38	16.9	33.6	67.4	136	270	541	1078	2151	4312
26	0.102	0.207	.472	1.28	4.15	8.28	16.7	33.2	66.6	134	266	534	1065	2126	4263
27	0.101	0.205	.467	1.26	4.05	8.10	16.3	32.4	65.1	131	260	524	1042	2076	4169
28	0.101	0.203	.462	1.24	3.97	7.93	15.9	31.7	63.7	128	255	512	1019	2034	4079
29	0.100	0.202	.455	1.22	3.88	7.77	15.6	31.1	62.3	125	249	501	997	1990	3991
30	0.0998	0.200	.450	1.20	3.80	7.60	15.3	30.4	61.0	123	244	491	976	1948	3907
31	0.0991	0.198	.445	1.18	3.71	7.43	14.9	29.8	59.7	120	239	481	956	1908	3826
32	0.0987	0.197	.442	1.17	3.65	7.28	14.5	29.2	58.5	118	234	471	936	1869	3747

TABLE 4

DATA FOR BOTTOM WITHDRAWAL TUBE SIZE ANALYSIS

Description: Depth-integrated sample, Cedar River near Conesville--Station 80   Date taken 5-6-42   Date run 5-7-42
Sample No. CC52   Run by F. W. P.   Computed by L. A. D.   Checked by P. C. B.   Tube No. 14   Temp. °C. 26
Column height 77.5 cm.   Volume 422.4 cc.   Sediment 0.45 gm.

Wt. of Suspension 422.85 gm.   P.P.M. 1,060   Dissolved solids 0.00022 gm./cc.

Note: Clear native water used in washing sample into tube and in bringing suspension to 100 cm. height at start of test.

Clock Time	Elapsed Time min.	Fall Ht. cm.	Dish No.	Weight					Depth Factor 100/(3)	Sed. in Susp. 100 cm. fall (9)x(10) gm.	Per Cent in Susp.	Time to Settle 100 cm. (2)x(10) min.
				Gross gm.	Tare gm.	Sediment (5) - (6) gm.	Net (7) - Dis. Solids gm.	Cum. (Read up) gm.				
1	2	3	4	5	6	7	8	9	10	11	12	13
	0	100						.4519	1.0	.4519	100	
	8	90.3	20	61.6420	61.5667	.0753	.0643	.3876	1.107	.4291	95.0	8.85
	24	80	10	65.8947	65.8100	.0847	.0737	.3139	1.25	.3924	86.9	30.0
	40	69.6	3	60.5398	60.4627	.0771	.0661	.2478	1.435	.3556	78.7	57.4
	54	60	38	58.3563	58.2931	.0632	.0522	.1956	1.667	.3261	72.2	90.0
	69	49.5	12	62.3001	62.2362	.0639	.0529	.1427	2.02	.2883	63.8	139.4
	82	40	50	70.7378	70.6869	.0509	.0399	.1028	2.50	.2570	56.9	205
	96	30	25	60.9525	60.9037	.0488	.0378	.0650	3.333	.2166	47.9	320
	110	20	24	64.0510	64.0087	.0423	.0313	.0337	5.0	.1685	37.3	550
	124	9.9	43	64.9908	64.9570	.0338	.0228	.0109	10.1	.1101	24.4	1252
		0	45	63.7403	63.7184	.0219	.0109					

Dissolved Solids: Gross Weight 42.3844   Volume of Sample 50 cc.
Wt. of dish 42.3734
Net 0.0110 gm.; dissolved solids = 0.0110/50 = 0.00022 gm./cc.

