NIWA

Taihoro Nukurangi

Suspended Sediment Manual

D M Hicks and J K Fenwick

NIWA Science and Technology Series No 6

ISSN 1173-0382

NIWA Science and Technology Series No 6

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NIWA

Christchurch

August 1994

Cataloguing-in-publication

Hicks, D.M.
Suspended Sediment Manual / D.M. Hicks and J. K. Fenwick -- Christchurch, NZ : National Institute of Water and Atmospheric Research Ltd., 1994. (NIWA science and technology series ; 6)

ISSN 1173-0382
ISBN 0-478-08337-8

I Fenwick, J.K. II National Institute of Water and Atmospheric Research Ltd. III Title. IV Series

The NIWA Science and Technology Series is published by NIWA (the National Institute of Water and Atmospheric Research Ltd.), New Zealand. It supercedes *NIWA Ecosystems Publications* (Issn 1172-3726; published by NIWA Ecosystems, Hamilton, *New Zealand Freshwater Research Reports* (ISSN 1171-9842; published by NIWA Freshwater, Christchurch) and *Miscellaneous Publications, New Zealand Oceanographic Institute* (ISSN 0510-0054).

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NIWA specialises in meeting information needs for the sustainable development of water and atmospheric resources. It was established on 1 July 1992.

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1. Introduction

The amounts of soil and sediment transported by rivers are of interest from the viewpoints of soil erosion and conservation, sedimentation of reservoirs, lakes, and river and irrigation channels, coastal erosion and deposition, survival of fish and other aquatic life, and water quality and aesthetics. These requirements for knowledge of sediment transport, particularly during flood flows when the sediment loads of rivers show a many-fold increase over low flow and are normally the most significant, make necessary a range of measurements which are often difficult to obtain.

In 1965 the New Zealand Ministry of Works Hydrological Survey, the precursor of NIWA Environmental Data, began using methods and samplers developed by the U.S. Geological Survey. However, there was a lack of adequate instructions until the distribution of copies of USGS manuals (Guy and Norman, 1970) some 12 years later, and even these did not clearly detail the field procedures. More recent developments in sampling methodology (Edwards and Glysson, 1988) point to sampling techniques needing to be more precise and, in the process, becoming more complex.

This manual seeks to address these needs and to provide field, laboratory and office instructions in order that sediment sampling is carried out using the best available techniques. Quality assurance and its associated management of data are vital, and procedures for these aspects are detailed as well.

This manual has been prepared to meet the requirements of Environmental Data's Suspended Sediment Programme (Hicks, 1992) and other sediment data requirements.

2. Background Information

This section defines suspended sediment in terms of where it is derived from, how it travels in the river, and what parameters of it we are concerned with measuring. The factors causing the suspended sediment concentration to vary over the flow depth and width are discussed, as are the strategies employed for sampling these variations in concentration.

2.1. Definitions

The following descriptions of sediment transport processes and terminology have been adapted from ISO 4363 (1977):

To begin with, for a proper comprehension of sediment movement and related terms, the flow of water over an artificially flattened bed of sediment may be considered. From no movement of bed material at very low velocities, some particles begin to move with the increase of velocity by sliding, rolling or hopping along the bed ("bed load"); at still higher velocities particles of bed material are thrown into suspension by turbulence ("suspended load"). The suspended load also includes finer particles in near permanent suspension brought in from the catchment ("wash load"). Bed load and suspended load may occur simultaneously, but the borderline between them is not well defined.

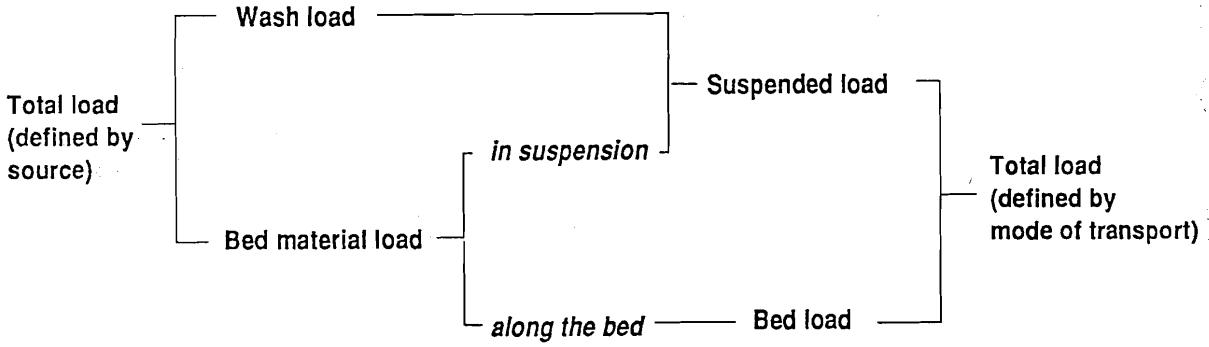


Figure 2.1 *Definition of sediment load components in terms of sediment origin and transport mode.*

Total load: In terms of mode of transport of the sediment, the "total load" comprises "bed load" and "suspended load". In terms of origin of the sediment, the "total load" comprises "bed material load" and "wash load" (see Figure 2.1).

Bed material: The material the particle sizes of which are found in appreciable quantities in that part of the bed affected by transport.

Bed material load: The part of the total sediment load which consists of bed material and whose rate of movement is governed by the transporting capacity of the channel.

Bed load: The sediment in almost continuous contact with the bed, carried forward by rolling, sliding or hopping. It is generally expressed in mass per unit time.

Suspended load: That part of the total sediment load which is maintained in suspension by turbulence in the flowing water for considerable periods of time without contact with the stream bed. It moves with practically the same velocity as that of the flowing water. It is generally expressed in mass per unit of time.

Wash load: That part of the suspended load which is composed of particle sizes smaller than those found in appreciable quantities in the bed material. It is in near permanent suspension and, therefore, is transported through the stream without deposition. The discharge of the wash load through a reach depends only on the rate at which these particles become available in the catchment and not on the transport capacity of the flow. It is generally expressed in mass per unit time.

Sediment concentration: The ratio of the mass of the dry sediment in a water-sediment mixture to the total mass or volume of the mixture.

2.2. Parameters to be measured

We are concerned primarily with measuring the discharge-weighted mean concentration of the suspended load passing the gauging section, C_m. This is found by dividing the total suspended sediment load passing the section, G_s, by the total water discharge, Q. G_s and Q are summed over sub-sections.

The water discharge in a sub-section, q, represented by a single vertical, is found by integrating the local flow velocity between the bed and the surface, thus

$$q = b \int_0^D v\,dz \qquad (2.1)$$

where v is the local velocity, z is the vertical dimension and equals 0 at the bed and D at the water surface, and b is the sub-section width, as shown in Figure 2.2.

In like fashion, the suspended load in a sub-section, g_s, is found by integrating the product of local flow velocity and sediment concentration between the bed and the surface, thus

$$g_s = b \int_0^D cvdz \qquad (2.2)$$

where c is the local concentration (Figure 2.2).

The sub-section sediment load can also be expressed as

$$g_s = bc_m v_m \qquad (2.3)$$

where v_m is the mean velocity in the vertical and c_m is the velocity- (or discharge-) weighted mean concentration in the vertical, equal to g_s/q.

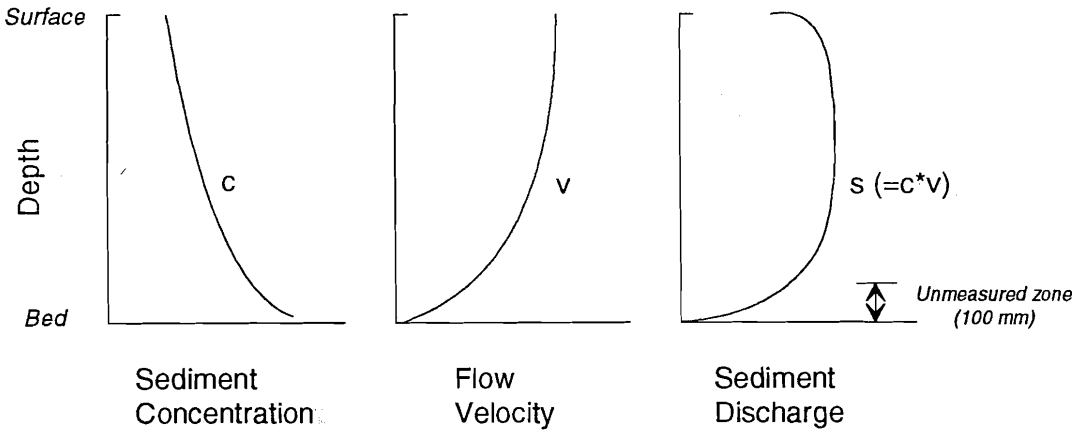


Figure 2.2 *Vertical profiles of velocity, sediment concentration and sediment load (cv product).*

2.3. Factors causing concentration to vary

As defined in section 2.1, the suspended load is dispersed above the stream bed by turbulence, specifically, the upwards components of turbulent eddies. The time-averaged concentration of the sediment in suspension at a point depends on the ratio of the time-averaged upward velocity components and the fall-velocity of the sediment grains. The fall velocity depends on the size, shape, and density of the sediment grains, plus the density and viscosity of the water (both a function of temperature), plus the sediment concentration when the concentration becomes large enough for grain settling to be hindered by collisions with other grains. To a first order of approximation, the turbulence intensity scales with the shear velocity, u_*,

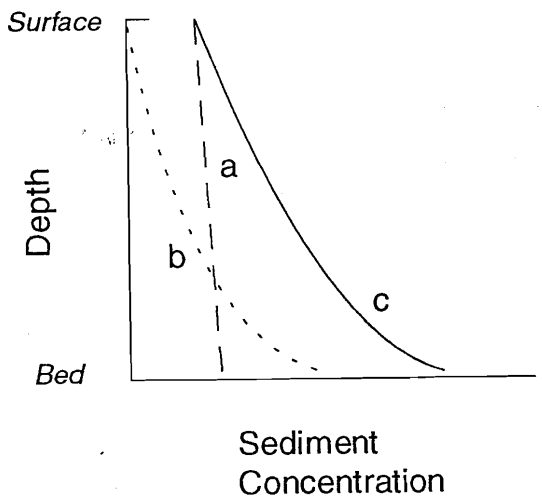


Figure 2.3 *Concentration profiles. (a) Fine sediment fraction silts and clays. (b) Coarse sediment fraction (sand). (c) Bulk load (all size fractions).*

which is closely related to the mean velocity, v_m, and also decreases away from the bed. Because sediment density and water temperature tend to vary little among most rivers, the principal controls on the extent of sediment mixing by turbulence are therefore the velocity and the sediment grain size.

Thus, for a given flow velocity in a vertical, fine particles (i.e., silts and clays), with a very low fall velocity, are easily mixed and tend to have a concentration profile that is uniform with depth (Figure 2.3a). In contrast, coarser particles (i.e., sands) have greater fall velocities and are concentrated near the bed (Figure 2.3b). Since the suspended load typically comprises a mixture of different grain-size fractions, the actual concentration profile will be a composite of the profiles for the individual size fractions (Figure 2.3c). Across the channel, while the fine fractions tend to be well mixed, the sand fractions tend to have higher concentrations where the velocity is highest.

2.4. Sampling Strategy

Variations in suspended sediment concentration across the section are catered for by sampling at multiple verticals and weighting each sample's concentration by the water discharge of the sub-section that each vertical represents. Variations in concentration in the vertical can be sampled in two ways, point-integrating or depth-integrating:

(i) Point-integrating. Point samples are collected over a period of time at a number of points in the vertical. Generally, the sediment load at a vertical is determined graphically by plotting the concentration and velocity profiles, multiplying the two to get the sediment load profile, then integrating the area under the latter (Porterfield, 1972). Alternatively, a weighting formula can be applied to calculate the mean concentration in the vertical from the point samples (WMO, 1989).

(ii) Depth-integrating. An isokinetic sampler traverses the flow depth at a constant rate, in the process it mechanically performs the integration defined in equation (2.2) above. An isokinetic sampler is one specially designed to accept its sample at the ambient velocity. As it traverses each small increment of depth, taking the same time

fraction to pass each increment, it accepts a sub-sample whose volume is proportional to the velocity at that depth, whose concentration equals the concentration at that depth, and whose sediment mass is proportional to the product of the local velocity and concentration (Figure 2.2). The amount of water and sediment is thus weighted according to the local velocity. After traversing to the bed and back to the surface, the total sample has a volume proportional to the mean velocity (and water discharge) in the vertical, a total mass of sediment proportional to the sub-section sediment load, and a concentration equal to the discharge weighted mean concentration for the vertical.

2.5. The "unmeasured" sediment load

The suspended sediment samplers in routine use can only sample to within 75 - 100 mm of the bed (by design, this helps to prevent the sampler scooping-up bed material and biasing its sample). This area of the flow is termed the "unmeasured" or "unsampled" zone (Figure 2.2). The mean concentration of the sampled part of the vertical is always less than or equal to the true mean concentration for the full depth of the vertical by an amount that depends on the proportion of sand in suspension. This is because the sand fractions of the suspended load are concentrated nearest the bed and their concentrations are highest in the unmeasured zone. In contrast, the silt and clay fractions tend to be uniformly mixed and their sampled concentrations are representative of their concentrations in the unmeasured zone.

The suspended sand load carried in the unmeasured zone can either be sampled with a "bed load" sampler whose intake spans this zone, or it can be calculated using information on the suspended sediment concentration and size distribution in the measured zone, plus information on the mean flow velocity and the bed material size distribution. Details of a procedure to adjust the mean concentration and size-distribution of the suspended load to incorporate the unmeasured zone are provided by Colby and Hembree (1955) and Vanoni (1975).

3. Sampling Equipment

Several of the extensive range of suspended sediment samplers designed by the United States Federal Interagency Sedimentation Project (F.I.S.P.) have been adopted in New Zealand by NIWA and other agencies. The DH-48 and D-49 samplers in particular, certified by F.I.S.P. in 1948 and 1949 respectively, have been used extensively in New Zealand since the early 1960's.

3.1. General

3.1.1 Designations of the US samplers

The designations of the US samplers represent the following:

D - depth integration sampling

H - hand-held, either by rod or hand-line

P - point integration sampling

PS - pumping sampler

48 - or other digits - the last two digits of the year of certification by F.I.S.P.

(e.g. a D-49 is a depth-integrating sampler certified in 1949.)

3.1.2 Principles of sampling

The purpose of a suspended sediment sampler is to obtain a representative sample of the water-sediment mixture which comprises the flow of the stream in the vicinity of the sampler.

The criteria used in the design of the U.S. samplers by F.I.S.P. were (Edwards and Glysson, 1988):

- to allow water to enter the nozzle isokinetically (in isokinetic sampling, the velocity of inflow through the nozzle is the same as that of the water approaching the nozzle)
- to permit the sampler nozzle to reach a point as close to the stream bed as physically possible

- to minimise disturbance to the flow pattern of the stream, particularly at the nozzle
- to be adaptable to suspension equipment already in use for streamflow measurement
- to be as simple and maintenance-free as possible
- to accommodate a standard bottle size.

In addition, International Standards (ISO 3716, 1977) specify that:

- the mouth of the sampler shall always face into the current
- the mouth of the sampler shall be outside the zone of disturbance of the flow set up by the body of the sampler and its operating equipment, with flow lines disturbed as little as possible
- filling shall be smooth so that there is no sudden inrush or gulping and so that air exhausting from the sampler does not hinder the entry of the sample.

3.1.3 Flow into the sampler

When a sampler is submerged with its nozzle pointing directly upstream, streamflow enters the nozzle at the same time as the air in the sample bottle exhausts out. This air exhaust is driven by the combined effects of three forces:

- the positive dynamic head at the nozzle entrance, due to the flow
- a negative head at the end of the air-exhaust tube, due to flow separation
- a positive pressure due to a difference in elevation between the nozzle entrance and the air-exhaust tube.

3.1.4 Over-filling

When the water in the sample bottle reaches the level of the air exhaust tube, the inflow rate drops but a flow-through effect begins. This causes streamflow to enter through the nozzle and exit through the air exhaust, with coarser particles settling out. Thus the concentration of coarse particles in the bottle will gradually increase, resulting in an erroneous sample.

3.1.5 Depth-integrating samplers

These samplers are designed to collect and accumulate a representative sample taken continuously whilst the sampler travels at a uniform rate from the surface to the bed and back again. As the inflow is directly proportional to the ambient velocity, the sample obtained will be velocity-weighted (and consequently, discharge-weighted) for the particular vertical.

3.2. Hand-held samplers, DH-48

The US DH-48 is used commonly in New Zealand for depth-integrated sampling in wading situations. It comprises a streamlined aluminium body which partially encloses the 470 ml (1 U.S. pint) glass bottle, and mounts on the standard wading rod (see Figure 3.1). The bottle is held in place by a spring-tensioned pull-rod assembly, which is readily operated by hand. A single screw-in brass nozzle of 6.4 mm (1/4 inch) diameter is standard.

The device will sample within 90 mm of the bed. It is useful in small streams where sampling can be carried out using wading rods, either when wading or from a low bridge.

Other lightweight plastic versions have been developed in the U.S. (DH-81, DH-75),

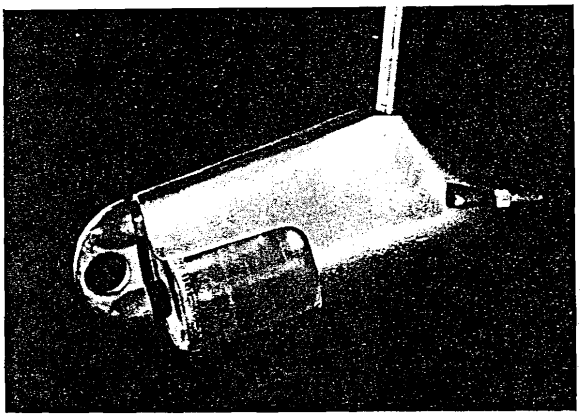


Figure 3.1 *U.S. DH-48 depth-integrating hand-held sampler (from Guy & Norman, 1970, p. 6).*

but they are less robust and are designed mainly for bacterial samples or freezing conditions.

Handline-suspended samplers are available, such as the US DH-59. This is a bronze sampler weighing 11 kg, which can be suspended on a handline in velocities up to 1.5 m/s, giving more convenient operation than a larger sampler. Its design is somewhat of a cross between the DH-48 and the larger D-49. It uses the standard 470 ml bottle.

3.3. Depth-integrating samplers, D-49 and D-74

The D-49 is a 28 kg (62 lb) sampler designed to be suspended from a gauging reel. It has a cast bronze body and its own stainless steel hanger bar for connection to the standard PB connector of the reel cable. It uses the standard 470 ml bottle which is installed by opening the sampler's hinged head (see Figure 3.2).

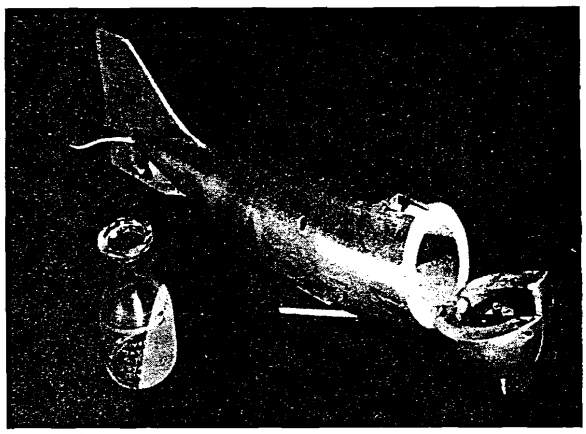


Figure 3.2 *US D-49 depth-integrating cable and reel sampler (from Guy and Norman, 1970, p. 7)*

In the U.S., the D-49 sampler has been replaced by the D-74, which is identical in specifications and use except for bottle size. It will accommodate a quart bottle, not so far used in New Zealand, but also accommodates the standard 470 ml bottle with the addition of an adaptor sleeve.

NIWA Environmental Data teams are mostly equipped with D-49 samplers, but future purchases are likely to be of D-74's.

Sampling techniques and details of their use are identical. Points to note in the use of both the D-49 and D-74 samplers are:

- Maximum depth is 4.7 m, beyond which water pressure inhibits the correct flow of water in, and of air exhausting out. At greater depths a point sampler is required (see below).
- Each sampler is equipped with three nozzles of different bore diameter, 6.4 mm, 4.8 mm and 3.2 mm (1/4, 3/16 and 1/8 inch). These nozzles are interchangeable between the D-49 and D-74 samplers but no others, even though they may physically fit. The reason is the differences in taper and other dimensions between designs for particular samplers.
- The soft neoprene gasket in the sampler head must be kept clean and must carry out its function of sealing the bottle's neck to the head. The neoprene has a tendency to compress over time to the extent that it will not seal. Test by blowing into the nozzle with a finger over the air outlet and check for escaping air.
- The 28 kg weight of these samplers may, in high velocities, be insufficient to prevent the sampler from being swept too far downstream. In such cases the use of a P-61 may be called for, or the sampler may be mounted below a Columbus weight.

3.4. Depth-integrating, high-volume sampler, D-77

The D-77 is a 34 kg depth-integrating sampler which accommodates either a 3 litre autoclavable sample bottle or a collapsible-bag inside a special rigid container (see Figure 3.3). The 3 litre bottle enables collection of large-volume, depth-integrated biological, chemical or sediment samples, but the depth limitation of 4.7 m applies.