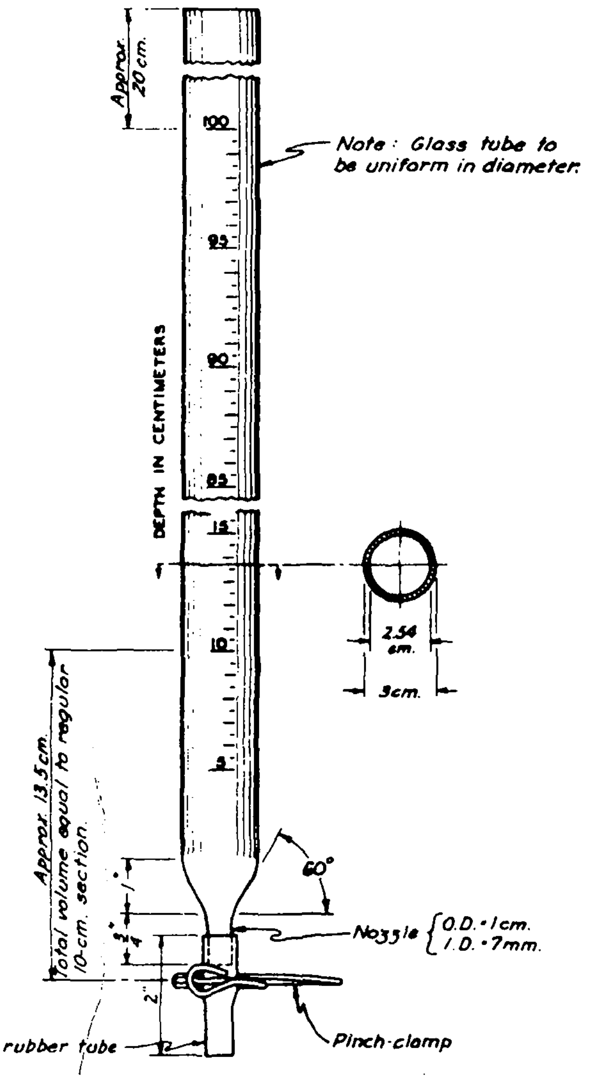
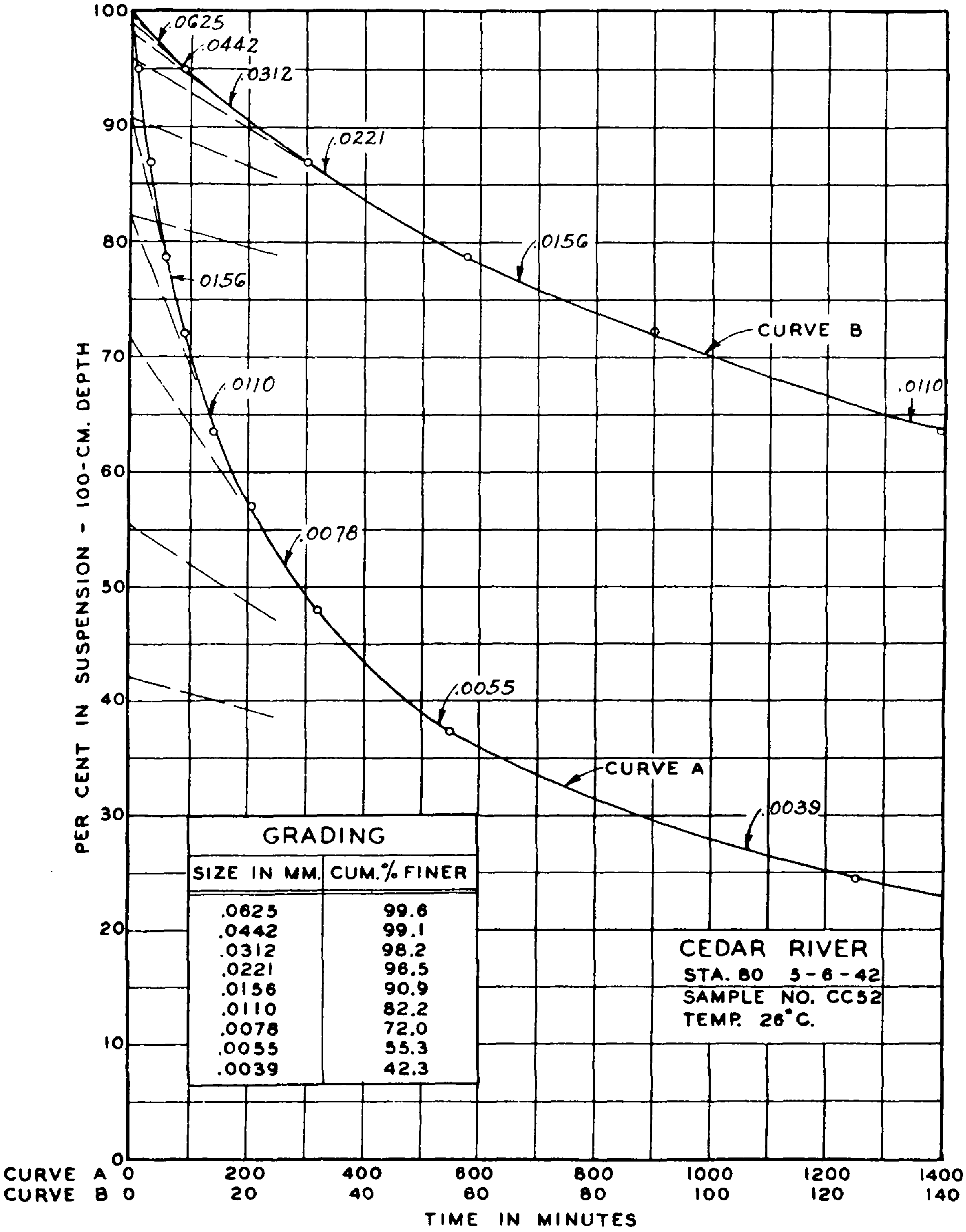