The collapsible bag virtually eliminates the depth range limit dictated by sample container size, nozzle size and stream velocity. (In addition, a valve assembly can be attached to the face of the sampler to enable it to operate as a point sampler.)

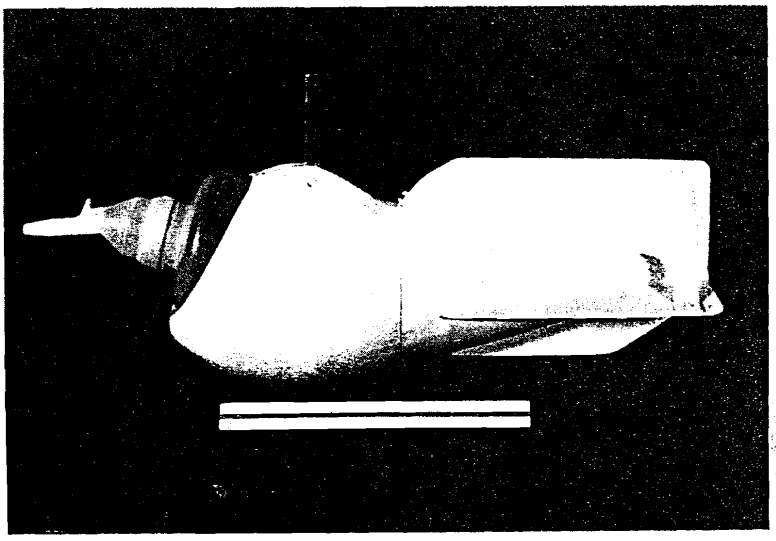


Figure 3.3 *US D-77 suspended sediment sampler (from Edwards and Glysson, 1988, pp.14)*

3.5. Point-integrating samplers, P-61, P-46 and P-72

Point samplers have a valve which enables the intake and air-exhaust passages to be opened when the sampler is at the required sampling location(s). They can be used for depth integration as well as point sampling to a maximum depth of 55 m.

The P-61 (Figure 3.3) is a 48 kg point sampler, which can be used when depths or velocities are too great for the D-49 or D-74 samplers. It will normally be used for one-way depth integration, either from the top down or the bottom up. Preferably, two samples should be taken, one in each direction. They can either be bulked together or used as replicate samples.

Points to note in the use of the P-61 are:

- This type of sampler uses the gauging reel "Ellsworth" cable for a circuit to energise the solenoid valve in the intake. A control box with a battery pack is plugged into the reel.

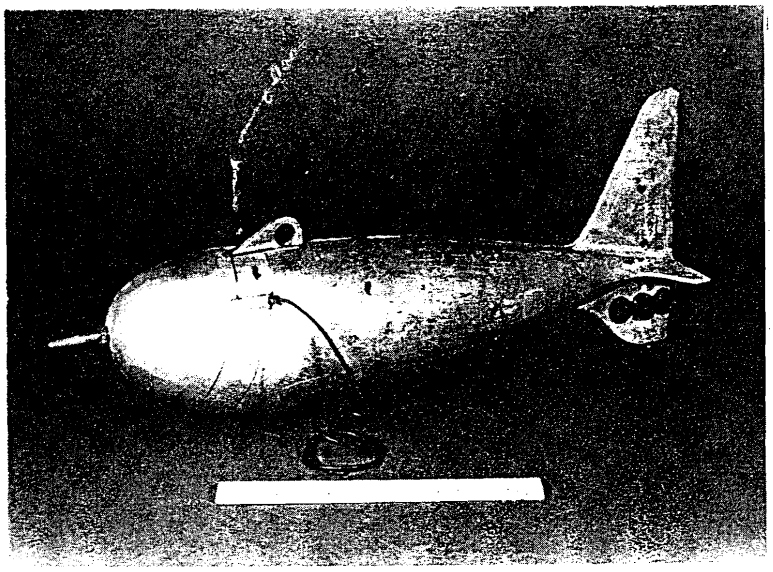


Figure 3.4 *US P-61 point-integrating sampler (from Edwards and Glysson, 1988, pp.15)*

- With reel cables longer than 30 m (e.g. the E-reel, which has 40 m, or extended-length reels), a large voltage drop may occur, and so a voltage source higher than the 24 - 28 volts of the standard battery pack may be necessary.
- As with the depth-integrating samplers, the seals at the bottle mouth should be tested by blowing into the nozzle with the air exhaust closed, and checking for escaping air. (When doing this, the nozzle must be held open by activating the solenoid.)

Warning: Do not place one's mouth directly in contact with the nozzle due to the likelihood of electric shock while the solenoid is activated. (Questionable water quality would be another good reason!). Instead, use a short length of clean plastic or rubber tubing which fits snugly over the nozzle. Keep this tubing in the sampler box.

The P-61 was preceded by the P-46 sampler, of which one or two examples were brought into New Zealand. Sampling techniques and general specifications are the same as for the P-61, but the valve mechanisms are more complex and difficult to service.

The P-72 is identical to the P-61 except that its body is cast from aluminium, so that it weighs only 19 kg. Because of its light weight, it can be considered a general purpose sampler, useful in lower velocity flows where point sampling is required, but it may also be used in high velocity flows with a Colombus weight mounted on its hanger bar.

3.6. Nozzles

3.6.1 Interchangeability

Each suspended sediment sampler is equipped with a set of nozzles specifically designed for that type of sampler. They are cut and shaped internally and externally to ensure that the velocity of water through the nozzle is close to (within $\pm 8\%$ of) the ambient stream velocity.

Thus nozzles for one sampler type should not be used in another; an exception is the D-49 and D-74 samplers, where the nozzles are interchangeable.

Nozzles can be identified as to the type of sampler by:

- colour coding of plastic nozzles matching the coloured plastic insert in the tail fin of the more modern versions of sampler
- DH-48 nozzles do not have a flat (for a spanner) on the knurled section

3.6.2 Nozzle diameters

A choice of three nozzle diameters (6.4, 4.8, and 3.2 mm) is provided with the depth-integrating samplers, except for the DH-48 (6.4 mm only).

The largest suitable nozzle shall be used wherever possible, but in higher velocities and greater depths the bottle will tend to overfill, necessitating the use of a smaller size. In theory, the maximum sampling depths for round-trip integration are about 2.3, 4.2 and 4.7 m for the 6.4, 4.8 and 3.2 mm nozzles respectively. These limits are controlled by the need to transit the sampler at a rate no faster than 0.4 of the mean velocity in the vertical, in order to avoid significant realignment of the streamlines into the nozzle, and by the compression factor discussed previously (see section 4.3 for further details).

Point-integrating samplers are equipped only with 4.8 mm diameter nozzles, as they must match the opening of the valve mechanism.

3.6.3 Damage to nozzles

Any damage to the tip or body of a nozzle will be detrimental to the efficiency of the sampler. Such nozzles should be replaced immediately, using the spares in the sampler boxes, and damaged ones returned to NIWA Kainga for repair or replacement.

3.6.4 Seals

The neoprene gasket in the head of each sampler seals the mouth of the bottle against the head of the sampler and the entry and air exhaust ports. It should be kept clean and free of dust which could contaminate the samples, and shall be tested as part of the field procedure by the "blow test" (see section 4.4.1). These gaskets have a tendency to become compressed and too thin to seal effectively, although use of a better material has improved this aspect. At least one spare gasket shall be kept with each sampler.

3.7. Bottles

3.7.1 Design

The standard 470 ml bottle is a glass wide-mouthed bottle which was originally a milk bottle of one U.S. pint capacity. The standard bottle is circular, although some square versions are in use. The latter should be treated with caution as there are some samplers they will fit into, but then the sampler will not seal properly.

The bottles are sealed with rubber bungs which need to be inserted securely to prevent them falling out.

A plastic version of the 470 ml glass bottle with a screw-cap is available. This is strong and has advantages over the glass one in handling and transport.

A glass one US quart bottle (940 ml) can be used in the P-61, P-72 and D-74 samplers.

In addition to the sampling bottles described above, other bottles may be used for holding bulked (composited) samples, such as those collected for particle-size analysis or when using the equal width increment (EWI) sampling technique. Typically, plastic two-litre or five-litre bottles are used for bulking samples. Two-litre plastic bottles may be obtainable from local town milk suppliers and are inexpensive and disposable, thus the cost of returning the sample bottles from the laboratory can be avoided.

3.7.2 Storage and transport

Empty bottles should be stored with their bungs or caps on to prevent both the bottle and bung from becoming contaminated with dust, dirt, etc.

Full bottles must be kept upright to prevent the bungs falling out and leakage. Suitable wooden, plastic or steel boxes (not cardboard) should be used for transport in the field and to and from the laboratory.

3.8. Care of samplers

Samplers are expensive, precisely-manufactured items of equipment, and the quality of the data they collect is governed in part by their being complete and in good condition. The following points shall be observed:

- samplers shall always be stored and transported in their purpose-built boxes
- all accessories and fittings shall be stored in the box, including a full range of nozzles, hanger bar and threaded pin, spare gasket and instruction sheet
- any nozzles lost or damaged shall be replaced by the correct type
- all samplers shall have a serial number recorded on ED teams' and NIWA Kainga's inventories
- any damage to or deformation of samplers, such as bent tailfins, is likely to alter sampling effectiveness, and such samplers shall be returned for repair and recalibration
- samplers shall be kept ready for use at very short notice, with batteries charged (for point samplers), maintenance attended to, and complete with all accessories.

3.9. Automatic pumping samplers

These samplers can be installed beside a stream, and embody a pumping system which abstracts a sample at intervals which can be determined by time, stage, or other events.

Samples are obtained by suction through a tube which is normally purged prior to sampling. However, unless equipped with a specially designed pumping system and a nozzle is installed in a suitable location in the stream, isokinetic sampling will not be accomplished, and the sample is taken only at one point. Thus in most situations, they can only provide a relatively small "window" of data on the suspended sediment load.

In these cases, manual sediment gaugings need to be done in order to compile a relationship calibrating the point concentration with the discharge-weighted cross-section mean concentration.

Details of the sampler types will be mentioned only briefly here as detailed operating manuals are required for each one.

3.9.1 Manning automatic sampler

This is a compact and relatively portable sampler with an integral circular tray of 24 specially-shaped plastic bottles. These can be filled in selected sequences by a pumping system, which has a maximum suction lift of about 6 m.

Features are:

- a purge cycle prior to sampling whereby the suction tube has air pumped out through it to clear it of foreign matter and stagnant water
- options (selectable on the control panel) of having multiple bottles per sample or multiple samples per bottle
- provision for an external input to initiate sampling
- selectable time intervals for sampling, ranging from 3.7 minutes to 24 hours
- provision for flow-weighted sampling via an input port from a flowmeter such as a model made by Manning Environmental Corporation (these flowmeters are only suitable for very small flows through flumes, and this provision is not generally used)
- 12-volt power supply.

3.9.2 ISCO sampler

ISCO and a number of other manufacturers make self-contained samplers similar in concept to the Manning one, with some variations. For details, consult their operating manuals.

3.9.3 Placement of sampler intake

Ideally, the intake of a pumping sampler should be placed at a point in the cross-section where the suspended sediment concentration approximates the mean concentration across the whole range of flows. This point may not exist, and is unlikely to be locatable at the beginning of a sampling programme. However, some guidelines which may assist in determining an appropriate location (Edwards & Glysson, 1988) are as follows:

- place the intake in a zone of high velocity and turbulence where the sediment will be well mixed
- the cross-section should be stable and of reasonably uniform depth and width to maximise the stability of the relationship between mean concentration and that at a point
- place at a depth which can be sampled using a manual sampler, as data from this instrument will be used to calibrate data from the pumping sampler
- using a point sampler, determine the mean depth of occurrence of the mean sediment concentration in the cross section (Edwards & Glysson, 1988, pages 34-35) as a reference depth for placement of the intake
- place at a depth to avoid interference by dune migration or bed load, but to ensure submergence at all times.

4. Field procedures for routine gaugings

The procedures listed in this section follow, with some modification, those employed by the US Geological Survey as detailed by Edwards and Glysson (1988).

4.1. Purpose of a field measurement

As discussed briefly in section 2.2, the main purpose of a suspended sediment gauging is to determine the discharge-weighted mean concentration of suspended sediment in the flow passing the gauging section. Often an additional purpose is to find the size distribution of the suspended load, and so find the concentrations of individual size fractions.

In New Zealand, the general approach is to do a suspended sediment gauging "concurrently" with (meaning directly following) a flow gauging. The resultant C_m:Q data pairs (for explanation see section 2.2) are then used to define a "sediment rating" curve, which, when applied to a discharge time-series, allows an estimate of the suspended sediment yield over a period of time. With particle size data, sediment rating curves and yields can be obtained for each size fraction.

Thus, typically, a suspended sediment gauging will consist of:

- a current-meter gauging, completed immediately prior to sediment sampling
- collection of a set of samples for analysis of concentration, and sometimes collection of a duplicate set for analysis of particle size
- collection of other "supporting" data, including water temperature, water surface slope, and any observations pertinent to sediment transport.

4.2. Sampling strategy

The concentration of suspended sediment varies in space and time. A sampling strategy ensures that these fluctuations are averaged-out accurately and efficiently with a minimum number of samples. Use of depth-integrating and point-integrating samplers takes care of concentration changes in a vertical and also high-frequency fluctuations at-a-point associated with turbulence. Across-stream variations are catered for by sampling at multiple verticals. Two main methods are available for selecting sampling verticals:

- the **Equal Discharge Increment** (EDI) method involves locating sampling verticals at the centroid of n sub-sections carrying equal portions of the total water discharge (this method assumes that the sample collected at the centroid represents the mean concentration for the sub-section). With this, the transit rate is varied from vertical to vertical so as to obtain samples of the same volume.
- the **Equal Width Increment** (EWI) method involves sampling at the mid-point of *n* sub-sections of equal width. The same transit rate is used for between 10 and 20 verticals, and the samples (which will be of

volumes proportional to the flow at each sub-section) may be bulked for laboratory analysis.

Both approaches are designed so that the samples from all verticals are flow-weighted. Each has advantages and disadvantages over the other.

The EDI approach generally requires fewer verticals - hence quicker gauging. Also it has the flexibility to be able to vary the sampler transit rate among verticals. It does, however, require prior knowledge of the depth-velocity distribution in the cross-section. Ideally, this should be obtained from a flow gauging conducted immediately before the sediment gauging. Alternatively, and providing that the cross-section has remained stable, older flow gaugings may be used to estimate the depth-velocity distribution at the current stage. With such flow information available, the EDI approach should be preferred, since it optimises the sampling requirements to the flow conditions.

The EWI approach can be used without prior gauging information. The trade-off is that, without tailoring the selection of sampling verticals to the flow distribution, more verticals are required to ensure that the flow is sampled adequately (thus where five verticals might suffice for an EDI gauging, generally at least ten are required for an EWI gauging). Also, the EWI approach is more susceptible to errors and less amenable to quality control checks. One error source involves "drift" in the transit rate. Strict concentration is needed to ensure that the transit rate does not change over the 10 to 20 verticals required. Another error source involves compositing. EWI samples are usually composited for analysis, and several verticals may be sampled into the same bottle, compositing "on the fly". Great care is required to avoid adding a bad sample such as after the bottle is over-filled or when the sampler nozzle has dug into the bed. One bad sample unnoticed is "sudden death" to an EWI gauging, and therefore individual samples should be closely inspected immediately after collection. Any doubtful samples should be discarded and re-collected.

With an EWI gauging the NIWA Environmental Data standard approach is to composite samples before analysis for both concentration and particle-size.

With an EDI gauging, the standard approach adopted by NIWA Environmental Data is to collect one set of samples to be analysed individually for sediment concentration. Because each sample of the set represents an equal portion of water discharge, the mean of the n sampled concentrations will equal the mean concentration for the whole section, while their standard deviation will indicate how uniform the concentration is across-channel. If particle-size data are required, a duplicate set of samples is collected and bulked for analysis of particle-size distribution. Within this set, it is important that all samples are of approximately equal volume, so that each fairly represents its sub-section. Equal sample volumes can be obtained by varying the transit time according to prior knowledge of the mean velocity in the sampling vertical, as explained in section 4.3.6. Collecting repeat samples at each vertical also has the advantage of identifying and if necessary repeating samples that have been biased through the sampler plunging into the bed.

4.3. Decisions to make before beginning sampling

4.3.1 General

In general, for every sediment gauging, decisions are required on whether to use the EWI or EDI approach, the number and location of sampling verticals, the number of samples to collect at each vertical, the best sampler and intake nozzle to use, and the optimal transit time (or rate) for moving the sampler from the surface to the bed and back again. These selections should be based on information on the variation in depth and velocity across the section (obtained, whenever possible, from a current-meter gauging made immediately beforehand) and, if available, prior information on the proportion of sand in the suspended load. They should be made and noted on the record form before sampling commences. Nomographs to assist in making these selections are presented in the following sections. For speed and simplicity in the field, programs are available to do this using a portable PC or the Psion Organiser. These programs, named SEDGAUGE, run in a similar manner on each machine, and are described in more detail in section 4.3.11.

4.3.2 EDI or EWI

Whenever possible, the EDI method should be used because of its superior control on data quality. Circumstances in which the EWI approach is used might be when there is insufficient time during a flood to do both flow and sediment gaugings, where a series of sediment gaugings are required over a flood, or where field circumstances, such as a jet boat or wading gauging, make the time required to calculate the equal discharge increments impractically long. The EWI approach should be avoided where the cross-channel velocity distribution is particularly non-uniform. This is because the transit rate required at the highest velocity vertical may be too fast and so induce sampling bias at verticals with lower velocities.

4.3.3 Number of verticals

The number of verticals required depends on the actual systematic variation in concentration across-channel and the accuracy sought. The cross-channel variation in concentration increases the less uniform the section and the greater the proportion of sand in the suspension. Almost all of the cross-sectional variation results from sand-sized material; finer sediment is uniformly dispersed.

NIWA Environmental Data have adopted two standards that affect the number of verticals:

- no sampling vertical should represent more than 20% of the total flow
- the standard error of the concentration amongst verticals should not exceed 15% of the mean.

With the EDI method, where each vertical represents an equal portion of the total flow, at least five verticals are required to meet the first standard. With the EWI method, the sub-sectional flow represented by each vertical varies and so more verticals are required to ensure that the vertical carrying the highest sub-sectional flow satisfies the standard. A default minimum value of 10 EWI verticals is generally

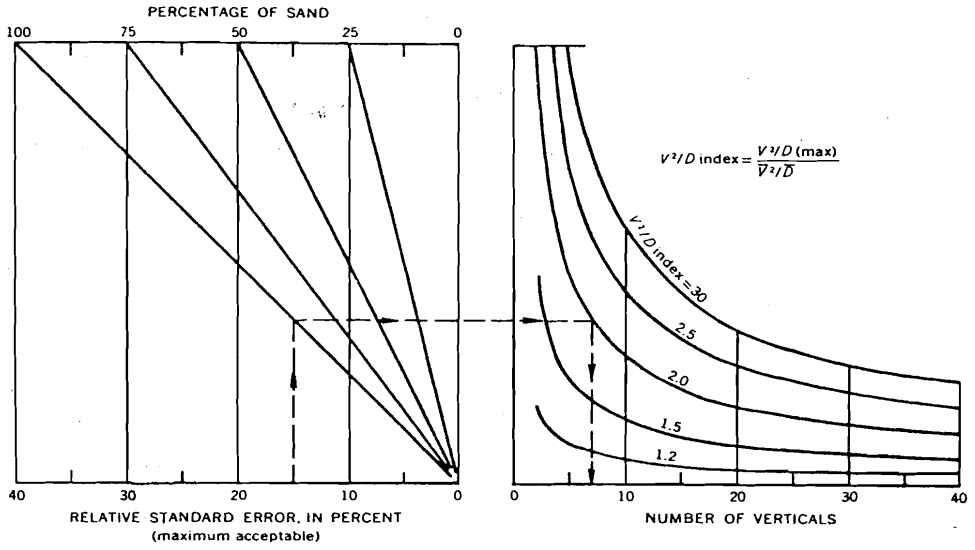


Figure 4.1 *Nomograph to determine the number of sampling verticals required to obtain results within an acceptable relative standard error. Example: for a section with a V^2/D index of 2.0 and with its suspended load estimated to be 100% sand, then to obtain a measurement of mean concentration with a standard error of 15% or less, 7 verticals should be sampled.*

assumed, although given information on the flow distribution from a prior current-meter gauging, it is possible to determine the number of EWI verticals exactly. The SEDGAUGE field-computer program has this facility (see section 4.3.11), and can either be used directly in the field, or can be used in the office with existing flow gaugings to help develop a relationship between stage and the required number of EWI verticals for given sites.

The second standard may require more than these minimum numbers of verticals. Three approaches may be used to check this.

Subjective Assessment

The first involves a subjective assessment based on the appearance of the river, knowledge of the flow distribution, and any prior knowledge on the sand content of the suspended load. Commonly this will be all that is possible in situations where the EWI method is used.

Jordan's Nomograph

The second approach involves use of Jordan's nomograph (Fig. 4.1). This is based on the work of Colby (1964) who showed that the discharge-weighted mean concentration of sand in a vertical was proportional to V^2/D, and thus the variability in this parameter should be a reasonable index of concentration variability. Using Figure 4.1, to achieve a given relative standard error in mean concentration, the number of verticals is estimated according to the percentage of sand and the V^2/D index, defined as

$$(V^2/D)_{max} / (\overline{V}^2/\overline{D} \qquad (4.1)$$

where v is the mean velocity in a vertical, D is the depth of the vertical, $(V^2/D)_{max}$ is the ratio from the vertical having the maximum V^2/D, and $\overline{V}$ and $\overline{D}$ are the mean velocity and mean depth of the whole section. These velocity and depth values should be obtained from the immediately preceding current-meter gauging. In general when using this nomograph, assume a 15% relative standard error and, unless information exists to the contrary, assume a percentage of sand equal to 50%.

Although Jordan's nomograph is featured in the U.S. Geological Survey's manuals, in practice it is rarely used by them. Its main limitation is that it is based on data from only one river. Thus it is not recommended as a stand-alone guide.

Analysis of Existing Concentration Data

The third approach uses statistics of the cross-sectional variation in sediment concentration compiled from previous sediment gaugings. It is the recommended approach for sites sampled by the EDI method, but will seldom be useful for EWI sites since, at these, samples from different verticals are generally bulked before being analysed for concentration.

The procedure to follow is:

- Build a table such as the following from previous sediment gaugings at the site:

Stage	Q	*n*	C_{mean}	s	*Cv (%)*	SE (95%)	*n* required

where $c_{mean} = \sum c_i / n$,

$s = \sqrt{(\sum (c_i - c_{mean})^2) / (n-1)}$,

$C_v(\%) = s/C_{mean} * 100$,

$SE = t_{95}.C_v / \sqrt{n}$

where t_{95} is a function of n, the number of verticals, and is found from the table:

n	3	4	5	6	7	8	9	10	15	20
t_{95}	4.3	3.18	2.78	2.57	2.45	2.36	2.31	2.26	2.13	2.09

- Use the plot in Figure 4.2 to estimate the minimum number of verticals required to give no more than a 15% standard error (i.e. the "n required" value in the above table).

The table should be compiled in the office and taken into the field where, by matching the stage and/or discharge with previous gaugings in the table, you can decide on the number of verticals.

Note that for the first few gaugings at an EDI site it is a good idea to sample a conservatively large number of verticals. The extra detail on cross-sectional variation in concentration gained from these should quickly indicate the optimal number of verticals required for subsequent gaugings.

Finally, there will be occasions at some sites where the stage is simply changing too fast to allow sampling at the desirable number of verticals. In those cases, field staff will have to use their judgement about a practical number. If forced into this situation, add a comment to the record form and pass it on to the archive.

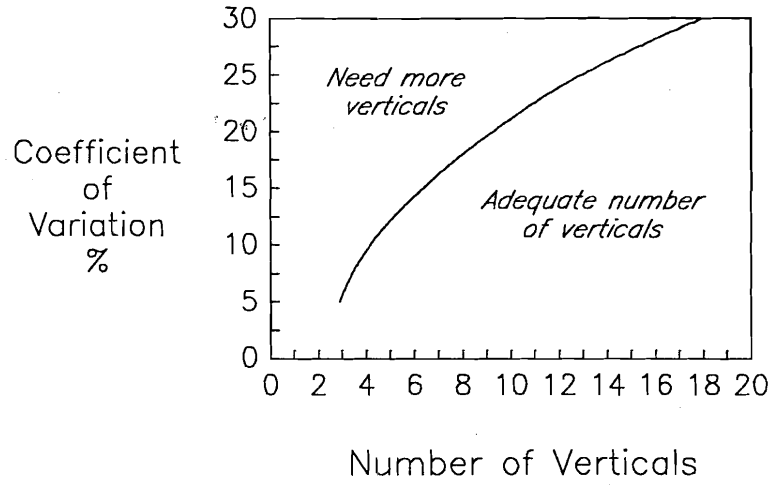


Figure 4.2 Example: *5 verticals were used for a sediment gauging, and the coefficient of variation for the concentration of the five samples collected was 14%. This result plots in the "need more verticals" part of the graph. Projecting a horizontal line from that point to the curved line indicates the number of verticals required for an acceptable result - in this case, 6. Thus for the next sediment gauging at this site, at least 6 verticals should be used. If the original c. of v. had been 12% or less, then 5 verticals would have been adequate.*

In summary, to decide the number of verticals:

For an EDI gauging

- use at least 5, no more than 10, verticals
- if no or little existing information on variations in concentration is available, use a conservatively large number of verticals
- use the standard error or coefficient of variation of the concentration from previous gaugings to fine-tune the required number of verticals
- Jordan's nomograph may be used as a guide if no other information is available

For an EWI gauging

- with no quantitative information on the flow distribution, visually assess the width of the narrowest span of channel conveying 20% of the flow, divide the total width by this value, and round the result up to find the number of verticals
- with quantitative information on the flow distribution and if a field-computer is available, use SEDGAUGE to calculate the optimal number of verticals
- use at least 10, no more than 20, verticals

For both EDI and EWI gaugings

- use a conservative number of verticals for the first few sediment gaugings at a site
- use more verticals if the sediment concentration is obviously non-uniform across-channel, such as immediately downstream from the confluence of a tributary stream.

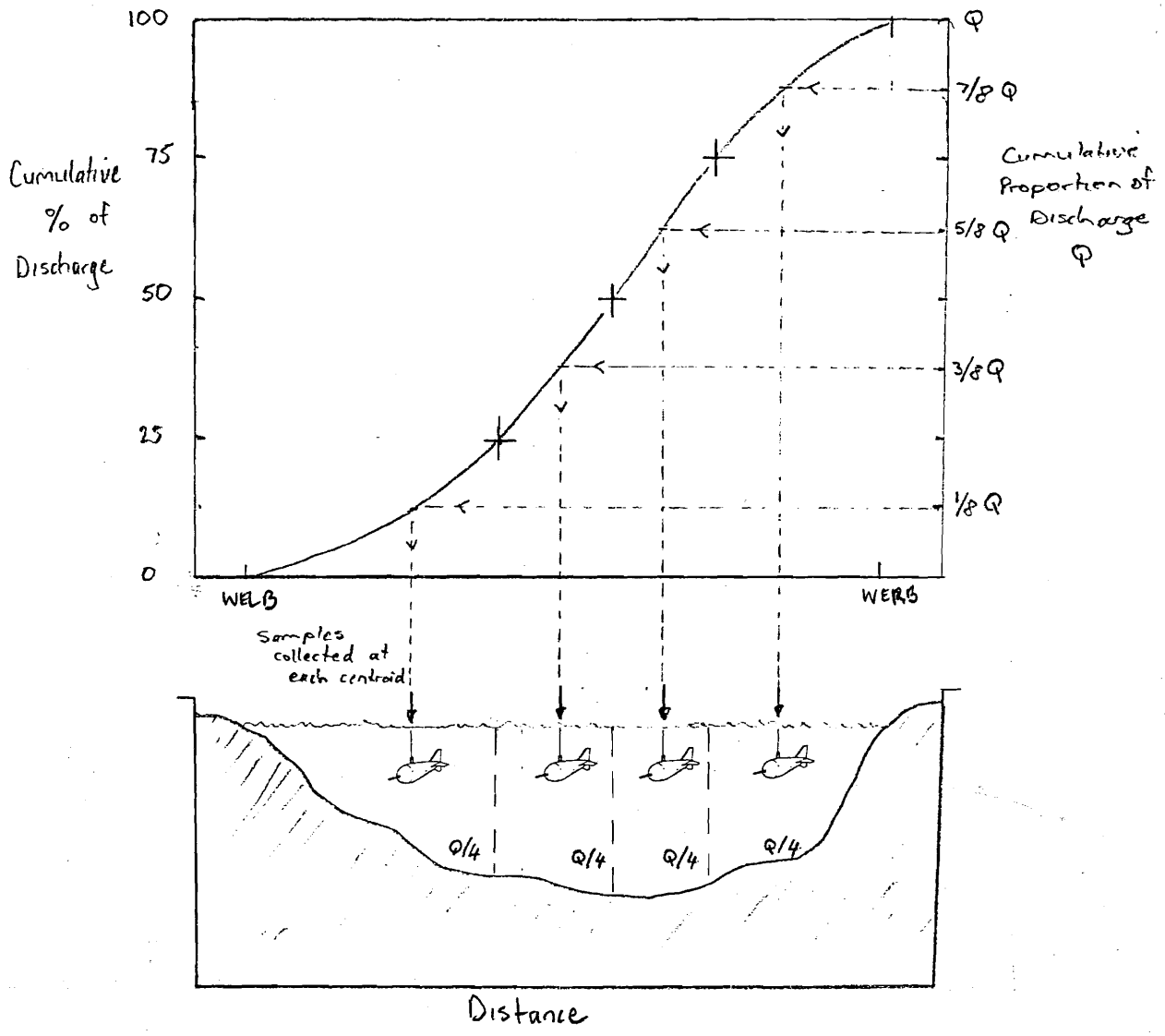
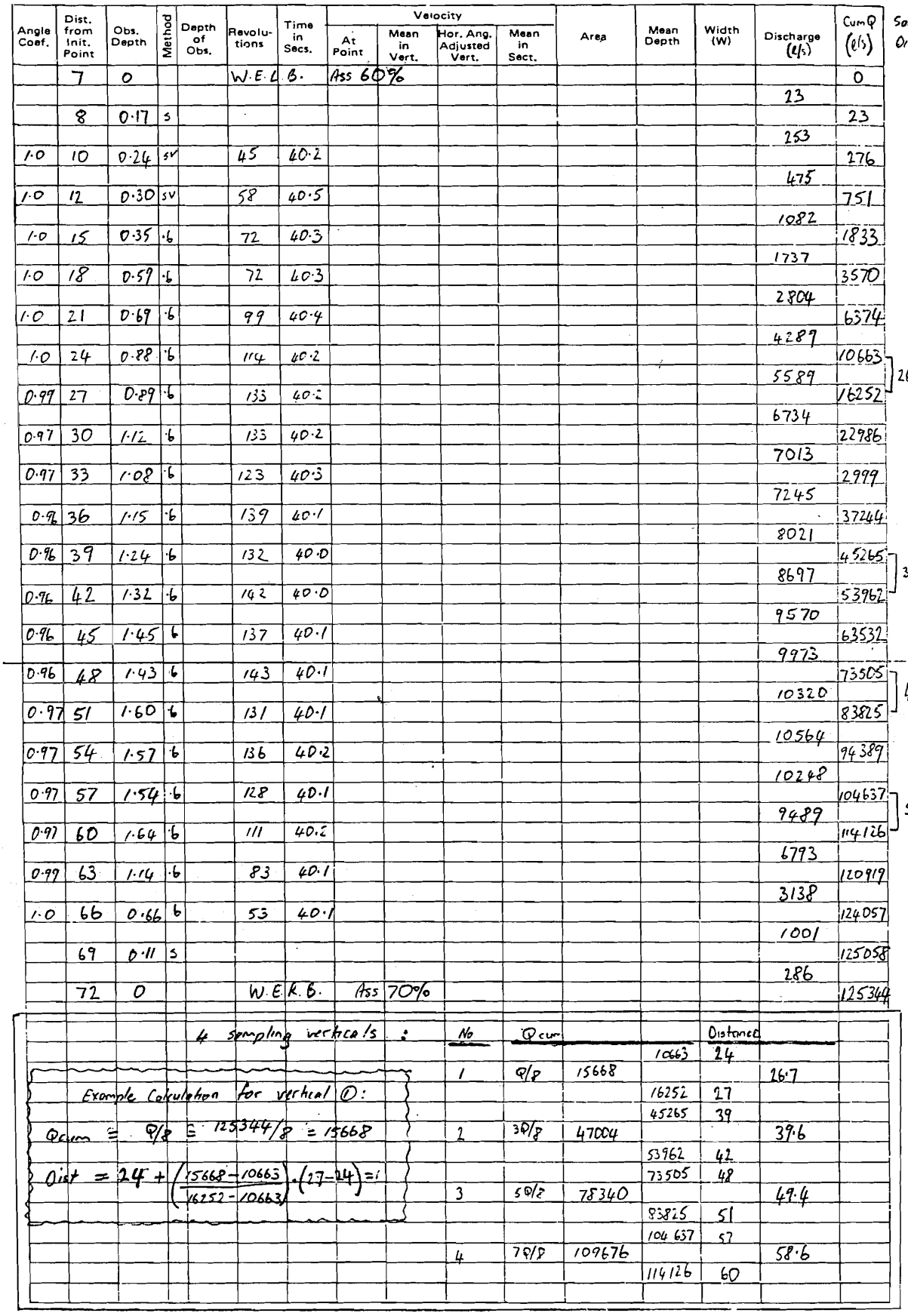


Figure 4.3 *Method of locating sampling verticals at centroids of sub-sections carrying equal increments of water discharge. For 4 sampling verticals, sub-sections each carry Q/4, and sub-section centroids are located at distances corresponding to $^{1}/_{8}Q$, $^{3}/_{8}Q$, $^{5}/_{8}Q$, and $^{7}/_{8}Q$ as indicated on the cumulative proportion of discharge plot.*



Angle Coef.	Dist. from Init. Point	Obs. Depth	Method	Depth of Obs.	Revolutions	Time in Secs.	Velocity: At Point	Velocity: Mean in Vert.	Velocity: Hor. Ang. Adjusted Vert.	Velocity: Mean in Sect.	Area	Mean Depth	Width (W)	Discharge (l/s)	Cum Q (l/s)
	7	0			W.E.L	B.	Ass 60%								0
														23	
	8	0·17	s												23
														253	
1·0	10	0·24	sv		45	40·2									276
														475	
1·0	12	0·30	sv		58	40·5									751
														1082	
1·0	15	0·35	·6		72	40·3									1833
														1737	
1·0	18	0·59	·6		72	40·3									3570
														2804	
1·0	21	0·69	·6		99	40·4									6374
														4289	
1·0	24	0·88	·6		114	40·2									10663
														5589	26·7
0·99	27	0·89	·6		133	40·2									16252
														6734	
0·97	30	1·12	·6		133	40·2									22986
														7013	
0·97	33	1·08	·6		123	40·3									29999
														7245	
0·96	36	1·15	·6		139	40·1									37244
														8021	
0·96	39	1·24	·6		132	40·0									45265
														8697	39·6
0·96	42	1·32	·6		142	40·0									53962
														9570	
0·96	45	1·45	6		137	40·1									63532
														9973	
0·96	48	1·43	6		143	40·1									73505
														10320	49·4
0·97	51	1·60	6		131	40·1									83825
														10564	
0·97	54	1·57	6		136	40·2									94389
														10248	
0·97	57	1·54	6		128	40·1									104637
														9489	58·6
0·97	60	1·64	6		111	40·2									114126
														6793	
0·99	63	1·14	6		83	40·1									120919
														3138	
1·0	66	0·66	6		53	40·1									124057
														1001	
	69	0·11	s												125058
														286	
	72	0			W.E.R.B.		Ass 70%								125344

4 sampling verticals :

No	Q cum			Distance	
			10663	24	
1	Q/8	15668			26·7
			16252	27	
			45265	39	
2	3Q/8	47004			39·6
			53962	42	
			73505	48	
3	5Q/8	78340			49·4
			83825	51	
			104637	57	
4	7Q/8	109676			58·6
			114126	60	

Example Calculation for vertical ①:

$Q_{cum} = Q/8 = 125344/8 = 15668$

$Dist = 24 + \left(\frac{15668 - 10663}{16252 - 10663}\right) \cdot (27 - 24) = ?$

Figure 4.4 *Current meter gauging card showing example calculation of distances to EDI sampling verticals.*

4.3.4 Location of verticals

For the EDI method, the n sampling verticals should be located at the centroids of sub-sections each carrying $1/n$ of the total water discharge, Q. Going from water's edge to water's edge, the sub-section centroids are assumed to occur where the cumulative discharge equals

$$\frac{(1,3,5,\ldots,2n\text{-}1)}{2n} Q \qquad (4.2)$$

For example, where there are to be four verticals, they should be located at $^1/_8$Q, $^3/_8$Q, $^5/_8$Q, and $^7/_8$Q (see Figure 4.3). The horizontal position of the cumulative discharge should be determined by interpolation from the results of the prior current-meter gauging. Figure 4.4 shows an example manual determination of sampling vertical locations on a current-meter gauging card. The steps are:

- list the cumulative discharges from WELB to each current-meter vertical
- locate current meter cumulative discharge pairs that straddle the cumulative discharges for the sampling verticals
- calculate appropriate cumulative discharges for sampling verticals (using equation 4.2)
- interpolate corresponding horizontal distances to sampling verticals.

For the EWI method, the n sampling verticals should be located at the centres of sub-sections each $^1/_n$ th of the total width, W. Going from water's edge to water's edge, the sub-section centres will occur where the distance from water's edge equals

$$\frac{(1,3,5,\ldots,2n\text{-}1)}{2n} W \qquad (4.3)$$

For example, where there are to be ten verticals, they should be located at $^1/_{20}$W, $^3/_{20}$W, $5/_{20}$W, etc., up to $^{19}/_{20}$W.

One practical method to locate EWI verticals is to:

- visually inspect the stream from bank to bank, observing the velocity and depth distribution
- estimate the width of the smallest partial section which would represent 20 % of the total flow (generally the deepest, fastest portion)
- use the smaller of this width or 1/10 of the total width as the interval to be used for the entire EWI gauging
- locate the first vertical at half of this interval from the water's edge
- space subsequent verticals by this interval.

Note: It is important that the sampling verticals be located at the precise locations, rather than at the nearest vertical in the prior current-meter gauging. If this is not done, then the calculation of discharge-weighted mean concentration becomes more complex and non-standard; also, and more importantly, the samples for particle size analysis will no longer be bulked in the correct proportions.

4.3.5 Sampler to use

Generally, the choice of sampler will depend on the access to the gauging section and the flow depth and velocity. The maximum operating ranges of the samplers described in section 3 are shown in Figure 4.5. Beyond these depth and velocity limits, the sampling efficiency, accuracy, and/or practicality of the samplers becomes unsatisfactory.

Figure 4.5 incorporates an absolute limit on the transit rate of 0.64 m/s, which equates to 2 revolutions per second of the crank handle on a standard type-A gauging reel (this limit controls the curved portions of the operating limit). This "arm-strength" limit is somewhat arbitary, and may not be achievable by all individuals. Accordingly, if the depth and velocity values plot on or just inside the operating region for a given sampler combination, then consideration should be given to selecting another combination that will use a lower transit rate.

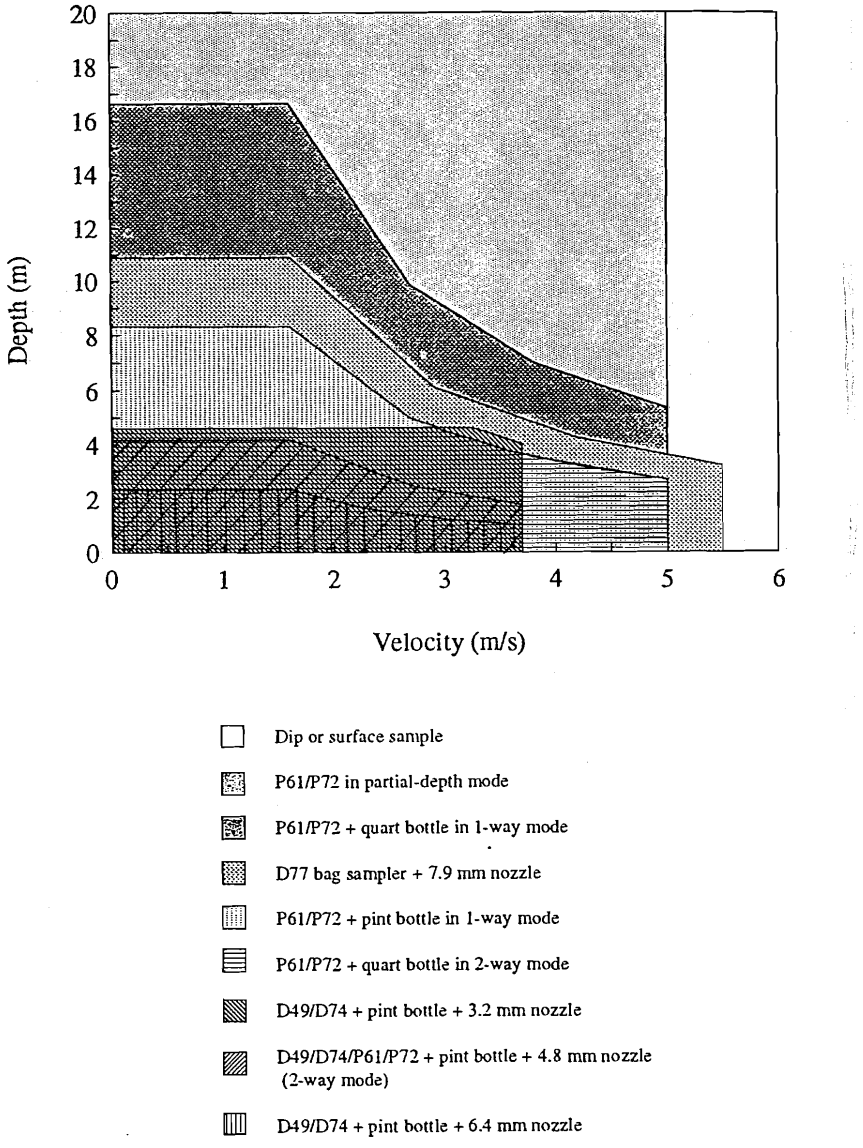


Figure 4.5 *Operating ranges of the various sampler/nozzle/mode combinations in terms of the depth and mean velocity at-a-vertical. The assumptions and equations for the field boundaries are derived in Appendix A.*

The absolute depth limit on the depth-integrating samplers (DH-48, D-49, D-74) is related to air compression in the sample bottle. As the sampler is moved through an increasing depth, the increasing hydrostatic pressure at the air exhaust port controls the escape of air exhausted as the sample enters the bottle. However, beyond 4.7 m depth, compression of the air remaining inside the bottle becomes excessive and prevents the sampler from operating isokinetically. The P-61 and P-72 samplers are not affected by this factor as they have a special chamber which equalizes the air pressure in the sample bottle with the external hydrostatic pressure. The D-77 is affected only when using a rigid sample container, not when the collapsible bag is used.