Fig. 10 - Proposed Bottom Withdrawal Sedimentation Tube

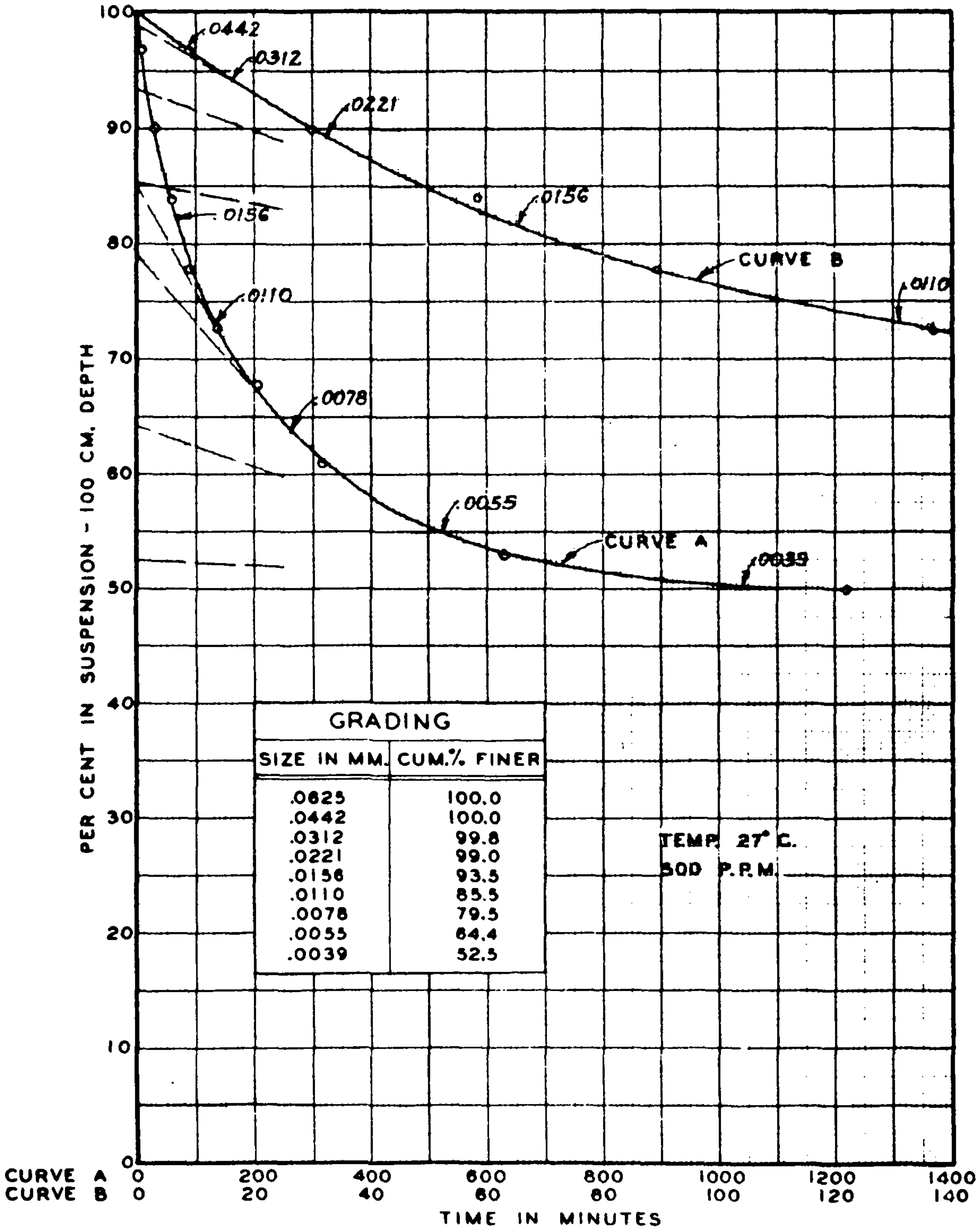


GRADING

SIZE IN MM.	CUM.% FINER
.0625	99.6
.0442	99.1
.0312	98.2
.0221	96.5
.0156	90.9
.0110	82.2
.0078	72.0
.0055	55.3
.0039	42.3

CEDAR RIVER
STA. 80 5-6-42
SAMPLE NO. CC52
TEMP. 26°C.