Generally:

- if the section is wadable or accessible from a low bridge, then a rod-mounted DH-48 sampler should be used
- if a cable sampler is required, use a D-49 or D-74 providing the depth at the critical sampling vertical (i.e., the sampling vertical where the velocity-depth product is highest) is less than 4.7 m and/or the mean velocity at that vertical is less than 3.7 m/s
- where the depth exceeds 4.7 m and/or the velocity does not exceed 5.0 m/s, a P-61 or P-72 point-integrating sampler should be used in either one-way depth-integrating or partial-depth mode
- for very shallow wadable sections and where the velocity exceeds 5.0 m/s, it is permissible to take a surface sample (depending on the situation, a bottle or a P-61 or P-72 sampler may be used)
- if a large sample volume is required, such as for analysis of particle-size when the concentration is relatively low, a D-77 is recommended.

4.3.6 Selecting intake nozzles

The different samplers come equipped with a varying selection of intake nozzles. The DH-48 has only the 6.4 mm nozzle. The D-49 and D-74 can be used with 6.4, 4.8, and 3.2 mm nozzles. The P-61 and P-72 use only a 4.8 mm nozzle. The D-77 has a 7.9 mm nozzle.

Different nozzle diameters provide a means to regulate the fill-rate of the sampler, and hence the volume of sample collected. In general, for the depth-integrating samplers, the largest nozzle size should be used, providing the sample bottle is not over filled and the transit rate required at the deepest, fasted-flowing sampling vertical is neither too fast to be practical nor exceeds the maximum permissible rate for the particular combination of intake nozzle, bottle size, and mean velocity and depth at the vertical.

As explained in section 4.3.7, for the standard pint bottles, the critical transit rate will be exceeded for depths greater than 2.3 m when using the 6.4 mm nozzle, for depths greater than 4.2 m when using the 4.8 mm nozzle, and for depths greater than 4.7 m when using the 3.2 mm nozzle. (This limit does not apply if using the P-61 sampler in one-way mode.) Figure 4.5 provides guidelines on the appropriate nozzle size to select for a gauging, given the depth and mean velocity at the critical sampling vertical. With the EDI method, generally it is easier to use the nozzle required for the critical vertical at all verticals, although different diameter nozzles can be substituted at other verticals. The same sampler should be used for all verticals. With the EWI method, the same sampler and nozzle should be used at all verticals.

The 3.2 mm nozzle should not be used where there are significant quantities (i.e. $\geq$16% by weight) of sand larger than 0.25 mm in suspension (knowledge of this will only be available after several sediment gaugings have been analysed for particle-size), nor where there are abundant small roots and plant fibres suspended. In these circumstances, where the velocity and depth exceed the operating limits of a D-49 or D-74 equipped with a 4.8 mm nozzle, the P-61 or P-72 samplers should be used.

4.3.7 Transit time and rate for EDI method

For a given sampling vertical and intake nozzle, the volume of sample is governed by the time taken to move the sampler from the surface to the bed and back again. This time, called the "transit time", T, in seconds, is

$$T = 4V / vd^2\pi \quad (4.4)$$

where v is the mean velocity in the sampling vertical (m/s), d is the diameter of the intake nozzle (mm), and V is the sample volume (ml). The rate of lowering and raising the sampler, called the "transit rate", R, in m/s, is

$$R = 2D / T = \pi D v d^2 / 2 V \quad (4.5)$$

where D is the flow depth in metres. Appropriate transit times and rates should be selected so that the sample volume is optimal while maintaining efficient and practical operation of the sampler.

The optimal sample volume to aim for, for the standard pint sample bottle, is 300 - 370 ml. The 370 ml maximum ensures that the bottle has not been completely filled and should prevent sample spillage during bottle removal. A completely filled bottle, having exhausted its remaining air, functions as a stilling basin, circulating water through and trapping sediment and thus creating a sample whose concentration exceeds

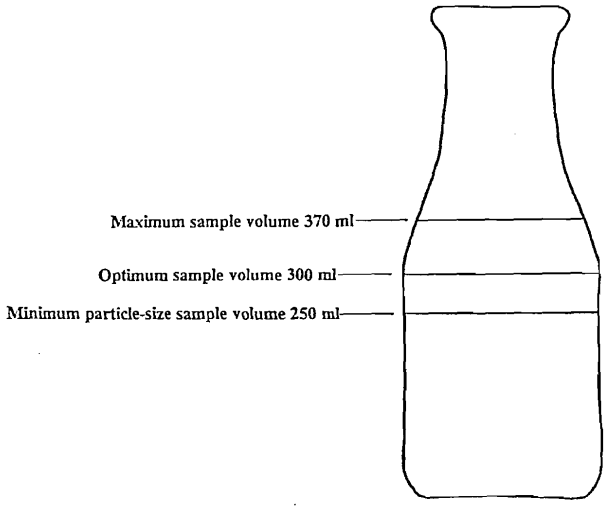


Figure 4.6 *The approximate levels of the minimum acceptable volume, 300 ml, and the maximum, 370 ml, in the standard 470 ml bottle.*

the ambient concentration; it is also bound to spill some of its sample during sampler retrieval and bottle unloading. One can never be sure whether an overfull bottle filled completely, where in the vertical it became full, and how much spilled after the sampler left the water. A sample smaller than 300 ml is acceptable, but may yield insufficient mass of sediment for analysis.

NOTE: These levels should be marked on all bottles following the guidelines in Figure 4.6.

There are two limits on the maximum transit rate. The first is related to the isokinetic operation of the sampler. If the transit rate is too fast, the rate of air compression inside the sampler cannot match the rate of increase in external hydrostatic pressure, and water may enter via the air exhaust port. Additionally, the fast transit rate alters the streamlines past the intake nozzle and results in intake velocities slower than the ambient velocity. This effect is particularly limiting with the smallest, 3.2 mm diameter, nozzle. To avoid these problems, with the standard pint sample bottle the ratio of transit rate to mean velocity in the vertical should never exceed 0.4 for 6.4 and 4.8 mm nozzles, nor should it exceed 0.2 for the 3.2 mm nozzle.

The second limit is determined by how fast the sampler can physically be raised - or how fast the gauging reel crank can be turned. A maximum of two revolutions per second on an A-type gauging reel has been assumed for this, equating to a transit rate of 0.64 m/s.

Equation 4.2 can be used to determine the depth and velocity conditions at which these limits are exceeded for each particular nozzle size and for the optimal range of sample volume (see Appendix A and Figure 4.5).

The appropriate transit time (and rate) required to obtain the optimal sample volume should always be pre-determined for each sampling vertical. This is particularly important for the samples collected for particle size analysis, since their bulking procedure assumes they are of approximately equal volume. The minimum transit time, corresponding to the maximum permissible transit rate, should also be pre-determined and checked against the actual transit time taken during sampling.

Determining transit time

Nomographs for selecting the optimal and minimum permissible transit times for a vertical with given mean velocity and depth, using pint- and quart-sized bottles, and using a given nozzle size, are shown in Figure 4.7.

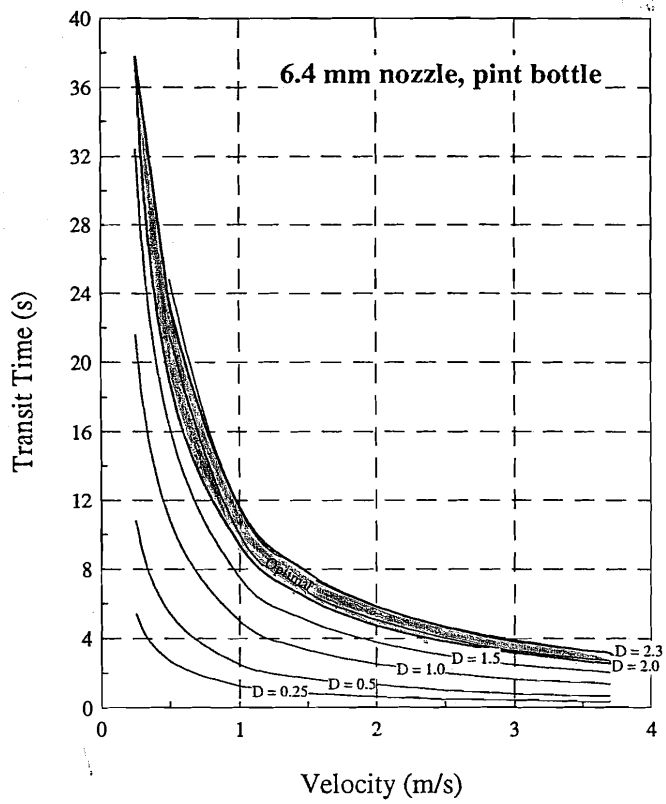
Example: For a vertical with mean depth of 2.5 m and a mean velocity of 2.0 m/s:

- Figure 4.5 indicates that a 4.8 mm nozzle would be appropriate, and therefore Figure 4.7b should be used to determine the transit time;

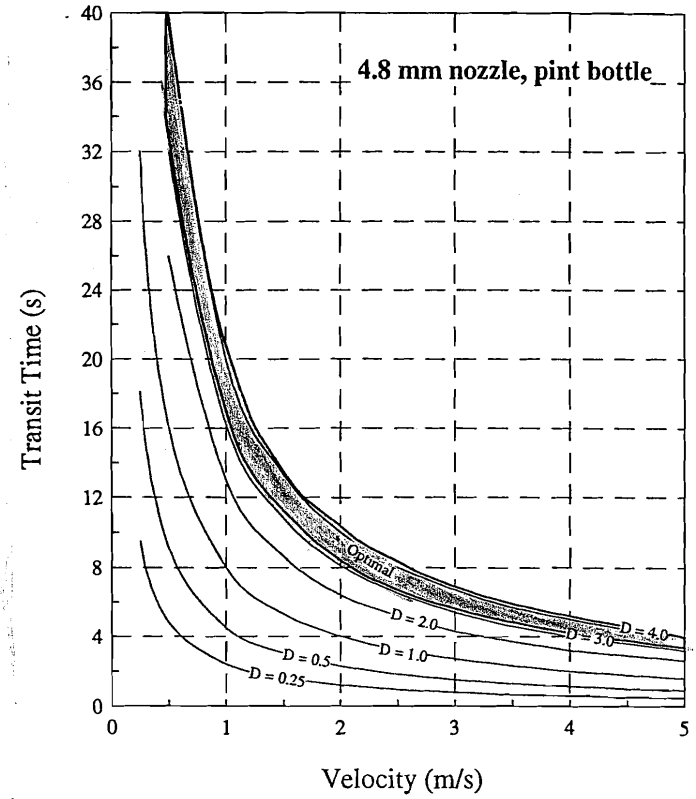
- from Figure 4.7b, the range of optimal transit times, 8.5 - 10.5 seconds, is found from the intersection of the $v = 2.0$ m/s line with the boundaries of the hatched "optimal volume for pint bottle" zone;

- the minimum permissible transit time, 7.5 seconds, is read from where the $v = 2.0$ m/s line intersects the $D = 2.5$ m curve (interpolated).

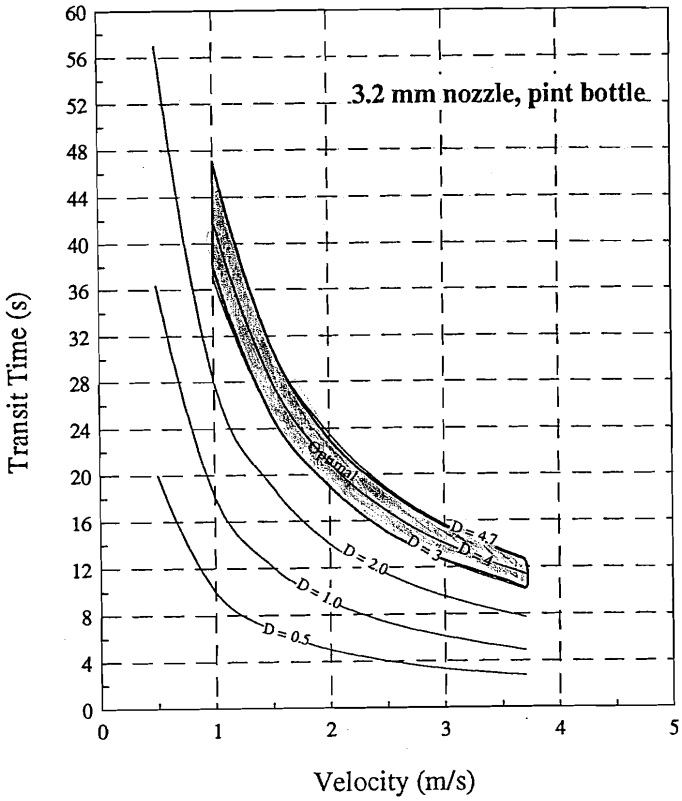
As an inspection of Figures 4.7 will show, these nomographs also depict the limiting depth-velocity ranges for each nozzle, since beyond a certain depth for a given



(a)

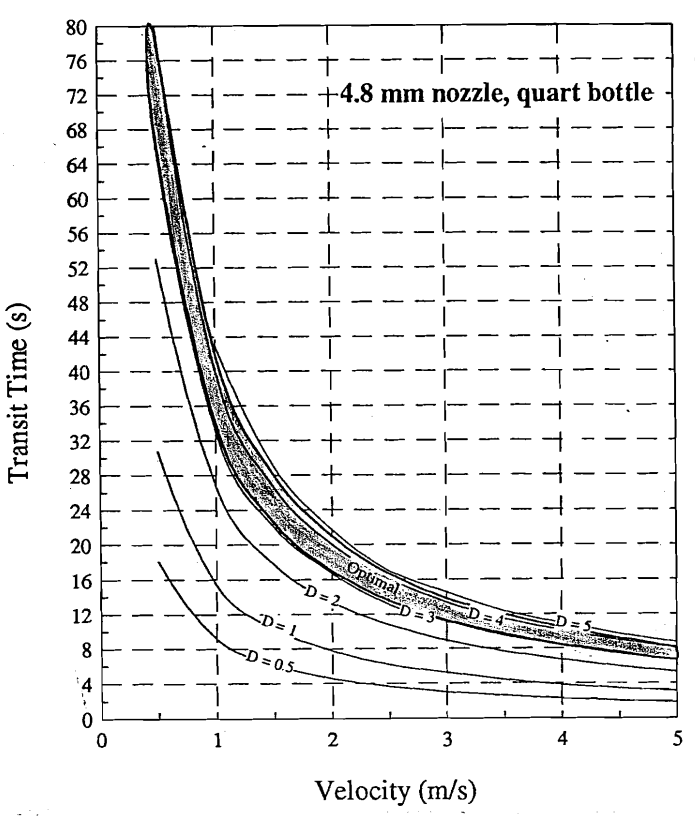


(b)

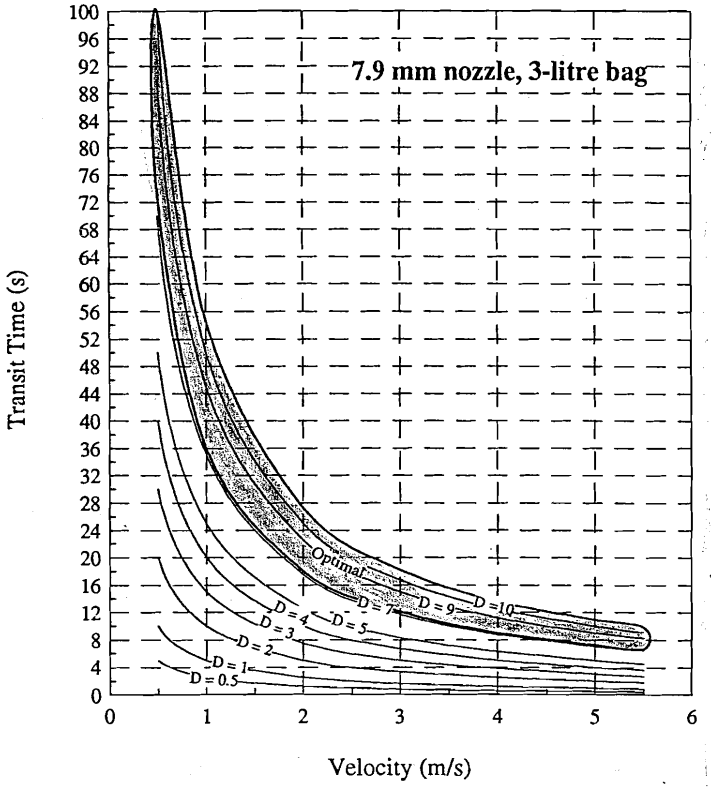


(c)

Figure 4.7 (a), (b) and (c) *Nomographs for determining optimal and permissible transit times for given flow depths and velocities, and for different diameter sampler nozzles. Example: for case where V = 2.5 m/s, D = 2.0 m, and 3.2 mm nozzle with pint bottle: from graph (c), optimal range of T is 15 - 19 s, and minimum permissable T is 12 s.*



(d)



(e)

Figure 4.7 (d) and (e). *Transit times for quart bottles and 3-litre bags.*

velocity, the "minimum permissible transit time" will exceed the "optimal volume transit time", resulting in the bottle being overfilled.

NOTE: The nomographs in Figure 4.7 summarise more complex diagrams and information provided on pages 69-74 of Edwards and Glysson (1988). Also, where Edwards and Glysson's nomographs are based on optimal sample volumes for the pint bottles of 350-420 ml, Figure 4.7 (a), (b) and (c) have been calculated for optimal volumes of 300-370 ml, Figure 4.7 (d) for twice that, and Figure 4.7 (e) for 2000 - 2700 ml.

When using the P-61 or P-72 samplers (which are always equipped with the 4.8 mm nozzle) in depth-integrating mode, Figure 4.7 (b) should be used to estimate the optimal transit time. This time will be the same whether they transit one-way or two-way, but for one-way transits the value of D to be used on the nomographs should be one-half of the total depth. Their operating depth range is limited only by the maximum permissible transit rate. The corresponding minimum permissible transit times should be determined from Figure 4.7 (b) according to the following rules:

- for two-way depth-integration with a pint bottle - as given in Figure 4.7(b)

- for one-way depth-integration with pint bottle - use the time at which the velocity line intersects the depth line corresponding to one-half the actual flow depth

When using the P-61 or P-72 samplers in one-way mode, duplicate samples are required, one transitting from bed to surface and the other transitting in the reverse direction. The same transit times should be used for both of these downward and upward transits. Such duplicates are bulked before analysis for concentration.

Determining transit rate

Use Figure 4.8 to convert transit time to transit rate. Depending on the situation, it may be preferable to control the transitting by the rate rather than the time; or both may be useful. Again, for one-way transitting use half the actual flow depth.

Enter the appropriate transit rates and times against each vertical on the record form.

Note: In situations where there is a significant vertical angle, vertical depth rather than the observed depth should be used in Figures 4.5 and 4.7. Transit rate estimations from Figure 4.8 require the observed depth. This observed depth could be determined for the sampler (rather than the current meter) by carrying out a trial sampling and observing the depth and volume of sample collected.

4.3.8 Transit time and rate for EDI method

With the EWI method, the same transit rate should be used at each vertical; this rate is set so that an optimal volume of sample is collected at the critical vertical i.e., the one with the greatest depth-velocity product. The sample volumes at the other verticals will always be smaller. The steps to follow are:

- identify the critical vertical and estimate the depth and velocity
- use Figure 4.7 to determine the transit time for the optimal volume of sample for this depth-velocity condition
- use Figure 4.8 to convert this transit time to a transit rate
- use the same transit rate for all verticals
- if the depths at the other sampling verticals are known, use Figure 4.7 to determine their transit times
- enter the required transit rates and times against each vertical on the record form.

4.3.9 Using P-61and P-72 Samplers in Partial-depth Mode

When the depth-velocity conditions are such that using P-61 and P-72 samplers in one-way mode still does not(see Figure 4.5), they should be used in partial-depth mode. This requires dividing the depth into equal segments and then using the sampler to depth-integrate a separate sample over each segment. Both upward-traversing and downward-traversing samples should be collected from each partial-depth segment.