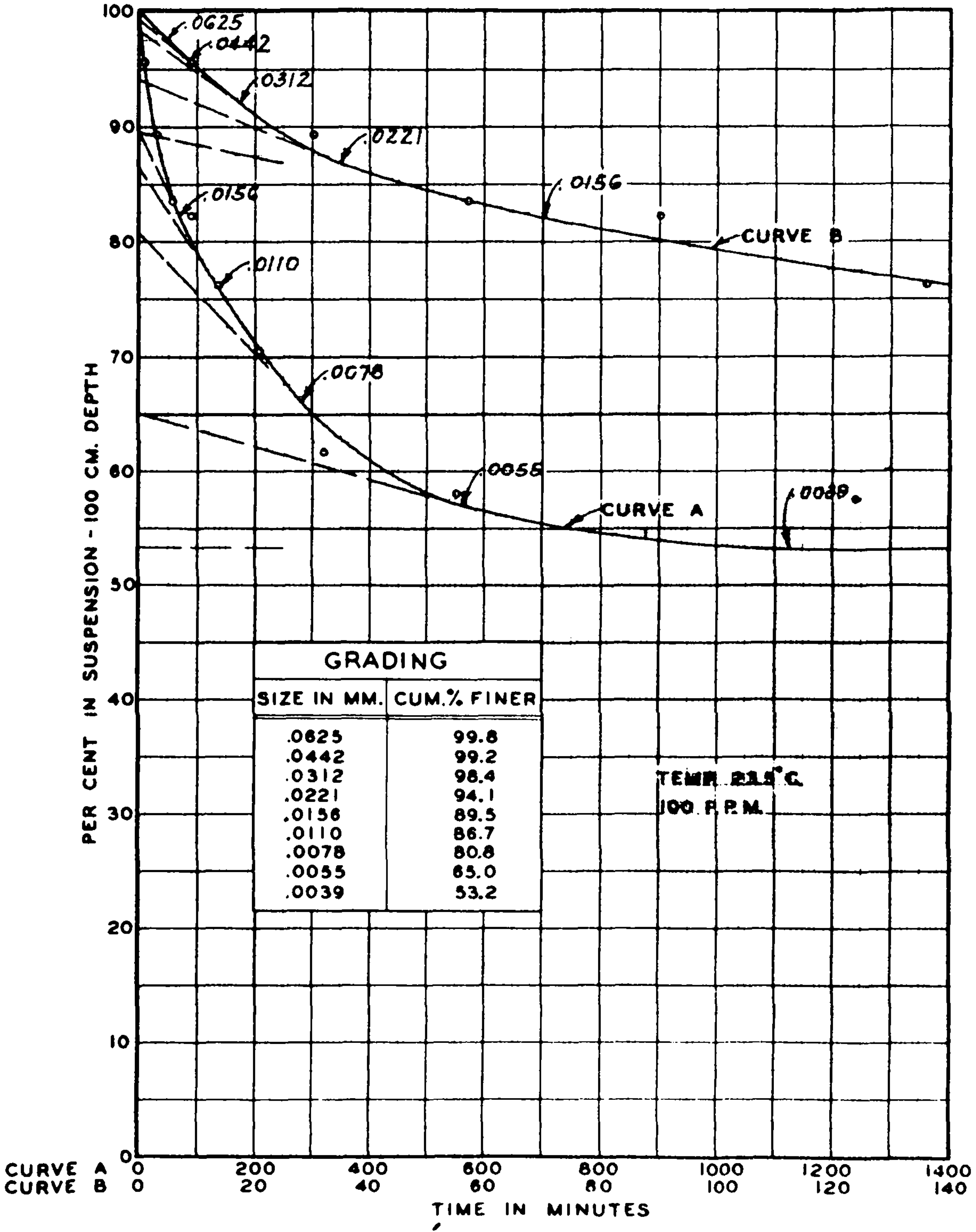
FIG. 25 - ODÉN CURVE
CONSTANT DEPTH, VARIABLE TIME



GRADING

SIZE IN MM.	CUM.% FINER
.0625	100.0
.0442	100.0
.0312	99.8
.0221	99.0
.0156	93.5
.0110	85.5
.0078	79.5
.0055	64.4
.0039	52.5

FIG. 26 - ODÉN CURVE - TEST NO. 39



GRADING

SIZE IN MM.	CUM.% FINER
.0625	99.8
.0442	99.2
.0312	98.4
.0221	94.1
.0156	89.5
.0110	86.7
.0078	80.8
.0055	65.0
.0039	53.2

FIG. 30 - ODÉN CURVE-TEST NO. 135

APPENDIX I

THE FLOW-DURATION SEDIMENT-RATING CURVE METHOD

THE FLOW-DURATION SEDIMENT-RATING CURVE METHOD

The average annual sediment load is computed by the "Flow Duration, Sediment Rating Curve Method", which consists of:

1. Developing a long term flow duration curve for the stream.
2. Developing a correlation between suspended sediment load and water discharge called a "Sediment Rating" curve.
3. Applying curve 2 to curve 1, and the resulting computation gives the long term average sediment yield.

The critical factor determining the accuracy of the final estimate is the Sediment Rating Curve. If this curve is accurately defined, an accurate forecast of the long term average sediment yield can be made. For this reason it is important that sufficient sediment data be collected in order to define the rating curve, especially in the region of high discharge.

The Flow Duration Curve is obtained in the following manner:

1. Obtain daily discharge records for the stream for the longest period of continuous record available. The record is then dissected to obtain the number of days the discharge fell within selected ranges of discharge. Form I.1 is used to calculate the number of occurences in each selected range for each year of record.
2. When all of the record is dissected, add up the number of days of each range for each year of record, Form I–1. Summarise the annual totals on Form I–2, columns 3–12, giving the number of days in each range for the period of record. Add up the annual totals, column 13, this total should check with the number of days in the period of record.
3. By the process of cumulative addition, obtain the number of days the discharge was equal to or greater than the lowest discharge of the range. This constitutes column 14.
4. In column 15, compute the percentage of the total time the discharge was equal to or greater than the lowest discharge of the range.
5. Column 1 gives the discharge against which the percentage of time is to be plotted.
6. Plot column 1 against column 15 on semi-logarithmic paper (Figure I.1) and draw in the Flow Duration Curve.

   For illustration, a Flow Duration Curve is constructed in Figure I.1 using the data of Form I–1.