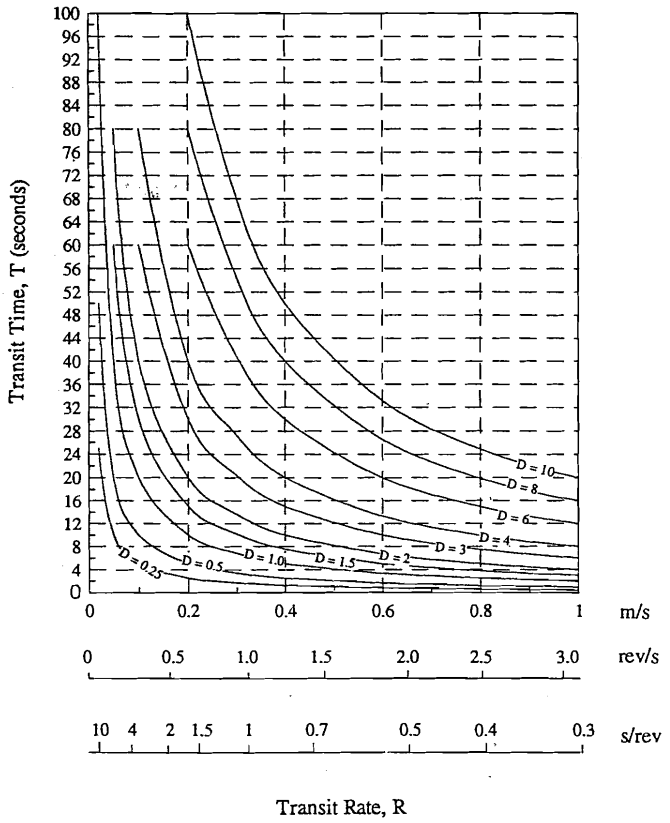


Figure 4.8 *Nomograph for converting transit time to transit rate (for 2-way traverse). Example for T = 12 s and depth, D = 2.0 m: R = 0.34 m/s, which is equivalent to 1.1 revolutions per second or 0.9 seconds per revolution for an A-reel. Notes: (1) always use the observed depth (2) when using a P-61 sampler in a one-way traverse, halve the depth value.*

The number of depth segments to sample, m, can be found by dividing the total depth, D, by m until the value of D/m falls within the operating range of the sampler in one-way mode as shown on Figure 4.5. Usually, two segments should be sufficient.

The transit time (and rate) should be the same for each partial-depth segment and should be keyed to the segment conveying the fastest velocity - which should always be the upper segment, nearest the surface. The mean velocity in this upper segment may be approximated by the surface velocity, which is assumed equal to 1.2 times the mean velocity in the vertical. This velocity and half the partial depth ($^1/_2$ x D/m) are used with Figures 4.7 (b) and 4.8 to determine the required transit time and rate.

A stop-watch should always be used to time the opening and closing of the sampler's inlet valve.

Samples from individual partial-depths in a vertical can be bulked for concentration analysis provided the same transit rates/times are used for each sample; otherwise, each sample will need to be analysed for concentration separately, and the mean concentration in the vertical will need to be determined by weighting the concentration from each partial depth by its corresponding point velocity.

> Example: Sampling is required at a vertical where the depth is 6.0 m and the mean velocity is 3.0 m/s. Figure 4.5 shows that dividing the depth into two 3.0 m segments will permit operation of the P-61 or P-72 sampler in one-way mode, thus four samples should be collected - from the surface to 3.0 m, from 3.0 m to the bed, from the bed back to 3.0 m, and from 3.0 m back to the surface. These four samples can be bulked for analysis provided that the same transit rates/times are used for each.

Use V = 3.0 x 1.2 = 3.6 m/s to determine the optimal transit time for the top segment from Figure 4.7 (b), and D as 1.5 m to find the minimum permissible transit time. Also use D as 1.5 m in Figure 4.8 to find the transit rate. Repeat this process for the lower segment using V = 3.0 m/s

4.3.10 Number of Samples for Particle-size Analysis

The total volume of bulked sample required for particle-size analysis, and hence the number of samples, depends on the concentration of the samples and the proportion of sand in them. The concentration determines the mass of sediment available to analyse. The various analysis techniques require different minimum masses (Table 4.1). Because the sand and silt-clay fractions are analysed separately by different techniques, minimum masses are required for both fractions.

Figure 4.9 (modified from Porterfield, 1972) is a nomograph for estimating the number of pint bottles required to yield a minimum of 0.2 g of sand (for sieve or V.A. tube analysis) and 0.8 g of silt and clay (for pipette analysis) when using the EDI method. It assumes that each bottle contains 335 ml of sample. Note that if there is no existing information on the sand proportion in the suspended load for a site, it should be assumed that this is 50%. Note also that if the sand proportion is less than 16%, then, when using the nomograph, it can be assumed that the sand proportion equals 16% since such a small sand fraction generally need not be sub-divided. Likewise, if the sand fraction exceeds 84%, assume that it equals 84% since the silt-clay fraction need not be sub-divided.

When using the EWI method, the volume of sample at each vertical varies according to the partial section discharge, and, except at the critical vertical, will almost always be less than the optimal 335 ml assumed in Figure 4.9. Therefore if Figure 4.9 is

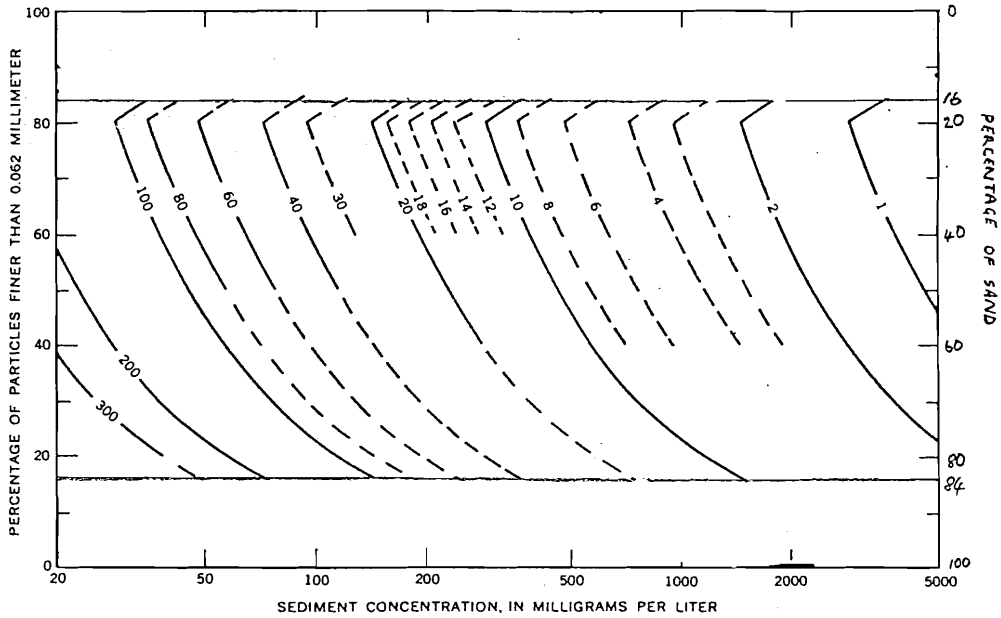


Figure 4.9 *Minimum number of pint bottles needed to yield sufficient sediment sample for size analysis, when using the EDI method. Modified from Porterfield (1972). Note that where the % sand exceeds 84%, assume that the % sand equals 84%. Likewise, where the % sand is less than 16 %, assume that it equals 16 %.*

Analysis	Size range (mm)	Desirable minimum quantity of sediment (g)
Sieves:		
Fine	0.062 - 0.5	0.07
Medium	.25 - 2	.5
Coarse	1.0 - 16	20
VA tube:		
Smallest	.062 - .5	.05
Largest	.062 - 2	5
Pipette	.002 - .062	.8[a]
BW tube	.002 - .062	.5[a]

[a]Double the quantities shown if both native and dispersed media are required.

Table 4.1 *Minimum masses of suspended sediment required for various size analyses. From Guy and Norman (1970).*

used, the indicated number of bottles should be increased by a factor of at least 1.5 to compensate.

The number of samples to be collected at each vertical is found by dividing the total number of samples (from Figure 4.9) by the number of verticals. Note that to ensure valid bulking, the same number of samples must be collected from each vertical. For example, if at one vertical a point sampler is required to be used in one-way or partial-depth mode requiring the collection of two or more samples, then the same number of samples would need to be collected from every vertical.

4.3.11 Using the field computer program

The program SEDGAUGE can be used to determine the number and location of sampling verticals, the best sampler and nozzle size, the mode of operation of a point sampler, and the permissible and optimal ranges of transit times and rates for depth-integration. An MS-DOS version can be run on portable or desk-top PC's and covers both EDI and EWI methods. Details of PC SEDGAUGE, plus supporting utilities, are given in Appendix C. A version for the PSION hand-held computer covers only the EDI method.

Both PC and Psion versions use distance-depth-velocity information from a preceding current-meter gauging. On the PC version, this is input via an ASCII file (an example format is shown in Figure 4.10). This file may either be prepared with a text editor or it can be created as an optional output from the GAUGE program using the CGAUGE /V process (this creates a file named < <GAUGING NO. > >.VEL). Also, with the PC version, there is the option of using a resource file of compressed data from previous flow gaugings in lieu of data from a "concurrent" flow gauging.

Additional information to be input (if available) includes estimates of the suspended load concentration, proportion of sand (i.e., coarser than 0.062 mm), and proportion coarser than 0.25 mm. This information is used to determine the number of samples required for particle-size analysis, to select the number of verticals, and to aid the selection of nozzles. The concentration estimate may be made visually, based on experience, or obtained from an existing sediment rating for the site knowing the discharge. If the proportion of sand is unknown, then it is assumed to be 50%, which is the average found in many New Zealand rivers. If the proportion coarser than 0.25

mm is unknown, this is assumed equal to zero. If the concentration is unknown, SEDGAUGE assumes one pint-bottle sample per vertical is adequate for particle-size analysis.

Inputting a non-zero value for the "stage rise since the current meter gauging" will add that value to the depths used from the current meter gauging. Stage falls should be entered as negative "rises". SEDGAUGE assumes that while the depths may change a little since the current meter gauging, the velocities remain unchanged.

PC SEDGAUGE will recommend an appropriate number of sampling verticals. If using the EDI method this recommendation is based on the V2/D index and Jordan's nomograph (see section 4.3.3). If using the EWI method the recommendation is based on the requirement that the critical partial section carries no more than 20% of the flow. The final selection of the number of verticals is left to the operator.

Psion SEDGAUGE relies upon operator selection of the number of verticals.

Both versions of SEDGAUGE then suggest the most appropriate sampler-nozzle-operating mode combination for the critical (i.e. the deepest, fastest) vertical, and display the necessary sampling times and transit rates. If it is necessary to use a point sampler in partial-depth mode, the required number of partial-depth segments is displayed. SEDGAUGE permits some opportunity to alter the sampler type, nozzle size, or mode of using a P-61 (point) sampler; however, it will not allow a result if a sampler/nozzle combination is attempted that would induce a biased sample.

Once the sampling requirements for the critical vertical have been decided, SEDGAUGE then sequentially displays for each sampling vertical the horizontal distance and suggests the required transit times and rates (and, if necessary, partial-depth intervals) using the same sampling combination as selected for the critical vertical. At this stage, (EDI method only) the option is available to alter the nozzle size for depth-integrating samplers or the mode of operation of a P61 (or P-72), but not the type of sampler (swapping samplers between verticals is not recommended - particularly on cableways!). As before, a sampler/nozzle combination that would induce a biased sample is not permitted.

```
Gauging 12345 39589 86093 173000 06 -1 -1 1.5 477 0 L 83200
7          0          0
8          0.17       0.86
10         0.24       1.20
12         0.30       1.46
15         0.35       1.79
.          .          .
.                     .
.          .          .
69         0.11       0.5
72         0          0.2
```

Figure 4.10 *Example format of ASCII input file required by SEDGAUGE. The first line is a descriptive header and can be up to 80 characters long. Subsequent lines list the distance (m), depth (m), and velocity (m/s), for each vertical in free format (i.e. any number of blanks or a tab between items). Note that decimal points should never be entered "bare", e.g. enter 0.11, not .11.*

Note that the transit rates recommended by SEDGAUGE assume no vertical angle deflection. If there is a significant deflection, then the apparent transit rate should be increased appropriately (see section 4.3.7).

The information supplied by SEDGAUGE should be transferred to the sediment record form before sampling commences.

4.4. Procedure at each vertical

4.4.1 Testing seals

The sealing of the mouth of the bottle against the head of the sampler is crucial to correct sampling. A poor seal can result from the neoprene gasket in the sampler head becoming lost, worn, damaged or compressed, or from a bottle being of an incorrect length or shape.

The "blow test" is fast and simple:

- install a bottle in the sampler and close the head
- press a finger firmly against the orifice of the air exhaust to close it off
- if a point sampler, operate the solenoid to open the valve and hold it open
- blow into the nozzle of the sampler (use a short length of plastic or rubber tubing, especially if it is a point sampler)
- listen for escaping air; if heard or felt, investigate the leak by replacing the gasket or bottle.

Carry out this test at the beginning of each sample run or whenever a different type of bottle is used.

4.4.2 Loading and unloading bottles

The pertinent points are:

- all bottles shall be clearly identified with a unique number
- for convenience, and to reduce testing of seals, preferably sort bottles so the same type is used for each run
- inspect bottles for cleanliness prior to use; reject any which appear dirty - these shall be washed with detergent and a brush
- insert bottles into the sampler and close the head, ensuring that the mouth is in contact with the sealing gasket
- note bottle number against the appropriate vertical as the bottle is loaded
- keep the bung or screw-cap clean and secure whilst sampling is carried out, and replace securely as soon as the bottle is unloaded
- unload the bottle whilst tilting the sampler slightly tail-downward, to avoid spilling
- keep bottles upright in a secure case during transport and storage.

4.4.3 Lowering and raising

(a) Depth-integrating samplers

- lower the sampler to just above the water surface
- with cable-suspended samplers, observe the reel counter and alter the zero if necessary
- with the sampler pointing upstream, begin the integration by lowering to the bed at the calculated transit rate; ensure that the transit rate is constant
- when the sampler touches the streambed (or at just above the sounded depth if the bed is soft), immediately reverse direction; note the elapsed time against $^1/_2$ of that calculated and decide if the upward transit rate needs to be faster or slower to ensure that the desired filling time is achieved
- continue raising the sampler to above water level and check whether water is spurting out of the nozzle; if so, the bottle is overfilled and the sample shall be discarded and repeated.

(b) One-way integration using a point sampler

- lower the sampler to just above the water surface
- observe the reel counter and alter the zero if necessary
- lower the sampler to the streambed keeping the solenoid closed, and note the depth to the bed
- begin raising the sampler using the appropriate constant transit rate, opening the solenoid valve at the same time
- raise the sampler to above water level and check whether water is spurting out of the nozzle; if so, the bottle is overfilled and the sample shall be discarded and repeated
- close the solenoid and raise the sampler
- unload the bottle and check its volume
- repeat the procedure at this vertical, sampling from the water surface to the bottom.

(c) Partial-depth integration

- determine the number of partial depths required in the vertical by dividing the depth into segments small enough to be within the operating range of the P-61 sampler in one-way mode; usually, two segments should be sufficient
- determine the required filling time for the surface section; then use this time for all sections in the vertical
- for each section, lower the sampler to the required starting depth, checking the zero of the reel counter on the way, and keeping the solenoid closed
- open the solenoid and traverse to the stopping depth over the required time and close again
- raise the sampler fully

- before opening, open the solenoid valve briefly to check whether water spurts out of the nozzle; if so the bottle is overfilled and the sample shall be discarded and repeated
- take a second sample at each partial-depth, traversing in the opposite direction.

4.4.4 Checking samples

Samples shall be checked for:

- overfilling; if water spurts out of the sampler nozzle when above the surface following sampling (and with the solenoid open on point samplers), or if the bottle is filled to higher than 70 mm from the top, then it shall be discarded and repeated (at a faster transit rate, if this is permissible)
- underfilling; for the required precision in analysis a sample of more than 250 ml is required - this corresponds to a depth of 70 mm in the standard bottle (the EWI method is exempt from this requirement since even though quite small samples may be collected at some verticals, the samples are composited (bulked) for analysis)
- large particles and extraneous matter; if any particles larger than 2 mm or any matter which is not sediment or water (e.g. organic debris) is present, the sample shall be discarded and repeated, possibly to a slightly higher distance above the bed.
- obviously higher sand content than other samples; this would suggest that the sampler has dipped into the bed - discard and repeat as above.

4.4.5 Compositing samples

Samples will be composited (bulked) in three circumstances:

- for all EWI gaugings
- when collecting for particle-size analysis with the EDI method
- when using point-integrating samplers in one-way or partial-depth modes with the EDI method

The samples should be transferred from the glass sampler bottle into a larger plastic container (such as a two litre milk bottle). Care should be taken that sand grains that have settled to the bottom of the glass bottle are transferred. Use the following procedure:

- inspect the sample in the glass bottle to check for overfilling or excessive sand, etc., and discard if there is any concern with its integrity
- swirl the bottle and transfer most of the sample to the compositing bottle
- swirl again and transfer the remainder
- inspect the glass bottle for remaining sediment grains - flush these with a graduated wash bottle of distilled water
- record on the record form the volume of water added from the wash bottle to each compositing bottle (to the nearest 5 ml).

4.4.6 Labelling

Each non-disposable sample bottle in use by Environmental Data shall be indelibly marked with a unique number. Numbering systems in existence usually have one or two letters preceding a numeric sequence. Numbered bottles can continue with their present numbers where such numbers are likely to be unique, but new bottles or those which require renumbering should be done in an alphanumeric sequence using a letter code identifying the team which owns them or is marking them. This will probably require teams to keep a register of numbers used. With at least some analyses being done at only one laboratory, it is important that this be followed.

Any un-numbered bottles used in the field should be marked with a temporary number using the initials of the person doing it, and assigned a sequential number at a convenient time.

A separate labelling system, including site and date, should be used for disposable bottles. If these are re-used, the labelling should be fully erased.

4.5. Sampling in high velocities

In high velocities, the downstream deflection of the sampler can cause problems in similar ways to suspended current meters. The 62 lb D-49 or D-74 samplers will certainly be deflected more than, say, the 100 lb Colombus weights, but this may be coped with by one of the following options:

- using a backstay if one is available
- the addition of a suitable Colombus weight above the sampler, provided it is an adequate distance above the sampler (say 0.4 m) to avoid disturbance of the streamlines around it

NOTE: A special hanger bar will be required for this; they can be obtained from NIWA Kainga.

- replacing a D-49 or D-74 with the heavier P-61 and carrying out one-way or two-way integration.

If necessary, follow the procedure given in Section 4.3.7 for optimising the transit rate to take account of the effect of vertical angle on the observed depth.

4.6. Record form

The one form is used to log field, summarised laboratory and office results. Field requirements are as follows:

- note on the record form the initial information regarding sampler type, nozzle size, method to locate verticals (usually EDI), etc; note the time and stage details at the beginning of sampling

- the pre-determined velocities, depths, transit rates and times shall all be noted on the record form for each vertical as a guide for the actual sampling
- continue to fill out the record form as samples are collected, noting bottle number, actual transit time and any comments
- note the time and stage when sampling is completed.

An example record form, for a typical EDI gauging, is shown in Figure 4.11. More examples, completed for various sampling options, are included in Appendix B.

4.7. Supporting data

The following items are required to assist in the interpretation of the suspended sediment data:

4.7.1 Slope

Where practical, the slope of the sampled reach should be measured in a similar manner to that required for slope-area gauging as outlined in the WRS Field Manual (Fenwick, 1991). Staff gauges should be set up at those sites selected (on the grounds of practicality) for slope measurements, and their readings recorded at the beginning and end of the sampling.

4.7.2 Temperature

The water temperature shall be measured during the associated flow gauging, using the techniques and equipment given in Fenwick (1991). The reading shall be recorded on the flow gauging record form (WS 4 or WS 4A).

4.7.3 Bed observations and comments

Comments are required for all instances of unusual phenomena or non-standard techniques or equipment. Possible examples will include:

- observing bed material moving in dunes or hearing boulders moving
- an inability to carry out sampling according to the prescribed techniques due to conditions or equipment failure
- notable or unusual sediment sources evident in the catchment or the river channel.

4.8. Final checks

On completion of sampling and prior to disassembly of equipment:

- check that the record form is complete in every respect insofar as the field section is concerned
- sign this section of the form, certifying it as correct and complete; under the Survey's QA procedures this is an essential part, and forms should not be accepted from anyone who does not carry out this step.

At the successive steps as listed in the certification box on the form, the person carrying out each step in the process shall initial and date the step, certifying that it is complete and correct.

4.9. Forwarding samples for analysis

Samples shall be forwarded to nominated laboratories for analysis whenever a full batch of twenty or more bottles have accumulated, but within no more than six weeks of the date of collection. Fill out the Suspended Sediment Analysis Form SSL to accompany the samples and to inform the lab. on the source of the samples, the analyses required, and to whom to send the results.

Where there is a likelihood of significant algae concentration in the samples (see below), they should be dispatched within a few days.

Note that only laboratories with approved methods shall be used; information on these will be provided from time to time.

4.10. Storage of samples

Storing samples for any period of time may cause problems due to the growth of algae in the water. This may have a small effect on the analysis results, but a more serious effect on the analysis process if the algae cause premature blockage of the filters during filtration. With most samples taken during floods this is unlikely to be a problem due to the dilution effect of the floodwaters on the normal algal load of the stream. However there will be same instances where this could be a problem, and the following safeguards should be taken:

- samples should be stored in the dark and kept cool, ideally in a refrigerator
- samples should be sent to the laboratory at the earliest opportunity, and any samples likely to have significant algae concentration should be brought to the notice of laboratory staff
- a preservative may be added, such as mercuric chloride (add 0.5 ml of 3 % mercuric chloride to each 250 ml of sample to give 40 - 60 ppm); this will normally be done only by the laboratory.