The Sediment Rating Curve is plotted on log-log paper, the data being supplied from records of computed sediment load; refer Section 7.2, Equations (7.1) and (7.2). Sediment load in tonnes per day is plotted as ordinate and the corresponding water discharge in m^3/sec as abscissa.

The sediment rating curve is applied in conjunction with the flow duration curve to the computations on Form I–3. The sediment rating curve gives the amount of sediment that a given flow can carry and the flow duration curve tells how often this flow is likely to occur over a given period. In the computation, the frequency of the range of flow is taken into account when calculating the sediment yield over a given period:

1. On Form I–3, column 1 shows the small lengths of time, or increments into which the flow duration curve is divided, expressed as percent of total time. Column 2 gives the length of each increment and column 3 the mid-abscissa, or centre, of the increments.
2. From the flow duration curve, obtain the value of discharge at each of the mid-abscissas of column 3 and enter these values in column 4.
3. From the sediment rating curve (Figure I.2) obtain the sediment loads corresponding to each of these discharges and enter them in column 5.
4. Multiply the values (q_w) in column 4 by the length of the increments in column 2, and enter the results in column 6.
5. Multiply the values (q_s) in column 5 by the length of the increments in column 2, and enter the results in column 7.

6. The summation of column 6 gives the daily mean discharge in m^3/sec and the summation of column 7 gives the daily mean sediment discharge in tonnes per day.

7. The sediment yield for a given period is obtained by multiplying the daily mean sediment discharge by the number of days in the period.

A correction for bedload is added to the suspended sediment yield and the total sediment yield obtained.

References [1], [17].

DURATION OF DAILY DISCHARGE

FORM I–1

WATER YEAR ENDING 19 ....

River .... Station .... No. ....

Min. daily flow ....38,1.... m³/sec Max. daily flow ....1470.... m³/s Max. instant flow ....1680.... m³/s

Discharge interval m³/sec		Number of days when discharge was equal to or greater than in the first column and equal to or less than that shown in the second column													Cumulated	
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Totals	Totals	% Time
700	1470					2			2	3				7	7	1.9
650	699															
600	649					1								1	8	2.2
550	599															
500	549					1		1	1					3	11	3.0
450	499						1							1	12	3.3
400	449						1	1	1	1			2	6	18	4.9
350	399						1							1	19	5.2
300	349					1				1	2		1	5	24	6.6
250	299					1	4	2		2				9	33	9.0
200	249					1	4	1	1				2	9	42	11.5
150	199			1	3	3	10	7	3	3	5		1	36	78	21.4
100	149			2	7	15	6	17	4	7	4		6	68	146	40.0
50	99	10	30	28	21	3	4	1	19	13	20	14	13	176	322	88.2
0	49	21										17	5	43	365	100
Totals		31	30	31	31	28	31	30	31	30	31	31	30	365	–	–

Computed by ....

Checked by ....

Note: The plotting position is column No. 1 and column No. 16, or No. 17.

SUMMARY OF DAILY DISCHARGE

FORM I–2

PERIOD 19 .... – ....

River .... Station .... No. ....

Min. daily flow .... m^3/sec

Max. daily flow .... m^3/s

Max. instant flow .... m^3/s

Discharge interval m^3/sec		Number of days when discharge was equal to or greater than in the first column and equal to or less than that shown in the second column.											Cumulated	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
		19.......	19.......	19.......	19.......	19.......	19.......	19.......	19.......	19 59..	19.......	Total days	Total days	% of time
700	1470									7				
650	699													
600	649									1				
550	599													
500	549									3				
450	499									1				
400	449									6				
350	399									1				
300	349									5				
250	299									9				
200	249									9				
150	199									36				
100	149									68				
50	99									176				
0	49									43				

Computed by ....

Checked by ....

Note: The plotting position is column No. 1 and column No. 14, or No. 15.

FORM I–3

SEDIMENT LOAD COMPUTATION SHEET

Station .... River .... Period ....

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Limits %	Intervals %	Mid-Ord. %	q_w m^3/sec	q_s Tonnes/day	(2) x (4) m^3/sec	(2) x (5) Tonnes/day
0.00 – 0.05	*0.05*	*0.025*	*580*	*5000*	*29.00*	*250.00*
0.05 – 0.10	*0.05*	*0.075*	*277*	*1580*	*13.85*	*79.00*
0.10 – 0.15	*0.05*	*0.125*	*200*	*950*	*10.00*	*47.50*
0.15 – 0.20	*0.05*	*0.175*	*164*	*700*	*8.20*	*35.00*
0.20 – 0.40	*0.20*	*0.30*	*118*	*410*	*23.60*	*82.00*
0.40 – 0.60	*0.20*	*0.50*	*86.5*	*250*	*17.30*	*50.00*
0.60 – 0.80	*0.20*	*0.70*	*68.0*	*175*	*13.60*	*35.00*
0.80 – 0.90	*0.10*	*0.85*	*53.5*	*120*	*5.35*	*12.00*
0.90 – 1.00	*0.10*	*0.95*	*46.5*	*96*	*4.65*	*9.60*
Daily mean discharge, water/sediment:					*125.55*	*600.10*

Annual water discharge, *125.55* x 31.56 x 10^6 = *3962.4* 10^6 m^3/ year

Annual sediment discharge, *600.1* x 365 = *219036.5* Tonnes/year

.... percent addition for bedload, = ... Tonnes/year

Total sediment discharge, = ... Tonnes/year

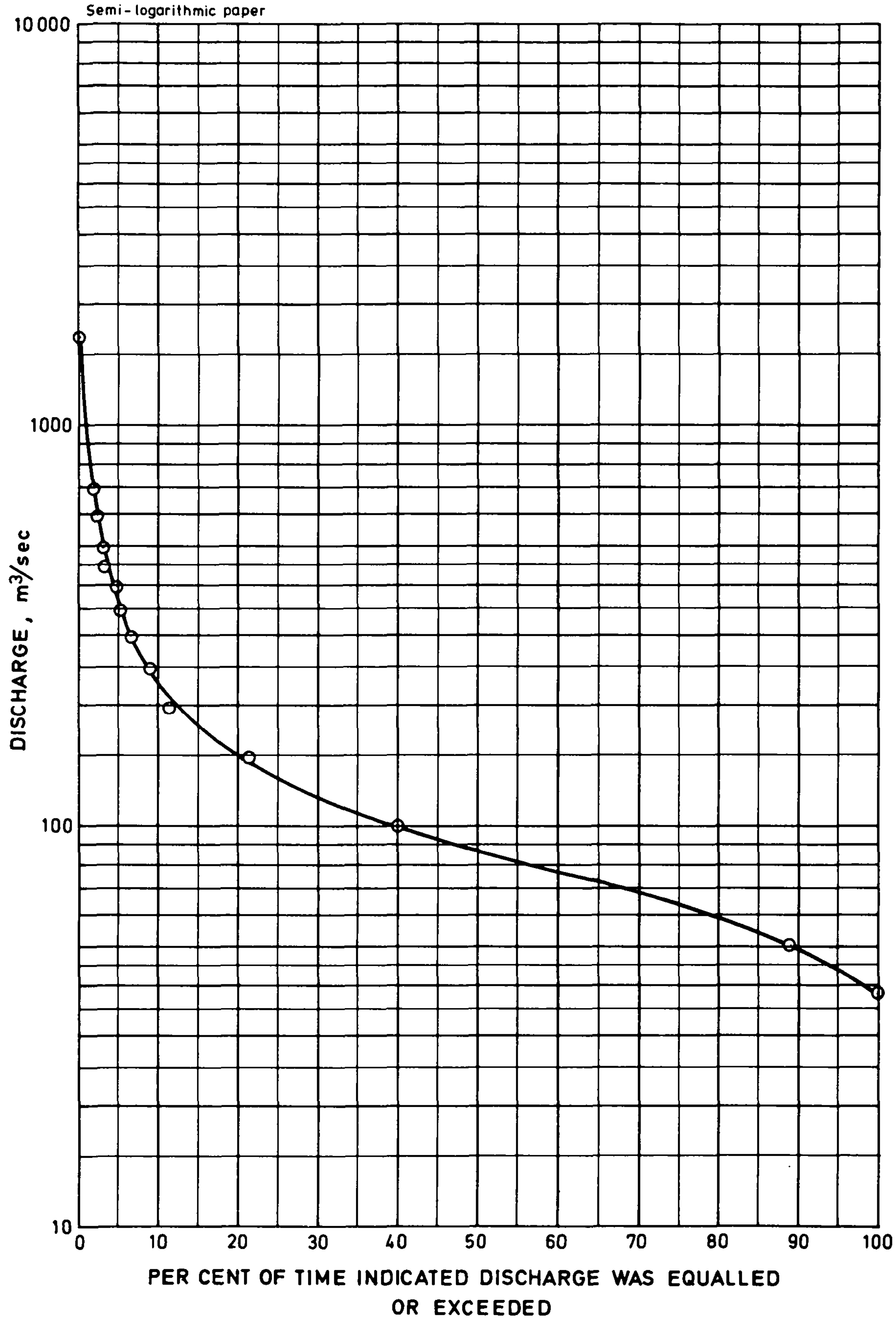


Figure I.1. Duration curve of daily flow.