Suspended Sediment Gauging Record Form

Form SSR 930629

FIELD

Date 14.4.93

River Waiau at Marble Pt. Site no. 64602 Party Fenwick Hicks Lwin

Accompanying Gauging No. 120892 Gauged water discharge 57494 l/s

V^2/D index (if used) — % sand (est.) 50 % sand coarser than 0.25 mm (est.) 0 %

Sampler type SS DH-48 48 /D-49 49 /D-74 74 /D-77 77/P-61 61 / P-72 72 /Bucket or bottle 99

Nozzle N: 3.2 3 /4.8 4 /6.4 6 /7.9 7 Container C: pint1/quart2/3l bottle3/3l bag4

METHOD CODE (9 digits) SSNCInnMF = 494120511 5

Integration mode I (at crit. vert) surface0 /1-way1 /2-way2 /part. depth3 /point integ.4

Verticals: No Verticals nn. 05 Selection Method M: EDI1/EWI2/Single vert.3/Other4

Flow data source F: gauging 1 /resource file 2 / table 3 / none 4

Particle Size Estimated conc.: 200 mg/l Bottles per vertical: 1

Time of start. 1400 NZST Slope reach SG 1 start — m SG 2 start — m Slope Reach length — m

Vertical No.	Gauging distance from initial point Distance (m)	Mean v at vertical $\bar{v}$ (m/s)	Depth at vertical D (m)	Min. allowable transit time T_{min} (s)	Optimum transit time T_{opt} (s)	Optimum transit rate R (m/s, r/s, s/r)	Bottle No.	Actual transit time T_{act} (s)	Give details of any compositing & amounts of washing water (also write the latter on bottle) Comment	Laboratory results: Net mass of sediment Mass (mg)	Laboratory results: Net volume of sample Vol. (ml)	Laboratory results: Sample conc. (mass/vol. x 1000) Conc (mg/l)
1	21.6	1.66	1.40	6	11 E1	1.3	G1	11.2				
2	27.1	1.47	1.53	7	13 E1	1.3	M50	12.5				
3	31.2	1.66	2.24	8	11	0.8	WR1	10.5				
4 crit. v.	34.1	1.39	2.87	11	13	0.7	WR2	12.4				
5	36.9	1.20	3.02	14	16	0.8	M60	18				
					Σ		No. of bottles n_b	Σ		Σ	Σ	

Time at end of sampling 1440 NZST Staff gauge 1 at end — m SG 2 at end — m

Comments:

Figure 4.11 *An example of a suspended sediment gauging record form, completed with the required field information.*

5. Laboratory Procedures

These procedures cover the analyses to be done on samples for both total suspended solids and particle-size measurement.

Quality assurance requirements will probably dictate that analyses are carried out at only one or two laboratories which can attain third-party QA accreditation or registration.

5.1. Concentration (total suspended solids)

The two most commonly-used methods for determining suspended sediment concentration are evaporation and filtration. Each has advantages and disadvantages (Guy, 1969).

With the evaporation method,

- an adjustment will be required for dissolved solids if the dissolved solids content is high, especially for samples having low sediment concentration
- the equipment and technique are simple
- the ratio of sample mass to tare mass is small, which produces less precision in the weighing operations
- with a significant amount of clay material, the settling time may make the method impractical.

With the filtration method,

- it is usually faster for samples of low concentration
- clogging of filters resulting in prolonged filtration is a problem for higher concentrations; practical limits suggested (Guy, 1969) are 10,000 mg/l of sediment which is mostly sand, and 200 mg/l of sediment which is mostly clay; the use of multiple filters will extend this, however
- high concentrations of dissolved material coupled with prolonged filtration may produce high results owing to excessive solids capture on the clogged filter (APHA, 1989), and may require thorough washing with distilled water to ensure removal of the dissolved material
- because excessive residue on the filter may form a water-entrapping crust, the sample size may need to be limited to that yielding no more than 200 mg of residue (APHA, 1989); this may entail sample splitting which is undesirable due to the uncertainties involved
- there is greater risk of loss of material from either passing through the filter or from its surface during handling for drying and weighing.

The ISO Standard ISO 4365 - 1985 outlines some of these factors, but gives no guidelines for the choice of methods, suggesting each case be judged on its merits.

Similarly, for Environmental Data's work it is recommended that:

- the filtration method should generally be used, unless samples are of such high concentration that filtration requires excessive times and/or use of multiple filters
- where samples are of such a high clay/fine particulate content that settling of the material to allow decanting will not occur in a reasonable time, the evaporation method will not be practical
- where the samples may have a high dissolved material content (dissolved material is in the order of 25 % of suspended solids) and/or a significant proportion of the sample's water (> 10 %) is evaporated during analysis, the evaporation method should not be used unless a correction is made for the inclusion of the dissolved material in the residue; an approximate method for this correction is given in 5.1.2.

5.1.1 Filtration method

This procedure follows that for "Total Suspended Solids Dried at 103 - 105 °C", method 2540 D of the American Public Health Association (1989), which is to be used as the standard.

Apparatus

The following items will be required:

- an analytical balance capable of resolution to 0.0001 g, and traceably calibrated against National Standards
- a top-weighing balance capable of resolution to 0.1 g or better, traceably calibrated against National Standards
- filtration units consisting of a sample reservoir (100 ml + capacity), a base to accommodate and adequately support glass-fibre filter papers of an appropriate diameter (normally 47 mm), and a suction flask combined with a sample reservoir (preferably of at least 400 ml capacity)
- a vacuum pump and system capable of supplying vacuum of at least 25 mm of mercury but no more than 38 mm to the filtration units
- filter papers, Whatman GF/C glass-fibre, pore size 1.2 microns, 47 mm diameter
- drying oven set to operate at 104°C + 1°C
- desiccator and freshly dried desiccant of a type which indicates moisture content
- planchets of aluminium foil of as light a weight as practical to provide greater precision in weighing. They shall be marked with identification numbers by scribing rather than marking pen, as the latter is prone to be lost on heating
- wash bottle of distilled water.

Procedure

(a) Preparation of glass-fibre filter paper:

- insert the paper with wrinkled side up in the filtration unit, using blunt-nosed tweezers

- apply vacuum and wash it with 3 successive 20 ml portions of distilled water (at least)
- continue suction to remove all traces of water
- release vacuum and remove filter, transferring it to a numbered planchet as a support
- dry in an oven at 103 to 105 °C for one hour
- transfer to desiccator to cool
- remove one planchet at a time from the desiccator and weigh to nearest 0.0001 g, recording this against the identification number
- repeat the cycle of drying, cooling and weighing until a constant weight is obtained, or until the weight loss is less than 0.0005 g between successive weighings
- store in desiccator until needed, but weigh immediately before use.

(b) Sample analysis

- shake each sample bottle to thoroughly mobilise all of the solids, and remove stoppers
- weigh each sample bottle plus contents but minus stoppers (unless these have positive numbering to match the bottle numbers), and record the weight to the nearest 0.1 g (ensure that the exteriors of the bottles are clean and dry.)
- assemble the filtration unit with the weighed filter, positively identifying each filter with its numbered planchet
- apply vacuum slowly (maximum of 38 mm Hg) and wet the filter with a small volume of distilled water from a wash bottle
- pour an aliquot of sample into the filtration unit(s)
- add further aliquots until all the sample has been dispensed, or the filter has become clogged
- if clogging occurs, dispense the remainder of the sample into a second filtration unit (or more if necessary), complete with a new filter paper prepared as above
- as necessary, when dealing with bulked or large samples, empty the suction flask
- when all the sample has been dispensed into each filter, wash with at least three successive 10 ml volumes of distilled water
- carefully remove the filter and transfer to its numbered planchet
- dry for at least one hour at 103 to 105 °C, cool in the desiccator to ambient temperature, and weigh
- repeat the cycle of drying, cooling and weighing until a constant weight is obtained or until the weight loss is less than 4 % of the previous weight or 0.0005 g, whichever is the less
- record the final weight on the result sheet
- wash, dry and weigh the empty bottle.

(c) Calculation

- Calculate the net volume of the sample by the formula

$$V = \frac{M_{ns} - v_w}{D_t}$$

where M_{ns} = net weight of sample (bottle weight full - bottle wt. empty) g

v_w = volume of any distilled water used for washing added in the laboratory, in ml (equivalent to g)

and D_t = density of the total sample (from table in Appendix F)

- calculate the net mass of sediment from the weights of the filter before and after the filtration, drying and cooling processes
- provide these data for each sample to the field office for entry onto the original Gauging Record Form and subsequent calculation and archiving.

5.1.2 Evaporation method

This procedure follows that for "Total Solids Dried at 103 - 105 °C", method 2540 B of the American Public Health Association (1989) which is to be used as the standard. However the provision in 2540 B for sub-sampling (i.e. only analysing a portion of the collected sample) is not allowable at present.

Note: At present NIWA has no approved methods for sub-sampling suspended sediment samples. A number of methods employed overseas will be investigated for their application in NZ.

Apparatus

The following items will be required:

- an analytical balance capable of resolution to 0.0001 g, and traceably calibrated against National Standards
- a top-weighing balance capable of resolution to 0.1 g or better, traceably calibrated against National Standards
- evaporating dishes of at least 100 ml capacity, made of either porcelain, platinum or high-silica glass
- a drying oven set to operate at 104°C + 1°C
- desiccator and freshly dried desiccant of a type which indicates moisture content
- wash bottle of distilled water.
- conductivity meter
- measuring cylinder of 500 ml capacity

Procedure

(a) Preparation of evaporating dishes

- heat clean evaporating dishes to 103 to 105 °C for 1 hour
- store dish in desiccator until needed
- weigh immediately before use

(b) Sample analysis

- weigh each sample bottle plus contents but minus stoppers (unless these have positive numbering to match the bottle numbers), and record the weight to the nearest 0.1 g (ensure that the exteriors of the bottles are clean and dry.)
- allow the sample to stand until suspended material settles to the bottom and the upper water is perfectly clear
- gently decant off the upper clear water (supernatant) into the measuring cylinder leaving a sample volume less than 100 ml if possible without removing fine sediment
- measure the conductivity of the supernatant water to determine whether a correction for dissolved material is required (see calculation section below)
- measure the volume of the supernatant
- transfer the sample from the bottle to a pre-weighed evaporating dish, rinsing the adhering sediment out with distilled water from a wash bottle
- evaporate the sample to dryness in the drying oven, which should have its temperature lowered to approximately 2°C below boiling to prevent splattering
- if necessary add successive sample portions to the same dish after evaporation
- dry the evaporated sample for at least 1 hour in the oven at 103 to 105 °C
- cool the dish in the desiccator to room temperature
- weigh
- repeat the cycle of drying, cooling, desiccating and weighing until a constant weight is obtained, or until weight loss is less than 4 % of previous weight or 0.5 mg, whichever is less
- record the final weight on the result sheet.

(c) Calculation

- Calculate the net volume of the sample by the formula

$$V = \frac{M_{ns} - v_w}{\overline{D_t}}$$

where M_{ns} = net weight of sample (bottle weight full - bottle wt. empty) g

v_w = volume of any distilled water used for washing added in the laboratory, in ml (equivalent to g)

and D_t = density of the total sample (from table in Appendix F)

- calculate the mass of sediment from the weights of the evaporation dish before and after the evaporation, drying and cooling processes
- calculate the net mass of sediment by subtracting the mass of dissolved load, M_{ds}, which is derived using the equation

$$M_{ds} = 0.7\ L\ (V_t - V_{sn}) \quad [1]$$

where L = specific conductance (25 °C) in micro-siemens/cm

1 The correction factor of 0.7 is considered to be conservative for the purposes of suspended sediment determination, and is derived from Hem (1970).

V_t = total sample volume before decanting

V_{sn} = volume of supernatant water decanted off

- provide these data for each sample to the field office for entry onto the original Gauging Record Form and subsequent calculation and archiving.

5.2. Particle size

Various standard methods are suitable, ranging from using the pipette or bottom withdrawal tube for analysis of the silt/clay fraction and wet sieving for the sand fraction, to sophisticated instrumentation such as laser granulometers.

Since this work will be undertaken at only a few specialised laboratories, details of the methods are not given here.

5.3. Reporting results

Raw data from the analyses will be recorded on the laboratory's own system and forms. Summarised data should be reported to the ED teams on the Suspended Sediment Laboratory Analysis Form SSL (see Appendix G) which accompanied the samples to the laboratory.

ED teams will transfer the pertinent summary results from the Laboratory Analysis Form (Form SSL) to the original Suspended Sediment Gauging Record Form for that gauging, in preparation for further calculations and archiving as described in Chapter 6.

6. Office Procedures

For processing a single suspended sediment gauging, carry out the following procedures:

6.1. Laboratory data transfer

The concentration and particle-size analysis results, when returned from the laboratory, should be copied onto the individual gauging record form. The lab. report sheet(s) should be stapled to the back of the record form.

6.2. Calculations

A number of results need to be calculated and added to the record form:

(a) Concentration

The concentration is the mass of dry sediment in the sample divided by the sample volume. Concentrations at individual verticals should be determined and entered onto the record form. Note that the sample volumes measured in the laboratory should first be corrected for any washings added when bulking.

With the Equal-Discharge-Increment method of locating sampling verticals, the discharge-weighted mean concentration for the whole section, C_m, simply equals the arithmetic mean of the concentrations of the n individual samples, thus

$$C_m = \sum C_i / n$$

(this also equals $\frac{\sum M_i}{\sum V_i}$, because in this case, all the V_i's are the same)

- where C_i, M_i, and V_i are the concentration, mass and volume of each individual sample.

With the EWI method, the discharge-weighted mean concentration is found by summing the total mass of sediment and total volume of sample

$$C_m = \frac{\sum M_i}{\sum V_i}$$

Where samples are bulked, C_m simply equals the concentration of the bulked sample.

(b) Standard deviation

The standard deviation of the concentration, s_c, which indicates the cross-channel variation in concentration is calculated as

$$s_c = (\sum (C_i - C_m)^2 / (n - 1))^{0.5}$$

Note: It may be calculated easily by using the statistical function on a scientific calculator; input the concentration values as data, and press the s (or σ_{n-1}) key.

(c) Water discharge

The water discharge at the mid-time of the sediment sampling should be found using the current rating. This may not always equal the water discharge measured during a preceding current-meter gauging. Any adjustments to the rating based on the latest gauging should be made beforehand.

(d) Slope

Whenever two or more staff gauges have been read, the water surface slope should be calculated as the average of the slopes at the beginning and at the end of the sediment gauging.

6.3. Quality control checks

The average volume of all the samples is used as a quality control check on bottle-filling volume. The average ratio of the actual transit time, T_{act}, to the theoretically-predicted optimal transit time, T_{opt}, provides a check for over-rapid transit rates. Viewed together, these two checks can indicate improper sampler function or operation. For example, low average sample volume with T_{act} / T_{opt} = 100% suggests that the sampler nozzle was damaged and not sampling isokinetically. Exclude samples collected for particle size analysis.

Thus for the quality control checks the following steps shall be carried out:

- total up and average the values in the columns of T_{opt} and T_{act}
- calculate the transit time accuracy, TA, in the "Office" section of the card
- all information on the record form shall be checked and signed off (this is essential).

Appendix B shows examples of completed and checked record forms.

6.4. Archiving results

Sediment gauging information is to be stored on the TIDEDA archive as 15-item kind INSTANT records. All of the results in fields 1 to 15 on the completed result card would then be archived, together with any comments. The sediment information will use the same site number as the matching water-level and flow gauging information, but will be archived in its own sub-directory, SEDIMENT. Care must be taken that these sediment records are not confused or mixed with GAUGINGS records for flow gaugings, or with water quality data, which are archived in other sub-directories.

The time at which a sediment gauging is filed shall be the mid-time of the sediment gauging.

Any unmeasured values shall be filed with values of -1 to differentiate them from values of zero.

The 15 series items are:

1 Cm (mg/l) - discharge-weighted mean concentration

2 s_c (mg/l) - standard deviation of the concentration

3 Q (l/s) - discharge at the mid-time of the sediment gauging

4 Slope (mm/km) - mean water surface slope over the time of the sediment gauging

5 Method code - a 9-digit number; numbers 1 and 2 indicate the sampler type, digit 3 indicates the nozzle size (at the critical vertical, if different nozzles were used), digit 4 indicates the sample container, digit 5 indicates the sediment gauging method, digits 6 and 7 indicate the number of sampling verticals, digit 8 indicates the vertical locating method and digit 9 indicates the source of the flow data used for the sediment gauging.

Code values are given in Table 6.1 and on the record form.

Example: A code of 494120512 indicates use of a D-49 sampler with a 4.8 mm nozzle, a pint bottle, 2-way depth integration and 5 verticals located by the equal-discharge-increment method, and at which one-way depth integration was used; and data was derived from a resource file to design the sediment gauging.

6 Quality control code - an 8-digit number; digits 1 to 4 show the average sample volume in ml, digits 5 to 7 give the transit time accuracy as a %, and digit 8 will equal 1 if comments are filed for that gauging, otherwise it should be 0.

Example: A code of 03501101 indicates an average sample volume of 350 ml, a transit ratio of 110 %, and a comment is filed for this gauging.

7 Cumulative % of sample finer than 0.004 mm.

8 " " " " " 0.016 mm

9 " " " " " 0.031 mm

10 " " " " " 0.063 mm

11 " " " " " 0.125 mm

12 " " " " " 0.25 mm

13 " " " " " 0.5 mm

14 " " " " " 1.0 mm

15 Particle-size method code - a 2-digit number; digit 1 indicates the method used to analyse the silt and clay fractions, digit 2 indicates the method used to analyse the sand fraction. Table 6.2 gives the code values, as does the record form.

Example: A code of 21 indicates that the fine fractions were analysed by the pipette method, while the sand was wet-sieved.

Any comments (e.g. describing how field procedures may have deviated from standard procedures) should be added to the COMMENTS file.

1,2		3		4		5		6,7	8		9	
Sampler	Code	Nozzle	Code	Container	Code	Sed. Gauging method	Code	No. verticals	Locating method	Code	Flow data source	Code
DH-48	48	3.2 mm	3	Pint	1	Surface	0	e.g. 05	EDI	1	gauging	1
D-49	49	4.8 mm	4	Quart	2	1-way DI	1		EWI	2	res. file	2
D-74	74	6.4 mm	6	3 l bottle	3	2-way DI	2		single vert.	3	table	3
P-61	61			3 l bag	4	Partial depth	3		Other	4	none	4
Bucket	99			Other	5	Point integration	4					

Table 6.1 *Values for the 9-digit method code; numbers 1 and 2 indicate the sampler type, digit 3 indicates the nozzle size, digit 4 indicates the sample container, digit 5 indicates the sediment gauging method , digits 6 and 7 indicate the number of sampling verticals, digit 8 indicates the vertical locating method and digit 9 gives the source of flow data.*

Method	Code
Pipette	1
Bottom withdrawal tube	2
R.S.A.	3
Wet sieving	4
Laser diffraction	5

Table 6.2 *Values for the 2-digit particle-size analysis method code; digit 1 indicates the method used to analyse the silt and clay fractions, and digit 2 the sand fraction.*

7. Site Management Procedures

As sites in the suspended sediment programme are normally flow measurement stations also, the site details required will be relatively minimal. The data collected each year will be reviewed in the context of the total sediment data for that site, using an annual data review procedure.

7.1. Site Profile

This form records the on-site details such as levels and distances between staff gauges on the slope reach, the water-level records available, etc., and outlines the sediment data requirements at the site.

An example form, filled in for a hypothetical site, is shown as Figure 7.1.

7.2. Annual Data Reviews

Annual Data Reviews (ADR's) should be prepared for every active site in the sediment sampling network at the end of each year. One copy should be kept at the field party office and another sent to the study management team. Field teams should use the ADR's to plan their sampling strategies at each site for the coming year. A file of ADR's should be accumulated as the years progress. An ADR consists of

- a listing of all sediment gaugings for the site
- a page of plots
- a summary page

The task of preparing the ADR's involves listing the data-to-hand, running the automated plotting procedure (as detailed in Appendix D), interpreting the plots, and completing the summary page.

7.2.1 Data Preparation

Suspended sediment data collected since 1 July 1992 should be archived as 15-item kind INSTANT files under the same site number but in a different directory or file than are the stage, ratings, and gaugings data for the same site - as explained in section 6.4. Older sediment concentration data, archived in the traditional fashion as item 10 on GAUGINGS files, should be merged with the new format data following the procedure set out in Appendix D.

NIWA Environmental Data

Suspended Sediment Site Profile Form SSP 930630

On Heron River at Port Adventure Station, Site No. 9433721

Data collection agency: ED - Oban

Sediment network(s): NHRN

National flood gauging

Overall data collection objectives at site: Long-term average yield and size distribution using rating method; at least 30 gaugings, 6 with particle-size method

Specific requirements

Suspended sediment gauging: Annual target: 6 gaugings; all above 1.5m stage / 42 m³/s

Techniques: (EDI)/EWI/

Susp. Sediment particle size:

Annual target 2 gaugings > 500 mg/l

Automatic sampling

(periods covered) 1/12/92 – 3/4/93

Auto sampler type and triggering Manning - CR10 triggers at adjustable stages

Turbidimeter

(periods covered) 6/4/93 to

Type Lange in-situ probe

Bed material

Wolman sampling Done 14/3/93 D_{50} = 121 mm

Bulk sampling Required

Slope

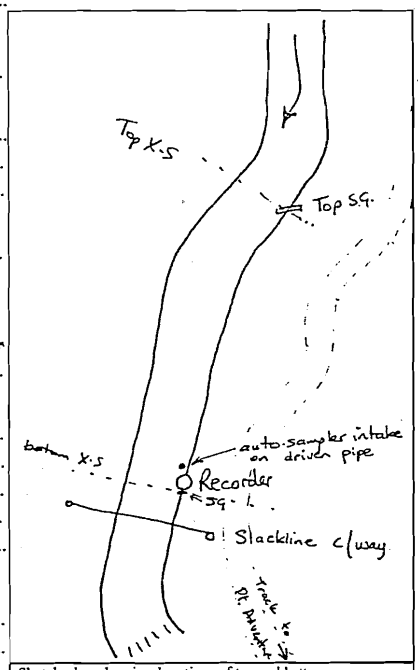
Location of reach Top SG: 157 m upstr. rec Bottom: use recorder

Water-level measured at top site by SG

at bottom site by Recorder & SG

Distance between 157 m, measured by tagline

Comments



Sketch plan showing locations of top and bottom cross-sections, distances, gauging site, recorder, auto sampler intake, etc.