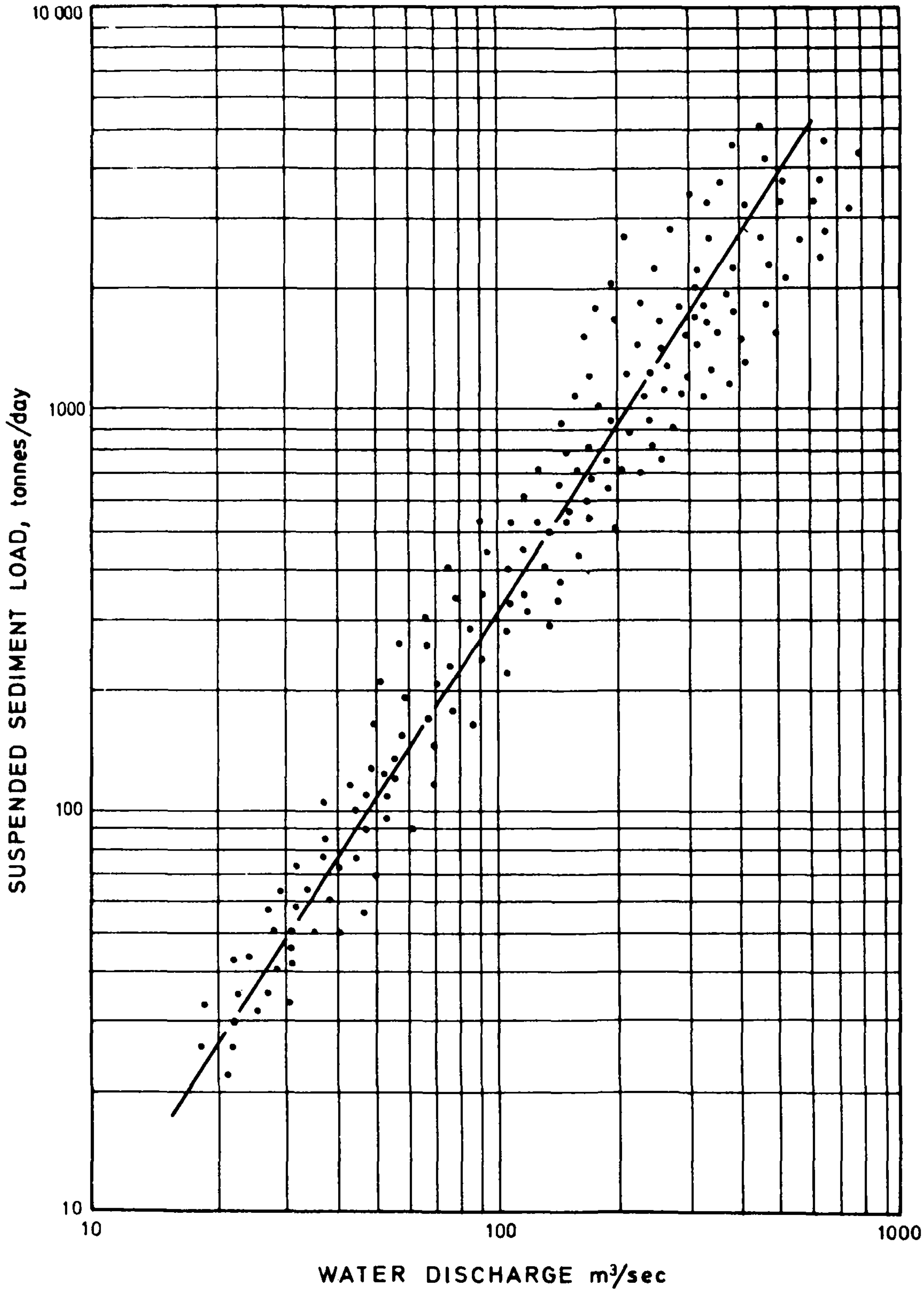


Figure I.2. Sediment rating curve.

APPENDIX J

VOCABULARY

VOCABULARY

AGGRADATION. The process by which the stream or reservoir bed is raised in elevation or built up by the deposition of material transported thereto by water or wind. It is the oppsite of degradation.

ANTIDUNES. Symmetrical waves of the bed sediment of a stream exist below symmetrical surface waves. Surface waves and bed waves may be relatively stable over a period of several minutes, or they may build up, break and reform rapidly.

BAR. A bank of sediment, i.e. sand or gravel, deposited in the streambed or at its mouth, which obstructs the flow or navigation.

BEDLOAD. Sediment that is transported in a stream by rolling, sliding or skipping along the bed and very close to it.

BEDLOAD DISCHARGE. The amount of bedload material moving through a cross-section of a stream in a unit of time; usually measured as tonnes per day.

BED MATERIAL. The sediment of which the streambed is composed.

CAPACITY. Refers to the maximum amount of sediment of a given size that a stream is able to carry past a given cross-section in a unit of time. The capacity depends on many factors, the principal of which are stream gradient, water discharge and calibre of the load.

CHUTES and POOLS. A sediment bed configuration occurring at relatively large slopes and sediment discharges, that consists of large mounds of sediment which form chutes on which the flow is supercritical, connected by pools, in which the flow may be subcritical.

CLAY. Sediment particles 0.0005 to 0.005 mm in diameter.

COMPOSITE SAMPLE. A single sample formed by combining the water-sediment mixture from all the individual bottles making up a set of samples. A set of samples taken by the equal-transit-rate method can be composited in the laboratory. A set taken by the centroid method can be composited provided all the individual samples are of the same volume.

DEGRADATION. The process by which the streambed is lowered in elevation by the carrying away of material due to the action of water. It is the opposite of aggradation.