Compiled by DKF (initials) on 12:5:93 (date)

Sent to sediment project leader (M. Hicks) on 12:5:93 (date) by DKF (init's.)

Figure 7.1. *An example of a sediment site profile form, filled in for a hypothetical site to demonstrate the various options available.*

7.2.2 Listing Data-to-hand

The TIDEDA LIST process should be used to produce a hard-copy listing of all the available sediment gauging data.

7.2.3 Automated Plotting Procedure

A package of utility programs, TIDEDA PSIM routines, and TIDEDA plot routines linked by TIDEDA script files is used to produce a one-page plot summarising the

suspended sediment data on-hand for a site. The instructions in Appendix D for producing these plots should be followed closely.

7.2.4 Interpreting plots

The ADR plots should be used to help decide the optimal sampling strategy for the site in the coming year.

The ADR plots show sediment rating data (log sediment concentration vs. log water discharge) differentiated according to whether the samples were collected on rising or falling stages, by season and by whether particle size information was collected.

Also plotted is a time-series of the logarithm of the water discharge, with the sediment gaugings overlain to show how the sediment gaugings are distributed in time. An effort should be made to collect an approximately equal number of samples per year (flood flows permitting) - about 5-6 per year on average is the target. It also shows how many gaugings were done in the current year, and, possibly, what opportunities were missed. Thus if the site has had few sediment gaugings in the most recent year or two, then it should receive greater sampling efforts.

The last plot compares the proportions of the long-term sediment yield carried per discharge band (dotted line) with the number of sediment gaugings per band (dashed line).

Finally, a suspended sediment rating equation is listed, along with the average sediment yield over the analysis period, and the most effective flow at transporting sediment over that period.

A detailed guide to interpreting the ADR plots is provided in Appendix D.

7.2.5 Summary Page

Recommendations for sampling at the site in the coming year, based on these plot interpretations, should be listed in the appropriate space on the summary page. An example summary page is shown as Figure D.2; it should be completed as detailed in Appendix D. When assessing whether to continue sampling sediment at the site, the error on the sediment yield, the length of record, the number of sediment gaugings and their distribution in terms of rising/falling stage, season, time, and flow band, the number of samples analysed for particle-size analysis, and any severe logistical constraints should all be considered.

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Appendix A: Derivation of Operating Ranges for Samplers

This sets out the derivation of the diagram showing the operating ranges of suspended sediment sampler-nozzle combinations in Depth-Velocity space.

The operating limits are set as shown in Table A.1.

maximum sample volume, V:		
	pint bottle	370 ml
	quart bottle	740 ml
	3 l container	2700 ml
maximum practical velocity, v:		
		3.7 m/s for depth integration
		5 m/s for P-61/P-72
		5.5 m/s for D-77
maximum practical transit rate, R:		0.64 m/s (equal to 2 revs per second for an A-reel)
maximum ratio of transit rate to velocity, F:		0.4 for 6.4 and 4.8 mm nozzles,
		0.2 for 3.2 mm nozzle
		0.4 for 7.9 mm nozzle
maximum depth for depth-integrating samplers due to compression, D:		4.7 m.

Table A.1 *Operating limits used for deriving the operating ranges of samplers.*

Maximum practical transit rate limit ("arm strength limit"):

Sample volume , $V = v \frac{\pi d^2}{4} .T$

$$= v \frac{\pi d^2}{4} . \frac{nD}{R} \quad (1)$$

where n =2 for two-way traverse and n = 1 for one-way traverse

Thus $Dv \leq \frac{4V_{max} R_{max}}{n \pi d^2}$ (2)

Example: for depth-integrating sampler with 6.36 mm nozzle, $R_{max} = 0.64$, $V_{max} = 370$ ml, d = 6.36 mm, n = 2, then $Dv \leq 3.72$.

Transit rate/velocity ratio limit:

For 6.36 and 4.76 mm nozzles, $F = R/v \leq 0.4$

For 3.18 mm nozzle, $F = R/v \leq 0.2$

Substituting R = Fv in equation (2) yields

$$D = \leq \frac{4V_{max} \cdot F}{n \pi d^2} \quad (3)$$

Example: For one-way traverse with P-61 sampler, Vmax = 370 ml, d = 4.76 mm, F = 0.4, n = 1, then $D \leq 8.32$

In Figure A.1 the curved lines are where the operating limit is controlled by the maximum practical transit rate (i.e. 2 revs per second of an A-reel). The horizontal lines are where the limit is controlled by the transit rate/velocity ratio (streamline approach angle limit) or by the compression factor. The vertical lines indicate the maximum practical velocity for using the samplers.

Sampler / Container / Nozzle	F_{max}	D_{max} (m)	DV_{max} (m^2/s)	V_{max} (m/s)
D-49/D-74, pint bottle, 6.36 mm nozzle,	0.4	2.33	3.72	3.7
" 4.76 "	0.4	4.16	6.65	3.7
" 3.18 "	0.2	4.66	14.91	3.7
P-61, pint bottle, 2-way mode	0.4	4.16	6.65	5.0
" 1-way mode	0.4	8.32	13.3	5.0
P-61, quart bottle, 2-way mode	0.4	4.58	13.3	5.0
" 1-way mode	0.4	16.64	26.6	5.0
D-77 sampler with bag	0.4	10.90	17.6	5.5
" bottle	0.2	4.7	17.6	5.5

Table A.2 *Summary of the calculated operating limits of the various sampler-nozzle-mode combinations.*

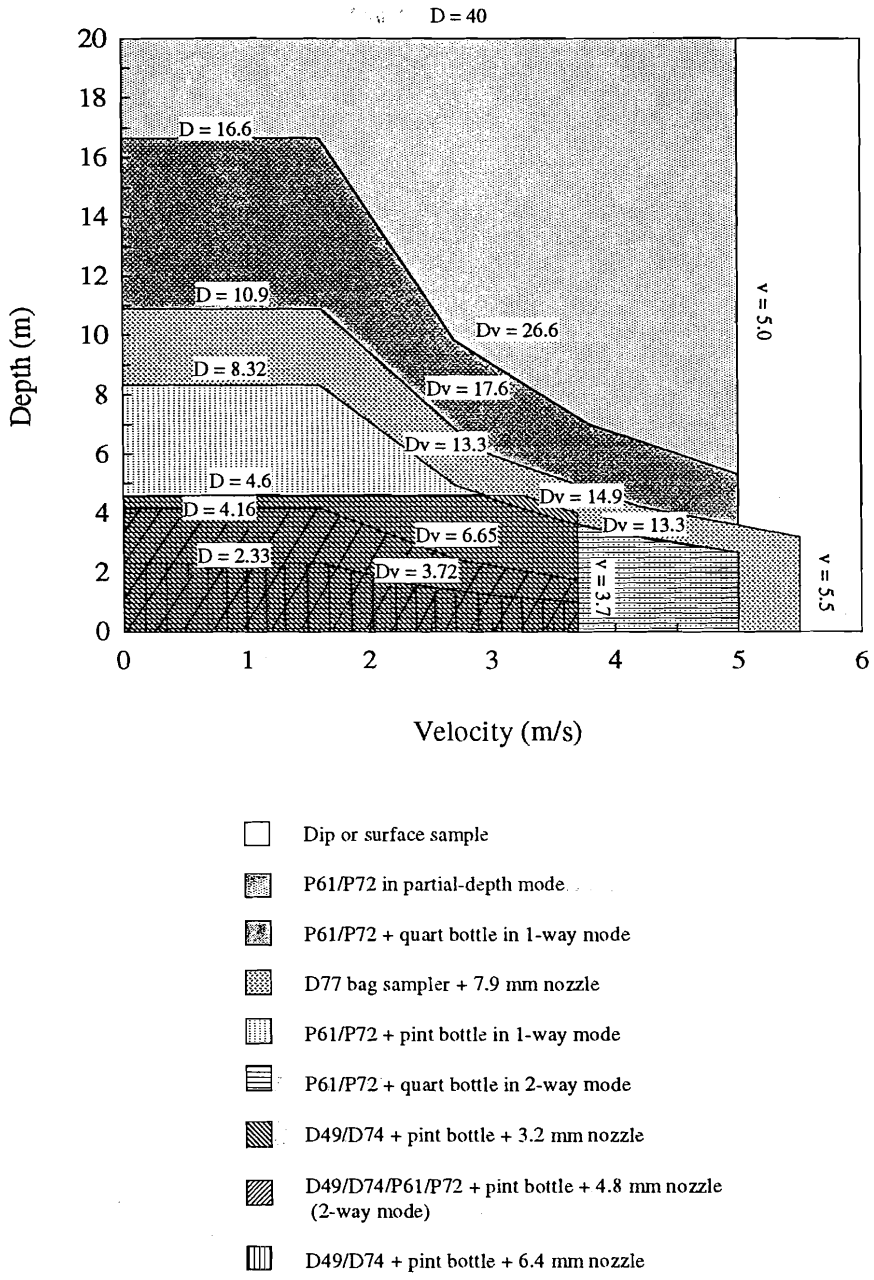

Figure A.1 *Definitions of operating zones in Depth-Velocity space for sampler-nozzle combinations.*

Suspended Sediment Gauging Record Form

Form SSR 930629

FIELD Date 14-4-93

River Waiau at Marble Pt Site no. 64602 Party Fenwick Hicks Lwin

Accompanying Gauging No. 120616 Gauged water discharge 128656 l/s

V^2/D index (if used) 1.14 % sand (est.) 50 % sand coarser than 0.25 mm (est.) — %

Sampler type SS DH-48 48 /D-49 49 /D-74 74 /D-77 77 (P-61 61) P-72 72 /Bucket or bottle 99

Nozzle N: 3.2 3 (4.8 4) /6.4 6 /7.9 7 Container C: pint1/quart2/3l bottle3/3l bag4

Integration mode I (at crit. vert) surface0 (1-way1) /2-way2 /part. depth3 /point integ.4

METHOD CODE (9 digits) SSNCInnMF = 614110515

Verticals: No Verticals nn 05. Selection Method M (EDI1) EWI2/Single vert.3/Other4

Flow data source F (gauging) /resource file 2 / table 3 / none 4

Particle Size Estimated conc.: 1000 mg/l Bottles per vertical:

Time of start 1130 NZST Slope reach SG 1 start m SG 2 start m Slope Reach length m

Vertical No.	Gauging distance from initial point Distance (m)	Mean v at vertical $\bar{v}$ (m/s)	Depth at vertical D (m)	Min. allowable transit time T_{min} (s)	Optimum transit time T_{opt} (s)	Optimum transit rate R (m/s, r/s, s/r)	Bottle No.	Actual transit time T_{act} (s)	Give details of any compositing & amounts of washing water (also write the latter on bottle) Comment	Laboratory results: Net mass of sediment Mass (mg)	Net volume of sample Vol. (ml)	Sample conc. (mass/vol. x 1000) Conc (mg/l)
1	25.2	2.08	0.81	2	9	3.6	A165	8		349	330	1057
2	36.3	2.38	1.08	2	8	2.3	B166	8	Up } bulked			
					8		B144	7	Down }	760	640	1187
3	44.7	2.36	1.36	2	8	1.9	A120	7	Up } bulked			
					8		A160	8	Dn }	690	645	1089
4	52.0	2.28	1.51	2	8	1.7	C74	8	Up } Bulked			
					8		B129	7	Down }	780	650	1200
5	59.5	1.96	1.55	2	10	2.0	B110	10		320	325	984
					Σ67		No. of bottles n	Σ63		Σ2899	Σ2590	

Time at end of sampling 1155 NZST Staff gauge 1 at end m SG 2 at end m

Comments:

Field data continued

Vertical No.	Distance (m)	$\bar{v}$ (m/s)	D (m)	T_{min} (s)	T_{opt} (s)	R (m/s, r/s, s/r)	Bottle No.	T_{act} (s)	Comment	Mass (mg)	Vol. (ml)	Conc (mg/l)
					Σ		No. of bottles n	Σ		Σ	Σ	

OFFICE

Concentration: Mean, $\bar{C} = \Sigma C/n =$ 1099 mg/l;

1. Discharge-weighted Mean Concentration C_m (= $\bar{C}$ for EDI, or $\Sigma M/\Sigma V$ for EWI) = 1099 1 mg/l

2. Standard Deviation, $s_c = \sqrt{(\Sigma(C-\bar{C})^2/n-1)} =$ 92 2 mg/l

3. Water discharge at mid-time of sediment gauging, Q = 129500 3 l/s 4. Slope -1 4 mm/km

5. Method code (from reverse) SSNCInnMF 614110511 5

6. Quality control code: Average sample volume, $\bar{V}_{VVVV} = \Sigma V/n_b =$ 2590/8 = 0324 ml (4 digits)

Transit time accuracy TA% = ($\Sigma T_{actual}/\Sigma T_{opt}$) x 100 = 094 % (3 digits)

C is 1 if comment filled, else 0

QC code (8 digits V V V V TA% C) = 03240940

7. to 14. Particle-size data

Size	0.004	0.016	0.031	0.063	0.125	0.25	0.5	1.0
Cum. % finer	-1 7	-1 8	-1 9	-1 10	-1 11	-1 12	-1 13	-1 14

Method Code, m: pipette 1 / bottom withdrawal 2 / rsa 3 S: wet sieve 4

CERTIFICATION	Date	Initials
Field	14/4	
Sent to lab	15/4	
Rec from lab	20/4	
Calc	22/4	
Calc checked	31/4	
Archived	31/4	

15. Particle-size method code ms -1 15

Comment added to archive is

Figure B.1. *An example suspended sediment gauging record form, for a gauging using the EDI method and one-way integration with a P-61 point sampler.*

Suspended Sediment Gauging Record Form

Form SSR 930629

FIELD

Date 29:2:93

River Waihau at SHB Site no. 969252 Party Fenwick Tint

Accompanying Gauging No. ..... Gauged water discharge ..... l/s

V^2/D index (if used) ..... % sand (est.) 50 % sand coarser than 0.25 mm (est.) 0 %

Sampler type SS DH-48 48 (D-49 49) /D-74 74 /D-77 77/P-61 61 / P-72 72 /Bucket or bottle 99

Nozzle N: (3.2 3) /4.8 4 /6.4 6 /7.9 7 Container C (pint1)/quart2/3l bottle3/3l bag4

Integration mode I (at crit. vert) surface0 /1-way1 (2-way2)/part. depth3 /point integ.4

METHOD CODE (9 digits) SSNCInnMF = 493121024 5

Verticals: No Verticals nn 10 Selection Method M: EDI (EWI2/5)ngle vert.3/Other4

Flow data source F: gauging 1 /resource file 2 / table 3 (none 4)

Particle Size Estimated conc.: 1500 mg/l Bottles per vertical: 1

Time of start 2200 NZST Slope reach SG 1 start 1:392 m SG 2 start 1:14 m Slope Reach length 387 m

Vertical No.	Gauging distance from initial point: Distance (m)	Mean v at vertical: $\bar{v}$ (m/s)	Depth at vertical: D (m)	Min. allowable transit time: T_{min} (s)	Optimum transit time: T_{opt} (s)	Optimum transit rate: R (m/s, r/s, s/r)	Bottle No.	Actual transit time: T_{act} (s)	Comment	Laboratory results: Net mass of sediment: Mass (mg)	Net volume of sample: Vol. (ml)	Sample conc. (mass/vol. x 1000): Conc (mg/l)
1	11:2				2	2	MP2	2				
							PS1	3				
2	17.6				6			5				
								6				
3	24.0				10			10				
								10				
4	30.4				13			13	All samples bulked for concentration in MP2, 120 ml washings added			
								14				
5	36.8				14			14				
								13				
6	43.2				16			17				
								16				
7	49.6	1.3 est	1.5 est		18			18				
								19	All samples for particle size bulked in PS1; 150 ml washings added			
8	56.0				18			18				
								18				
9	62.4				14			14				
								13				
10	68.8				1	↓	↓	1				
								1				
					Σ 112		10 No. of bottles n	Σ 112		Σ 4010	Σ 2060	1947

Time at end of sampling 2222 NZST Staff gauge 1 at end 1.388 m SG 2 at end 1:13 m

Comments: .....

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.....

Field data continued

Vertical No.	Distance (m)	$\bar{v}$ (m/s)	D (m)	T_{min} (s)	T_{opt} (s)	R (m/s, r/s, s/r)	Bottle No.	T_{act} (s)	Comment	Mass (mg)	Vol. (ml)	Conc (mg/l)
					Σ		No. of bottles n	Σ		Σ	Σ	

OFFICE

Concentration: Mean, $\bar{C} = \Sigma C/n =$ ..... mg/l;

1. Discharge-weighted Mean Concentration C_m (= $\bar{C}$ for EDI, or ($\Sigma M/\Sigma V$ for EWI)) = 1947 1 mg/l

2. Standard Deviation, $s_c = \sqrt{(\Sigma(C-\bar{C})^2/n-1)}$ = -1 2 mg/l

3. Water discharge at mid-time of sediment gauging, Q = 105660 3 l/s 4. Slope 62 4 mm/km

5. Method code (from reverse) SSNCInnMF 493121024 5

6. Quality control code: Average sample volume, $\bar{V}_{vvvv} = \Sigma V/n_b =$ 0206 ml (4 digits)

Transit time accuracy TA% = ($\Sigma T_{actual}/\Sigma T_{opt}$) x 100 = 100 % (3 digits)

QC code (8 digits V V V V TA% C) = 02061000 6 (C is 1 if comment filed, else 0)

7. to 14. Particle-size data

Size	0.004	0.016	0.031	0.063	0.125	0.25	0.5	1.0
Cum. % finer	8 7	18 8	38 9	51 10	76 11	89 12	91 13	100 14

Method Code, m: pipette 1 / (Bottom withdrawal 2 / rsa 3) S: (wet sieve 2)

15. Particle-size method code ms 24 15

Comment added to archive is.....

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CERTIFICATION

	Date	Initials
Field	29/2/93	KT
Sent to lab	29/3/93	KT
Rec from lab	29/4/93	KT
Calc	29/5/93	KT
Calc checked	29/5	KT
Archived	29/6	KT

Figure B.2. *An example suspended sediment gauging record form, for a gauging using the EWI method, with all samples being bulked, and with another set of samples collected for particle-size analysis.*

Suspended Sediment Gauging Record Form

Form SSR 930629

FIELD Waihau Date 29.2.93

River Waihau at SHB Site no. 969252 Party Fenwick Tait

Accompanying Gauging No. ..... Gauged water discharge ..... l/s

V^2/D index (if used) ..... % sand (est.) ..... % sand coarser than 0.25 mm (est.) ..... %

Sampler type SS DH-48 4 /D-49 49 /D-74 74 /D-77 77/P-61 61 / P-72 72 /Bucket or bottle 99

Nozzle No. 3.2 3 /4.8 4 /6.4 6 /7.9 7 Container C: pint1/quart2/31 bottle3/31 bag4

Integration mode I (at crit. vert) surface0 /1-way1 /2-way2 part. depth3 /point integ.4

METHOD CODE (9 digits)
SSNCInnMF = 493121024 3

Verticals: No Verticals nn 10 Selection Method M: EDI/EWI2/Single vert.3/Other4

Flow data source F: gauging 1 /resource file 2 / table 3 none 4

Particle Size Estimated conc.: .....mg/l Bottles per vertical: 1

Time of start 2200 NZST Slope reach SG 1 start. 1.392 m SG 2 start. 1.114 m Slope Reach length 387 m

Vertical No.	Gauging distance from initial point: Distance (m)	Mean v at vertical: $\bar{v}$ (m/s)	Depth at vertical: D (m)	Min. allowable transit time: T_{min} (s)	Optimum transit time: T_{opt} (s)	Optimum transit rate: R (m/s, r/s, s/r)	Bottle No.	Actual transit time: T_{act} (s)	Give details of any compositing & amounts of washing water (also write the latter on bottle): Comment	Laboratory results: Net mass of sediment: Mass (mg)	Net volume of sample: Vol. (ml)	Sample conc. (mass/vol. x 1000): Conc (mg/l)
1	11.2				2	2	A3	2		63	35	1800
2	17.6				6		A21	5		187	90	2078
3	24.0				10		A14	10		432	210	2057
4	30.4				13		A34	13		501	240	2088
5	36.8				14		A7	14		612	280	2186
6	43.2				16		A9	17		599	295	2031
7	49.6	1.3 est	1.5 est		18		A12	18		613	330	1858
8	56.0				18		A15	14		524	290	1807
9	62.4				14		A2	14		462	280	1650
10	68.8				1	↓	A49	1		17	10	1700
					Σ112		10 No. of bottles n	Σ 112		Σ1010	Σ2060	

Time at end of sampling 2220 NZST Staff gauge 1 at end 1.382 m SG 2 at end 1.113 m

Comments:.....