DEPTH-INTEGRATED SAMPLE. A water-sediment mixture that is accumulated continuously in a sampler that moves vertically at an approximately constant transit rate between the surface and a point a few centimetres above the bed of a stream, and that admits the mixture at a velocity about equal to the instantaneous stream velocity at each point in the vertical. Because the sampler intake is a few centimetres above the sampler bottom, there is an unsampled zone a few centimetres deep just above the bed of the stream.

DISCHARGE OF WATER, or SEDIMENT. Time rate of movement of volume or weight of the water or sediment through a cross-section.

DISCHARGE-WEIGHED CONCENTRATION. The dry weight of sediment in a unit volume of stream discharge.

DUNES. Irregularly spaced low mounds of loose sand which travel slowly downstream as the result of sand being moved along their comparatively gentle upstream slopes and being deposited on their steeper downstream slopes.

EQUAL-DISCHARGE-INCREMENT (EDI) SAMPLING METHOD. A method of sampling the suspended sediment transported by a stream through a cross section whereby individual samples are taken at the mid-points of several parts of equal discharge. Also called the CENTROID method.

EQUAL-TRANSIT-RATE (ETR) SAMPLING METHOD. A method for sampling the suspended sediment transported by a stream through a cross-section. Between 10 and 20 sampling verticals are used, and the same transit rate is used at all verticals. A method for sampling the suspended sediment that is discharge-weighed (more water-sediment mixture is obtained in the parts of a stream with greater discharge than in other parts with less discharge.) The ETR sampling method is the most accurate method for sampling suspended sediment for concentration and for sampling the suspended sediment particle size distribution.

FLUVIAL SEDIMENT. Sediment that is transported by, suspended in, or deposited by water.

PARTICLE SIZE. Sediment grain size or the size of an individual piece of sediment. Particle size is usually measured in millimetres or in microns (1 micron = 0.001 millimetre).

POINT-INTEGRATED SAMPLE. A water-sediment mixture that is accumulated continously in a sampler that is held at a fixed point in a stream and that admits the mixture at a velocity about equal to the instantaneous stream velocity at the point.

RIPPLES. Small undulating ridges and furrows or crests and troughs on water, or formed by the action of the flow of water on the bed of a channel.

SAMPLED ZONE. That part of a sampling vertical that is sampled by a suspended sediment sampler, the part above the unsampled zone.

SAMPLING VERTICAL, or VERTICAL. An approximately vertical path from the water surface to the streambed along which a sample is accumulated to define suspended sediment concentration or particle size distribution.

SAND. Sediment particles between 0.062 and 2 mm in size.

SEDIMENT. Fragmental material that originates from the disintegration of rocks and is transported by, suspended in, or deposited by water or air.

SEDIMENT CONCENTRATION. Ratio of dry weight of sediment to the total weight of water-sediment mixture.

SEDIMENT DISCHARGE. The quantity of sediment that is carried past any cross-section of a stream in a unit of time. Usually expressed as tonnes per day.

SEDIMENT LOAD. The sediment that is being moved by a stream. (Load refers to the material itself and not to the quantity being moved.)

SILT. Sediment particles between clay and sand 0.005 to 0.062 mm in diameter.

SIZE DISTRIBUTION. When applied in relation to any of the size concepts, refers to distribution of material by percentage or proportions by weight.

SIZE SAMPLES. Samples of the suspended sediment transported by a stream that are used to determine the distribution of the particle size. The equal-transit-rate (ETR) sampling method is used always.

STREAM DISCHARGE. The volume of water passing through a cross-section in a unit of time, usually expressed as cubic metres per second (m^3/sec).

SUSPENDED SEDIMENT. Sediment that is held in suspension for appreciable lengths of time in a stream.

SUSPENDED SEDIMENT DISCHARGE. The weight of suspended sediment passing through a cross-section in a unit of time, usually expressed as tonnes per day.

TOTAL SEDIMENT DISCHARGE. The sum of the suspended sediment discharge and the bedload discharge.

TOTAL SEDIMENT LOAD. The total sediment in transport in a stream. That is, the sediment moving as suspended load plus that moving as bedload.

TRANSIT RATE. The rate, that is, metres per second at which a suspended sediment sampler is lowered or raised in a sampling vertical.

TURBULENCE. Agitation of water or air, characterized by cross-currents and eddies.

UNSAMPLED ZONE. The bottom part of a sampling vertical which cannot be sampled by a suspended sediment sampler. The nozzle on samplers is located 9 to 10 centimeters above the bottom of the sampler. When the sampler has been lowered to the streambed, this height of the nozzle leaves an unsampled zone between the nozzle and the streambed.

VELOCITY-WEIGHED CONCENTRATION FOR A VERTICAL, or CROSS-SECTION. Concentration that is obtained from samples whose rate of collection at all sampled points was about in proportion to velocity. Such a concentration can be used with water discharge to compute sediment discharge for the sampled part of a vertical or cross section.

WEATHERING. The action of the weather (wind, heat, frost and the mechanical and solvent action of water) on the surface of the earth that reduces the size of rock fragments forming smaller rocks, gravel, sand, silt and clay.