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Field data continued

Vertical No.	Distance (m)	$\bar{v}$ (m/s)	D (m)	T_{min} (s)	T_{opt} (s)	R (m/s, r/s, s/r)	Bottle No.	T_{act} (s)	Comment	Mass (mg)	Vol. (ml)	Conc (mg/l)
					Σ		No. of bottles n	Σ		Σ	Σ	

OFFICE

Concentration: Mean, $\bar{C} = \Sigma C/n$ = ... mg/l;

1. Discharge-weighted Mean Concentration C_m (= $\bar{C}$ for EDI, or $\Sigma M/\Sigma V$ for EWI) = 1947 1 mg/l

2. Standard Deviation, $s_c = \sqrt{(\Sigma(C-\bar{C})^2/n-1)}$ = 185 2 mg/l

3. Water discharge at mid-time of sediment gauging, Q = 105660 3 l/s 4. Slope 62 4 mm/km

5. Method code (from reverse) SSNCInnMF 493121024 5

6. Quality control code: Average sample volume, $\bar{V}_{VVVV} = \Sigma V/n_b$ = 0.206 ml (4 digits)

Transit time accuracy TA% = ($\Sigma T_{actual}/\Sigma T_{opt}$) x 100 = 100 % (3 digits)

C is 1 if comment filed, else 0

QC code (8 digits V V V V TA% C) = 02061000 6

7. to 14. Particle-size data

Size	0.004	0.016	0.031	0.063	0.125	0.25	0.5	1.0
Cum. % finer	-1 7	-1 8	-1 9	-1 10	-1 11	-1 12	-1 13	-1 14

Method Code, m: pipette 1 / bottom withdrawal tube 2 / rsa 3 S: wet sieve 4

15. Particle-size method code ms -1 15

Comment added to archive is.....

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CERTIFICATION

	Date	Initials
Field	29/2/93	[illegible]
Sent to lab	29/3	[illegible]
Rec from lab	29/4	[illegible]
Calc	29/5	[illegible]
Calc checked	29/6	[illegible]
Archived	29/6	[illegible]

Figure B.3. *An example suspended sediment gauging record form, for a gauging using the EWI method, with all samples being analysed. (This would normally be done in order to measure the variability of the concentration across the section, as indicated by the standard deviation.)*

Suspended Sediment Gauging Record Form

Form SSR 930629

FIELD

Date 14.4.93

River Waiau at Marble Pt Site no. 64602 Party Fenwick, Hicks, Lwis

Accompanying Gauging No. 120616 Gauged water discharge 128656 l/s

V^2/D index (if used) 1.4 % sand (est.) 50 % sand coarser than 0.25 mm (est.) %

Sampler type SS DH-48 48 /D-49 49 /D-74 74 /D-77 77 (P-61 61) / P-72 72 /Bucket or bottle 99

Nozzle N: 3.2 3 (4.8 4) 6.4 6 /7.9 7 Container C: pint1/quart2/3l bottle3/3l bag4

Integration mode I (at crit. vert) surface0 /1-way1 /2-way2 (part. depths) /point integ.4

METHOD CODE
SSNCInnMF = 61413051 1 5

Verticals: No Verticals nn 05 Selection Method M: (EDI1) EWI2/Single vert.3/Other4

Flow data source F: gauging 1 /resource file 2 / table 3 / none 4

Particle Size Estimated conc.: mg/l Bottles per vertical:

Time of start 1400 .NZST Slope reach SG 1 start 1.492 m SG 2 start 1.292 m Slope Reach length 797 m

Vertical No.	Gauging distance from initial point Distance (m)	Mean v at vertical $\bar{v}$ (m/s)	Depth at vertical D (m)	Min. allowable transit time T_{min} (s)	Optimum transit time T_{opt} (s)	Optimum transit rate R (m/s, r/s, s/r)	Bottle No.	Actual transit time T_{act} (s)	Give details of any compositing & amounts of washing water (also write the latter on bottle) Comment	Laboratory results: Net mass of sediment Mass (mg)	Net volume of sample Vol. (ml)	Sample conc. (mass/vol. x 1000) Conc (mg/l)
1	26.4	2.22	2.81	4	8	1.0	YP9	9	Up } Bulked	890	710	1253
					8		YP8	8	Dn } added +10ml H_2O			
2	36.9	2.35	4.25	7	8	0.6	YX7	7	Up } bulked	855	700	1221
					8		YX6	8	Dn } +10ml H_2O			
3	43.6	2.40	0-2.9	5	7	0.7	YZ1	8	U }			
					7	0.7	YZ3	7	D } bulked			
			2.9-5.8		7	0.7	YK8	7	U } +20ml H_2O			
					7	0.7	YK9	6	D }	1810	1420	1274
4	49.6	2.35	0-2.6	4	7	0.8	YP2	7	Up }			
					7	0.8	YP3	6	Dn } bulked			
			2.6-5.8		7	0.8	YP5	6	Up } +25ml H_2O			
					7	0.8	YP4	7	Dn }	1970	1380	1427
5	57.2	2.18	3.79	6	9	0.7	YZ4	10	U } Bulked			
					9	0.7	YZ5	9	D } + 10ml	780	680	1147
					Σ 106		No. bottles n	Σ 105		Σ 6305	Σ 4890	

Time at end of sampling 1430 .NZST Staff gauge 1 at end 1.362 m SG 2 at end 1.162 m

Comments:

Field data continued

Vertical No.	Distance (m)	$\bar{v}$ (m/s)	D (m)	T_{min} (s)	T_{opt} (s)	R (m/s, r/s, s/r)	Bottle No.	T_{act} (s)	Comment	Mass (mg)	Vol. (ml)	Conc (mg/l)
					Σ		No. of bottles n	Σ		Σ	Σ	

OFFICE

Concentration: Mean, $\bar{C} = \Sigma C/n =$ 1264 mg/l;

1. Discharge-weighted Mean Concentration C_m ($= \bar{C}$ for EDI, or $\Sigma M/\Sigma V$ for EWI) = 1264 1 mg/l
2. Standard Deviation, $s_c = \sqrt{(\Sigma(C-\bar{C})^2/n-1)} =$ 103 2 mg/l
3. Water discharge at mid-time of sediment gauging, Q = 462172 3 l/s 4. Slope 251 4 mm/km
5. Method code (from reverse) SSNCInnMF = 61413051 5
6. Quality control code: Average sample volume, $\bar{V}vvvv = \Sigma V/n_b =$ 4890/14 = 0349 ml (4 digits)

Transit time accuracy TA% = ($\Sigma T_{actual}/\Sigma T_{opt}$) x 100 = 099 % (3 digits)

C is 1 if comment filled, else 0

QC code (8 digits V V V V TA% C) = 03490990 6

7. to 14. Particle-size data

Size	0.004	0.016	0.031	0.063	0.125	0.25	0.5	1.0
Cum. % finer	~1 7	~1 8	~1 9	~1 10	~1 11	~1 12	~1 13	~1 14

Method Code, m: pipette 1 / bottom withdrawal 2 / rsa 3 S: wet sieve 4

CERTIFICATION

	Date	Initials
Field	14/4/93	MCT
Sent to lab	15/4	SJO
Rec from lab	25/4	SJO
Calc	28/4	SJO
Calc checked	20/5	MCT
Archived	20/5	MCT

15. Particle-size method code ms ~1 15

Comment added to archive is:

Figure B.4. *An example suspended sediment gauging record form, for a gauging using the EDI method and a P-61 point sampler in partial depth mode.*

Appendix C: Programs to Aid Suspended Sediment Gaugings

Overview

The shell program SED activates several PC programs to aid suspended sediment gaugings. These programs are:

SEDGAUGE

A program for use in the field and as a learning guide, it will determine suspended sediment gauging requirements for both the EDI and EWI methods. For input data, it requires either a *.VEL file generated by GAUGE from a "concurrent" flow gauging or a *.RES resource file containing compressed data for a number of gaugings covering a range of stage, generated by MAKERES.

MAKERES

A program used in the office for making a resource file for use by SEDGAUGE and MAKETABL. It uses gaugings data from any number of *.VEL files produced by GAUGE, covering a range of stage and discharge.

MAKETABL

A program used in the office to tabulate the offset, depth, and mean velocity at EDI sampling verticals using data from a *.RES resource file. Separate tables are generated for different numbers of verticals. The tables are output to a *.TAB text file. A print-out of this can be taken in the field and used to estimate suspended sediment sampler operating requirements after a decision has been made on the number of verticals. The procedure can be used in lieu of using SEDGAUGE with a field computer.

SD

A program used in the office to calculate the mean, standard deviation, coefficient of variation, and standard error in the suspended sediment concentration sampled at a number of verticals over a cross-section. It also estimates the number of verticals required to achieve a 15% standard error in the mean concentration.

The exchange of files amongst these programs is illustrated in Figure C.1.

Running the Programs

SD

Data input is simple, requiring only the number of verticals sampled during a sediment gauging, then the mean concentration for each vertical (note that if more than one sample was collected from a vertical and these were not bulked before analysis, then their concentrations should be "pre-averaged"). The mean and standard deviation can be entered on the sediment gauging record form (only for an EDI gauging). If the 95% standard error is less than 15%, then an adequate number of verticals was sampled. If not, then the "minimum recommended number of samples" should be used as a guide for the number of verticals at subsequent gaugings (refer to the

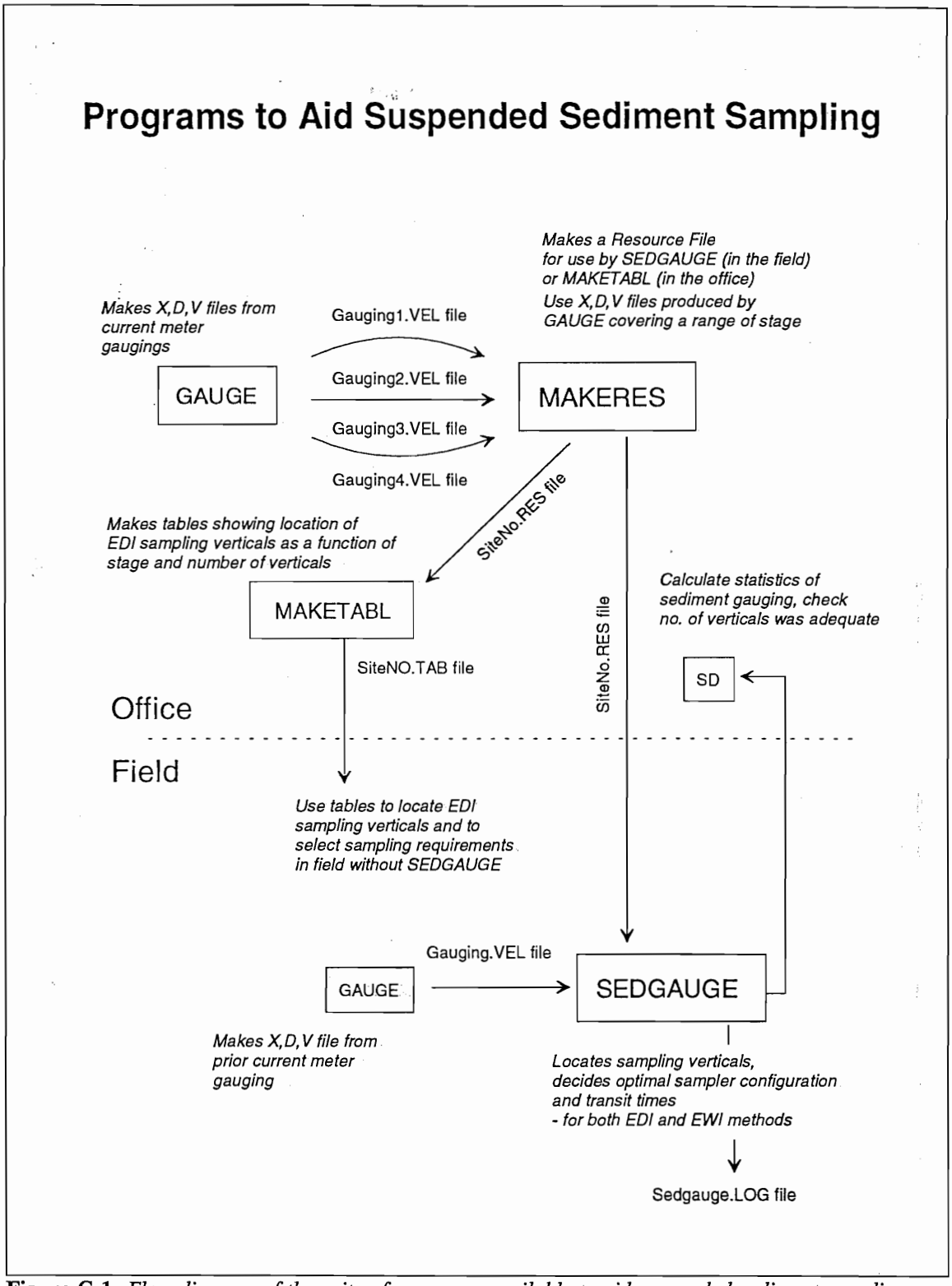

Figure C.1 *Flow diagram of the suite of programs available to aid suspended sediment sampling.*

procedure for selecting the optimal number of EDI sampling verticals outlined in section 4.3 of the sediment manual.

MAKERES

The first item to enter is the pathname of the resource file to be created (you can get away with simply the file name if you want the file to be created in the current directory, otherwise you should use the full DOS pathname, e.g. a:\SEDIMENT\filename.RES

- typically you would use the Site Number for Filename). If a resource file of that name already exists, then you will be asked whether to overwrite or append to this file. New resource files should be compiled after significant rating changes.

The next input request is for the pathname of the first gauging file to add - usually this will have a .VEL suffix. If the summary information on this file is acceptable, enter Y to accept it. Note that the header line of the gauging file must be consistent with header line in the intermediate file created by the latest version of GAUGE, consisting of the following 13 data items:

```
GAUGING    Gauging no.    Site no.    Date    Time    Method
code      Slope      Sed. conc.      Temperature  Mean stage
height     Stage change     Discharge units     Discharge
```

Older versions of GAUGE don't add the Discharge value. If you only have an older version, you will need to add the Discharge to the end of the header line manually using a text editor.

You can add any number of gaugings to the resource file, but generally, at least 5 or 6 should be loaded, covering as wide a range of stage and discharge as possible. It is a good idea to make a list of the gauging file name names before you start running MAKERES. You can add the gaugings in any order at any time; MAKERES will sort them into order of increasing stage.

MAKETABL

The first information to enter is the pathname of the input resource file. Usually, this will be named <<SiteNo>>.RES. The header line of the resource file is then displayed, along with the range of stage represented by the gaugings compressed onto the resource file. The next information requested is the range of number of sampling verticals - a separate table will be created for each number of sampling verticals. For example, if you want tables created for the cases of 5,6,7,8,9, and 10 sampling verticals, then you would enter 5 then 10. Press the Enter key after each value. Next to be entered is the range of stage over which the tables are calculated. Ideally, this should lie within the range covered by the resource file data. If you enter a wider range, MAKETABL will give a warning message that the data had to be extrapolated. The stage interval for the tabulations will vary depending on the stage range. Typically, it should be chosen so that there are 10-20 records in the tables. For example, if the stage range is 3.00 to 6.00 m, then an interval of 0.25 m would give 13 records in the output table, covering stages equal to 3.00, 3.25, 3.50, 3.75 ..... 6.00.

The program then offers termination options. To view the tables, you can use the BROWSE utility included with the SED package or any text-editor or word-processor. The tables file takes the first part of its name from the input resource file and has a TAB suffix, thus typically, the tables file will be called <SiteNo>.TAB. Use the DOS command PRINT to directly print the tables on your default printer.

SEDGAUGE (version 2.20)

The first item to enter is whether the EDI or EWI method is being used (as discussed in the sediment manual, the EDI method should be used whenever possible).

Using EDI Method

If you choose the EDI method, the next request is for the type of gauging data to be used. This will either be a gauging file created immediately beforehand using GAUGE or a resource file, of compressed older gaugings, created in the office using MAKERES. You are then asked for the pathname of either the gauging or resource file.

If using a gauging file, you may make some adjustment to the stage if it has changed since the current-meter gauging was completed. Note the mm units.

If using a resource file, the ranges of stage and discharge covered by the resource file are displayed, and the present stage height is requested (note the metres units). Ideally, this should lie within the range of the resource file data; if it isn't, SEDGAUGE will extrapolate assuming that the river banks are vertical above the waters edges corresponding to the highest stage on the resource file. Note also, three essential assumptions of using a resource file are

- the current-meter gaugings were made at the section to be used for sediment gauging,
- there is negligible change in water-surface elevation between the staff gauge and the gauging section (i.e., you can't use a staff gauge that is several km upstream from the gauging site),
- the rating hasn't changed significantly since the resource file gaugings were made.

Thereafter, SEDGAUGE appears the same, whether a gauging or resource file has been used.

Information is then requested on the % sand in the suspended load, the % coarser than 0.25 mm, and the concentration. This information is used to determine the number of samples required for particle size analysis, to select the number of verticals, and to aid the selection of intake nozzles. The concentration estimate may be made visually, based on experience, or obtained from an existing sediment rating for the site. A sensible value for this is required only if samples are being collected for particle size analysis; otherwise you can enter zero for this. If the proportion of sand is unknown, then it is assumed to be 50%, which is the average found in many New Zealand rivers. If the proportion coarser than 0.25 mm is unknown, this is assumed equal to zero.

SEDGAUGE then calculates the V^2/D index and suggests an appropriate number of sampling verticals based on Jordan's Nomograph (see Figure 4.1 of the sediment manual). This should be used as a guide only. Refer to the sediment manual for other approaches for selecting the number of sampling verticals.

SEDGAUGE then suggests the most appropriate sampler-nozzle-operating mode combination for the critical (i.e. the deepest, fastest) vertical, and displays the necessary sampling times and transit rates. If it is necessary to use a P61 in partial-depth mode, it will also display the required number of partial-depth segments. SEDGAUGE permits some opportunity to alter the sampler type, nozzle size, or mode of using a P61 sampler; however, it will not allow a result if a sampler/nozzle combination is attempted that would induce a biased sample. Probably, you'll want to change the sampler, etc, if the transiting times seem too fast or if the margin for error in the transit time seems too small (i.e. +/- 0 to 1 s). Select the N option if you want to change, or at least investigate, another sampler combination.

Once the sampling requirements for the critical vertical have been decided, SEDGAUGE then sequentially displays for each sampling vertical the horizontal offset distance and suggests the required transit times and rates (and, if necessary, partial-depth intervals) using the same sampling combination as selected for the critical vertical. An example display is shown below

```
Vertical no: 1

Distance:  21.9  Vel: 0.89  Depth:  1.71

Use D49 or D74 and Pint container

with 3.2 mm nozzle

 Transit time - optimal: 48 +/- 5 s

              - minimum: 30 s

Transit rate - optimal: 0.07 +/- 0.01 m/s (4.4 sec/rev) )

              - maximum: 0.12 m/s          (2.8    "    )

Is this OK? - Answer Y for yes, N to change:
```

In this example, the optimal transit time of 48 +/- 5 s means that transiting for 43 to 53 seconds should provide a sample volume in the "optimal" range (i.e. 300-370 ml for a standard pint bottle). A minimum transit time of 30 s is required so as to avoid sample bias associated with too fast a transit rate (in this case, the maximum permissible transit rate is 0.12 m/s). Note that the transit rates are given as both a vertical speed (in m/s) and as revolutions per second for a standard A-reel.

Note that the transit rates recommended by SEDGAUGE assume no vertical angle deflection. If there is a significant deflection, then the apparent transit rate should be increased appropriately.

At this stage, the option is available to alter the nozzle size for depth-integrating samplers or the mode of operation of a P61, but not the type of sampler (swapping samplers between verticals is not recommended - particularly on cableways!).

With the termination options, choose R if you want to rerun SEDGAUGE with the same set of input data. if you choose this, the program jumps straight to the selection of the number of sampling verticals.

Using EWI Method

An EWI gauging can use for input data either a gauging file, a resource file, or some "bare bones" estimates entered via the keyboard.

If you select the gauging or resource file options, then SEDGAUGE proceeds largely as detailed for the EDI method. However, when recommending the number of sampling verticals, it uses the flow gauging data to ensure that no sampling vertical represents more than 20% of the total discharge. Generally, SEDGAUGE's recommended number of verticals should be used, although playing around with the

N option and choosing a different number of verticals will show you how the % discharge carried by the critical vertical varies as the number of verticals is varied.

The appropriate sampler/nozzle/operating-mode combination is then chosen as per the EDI method. This choice is keyed to the depth and velocity at the critical vertical (i.e. the one carrying the largest partial discharge).

A table is then displayed, setting out the offset, transit rate (in both m/s and revolutions/s of an A-reel), and transit time for each sampling vertical. Also displayed are the depth, velocity, % of the total discharge represented by the vertical, and finally the ratio of the transit rate to the mean velocity in the vertical, F. An example table is shown below.

Vert	Dist.(m)	Tr rate (m/s)	(s/rev)	Tr time (s)	Depth(m)	Vel(m/s)	%Q	F
1	10.5	0.22	1.4	3	0.3	0.4	1	0.51
2	15.5	0.22	1.4	8	0.9	0.6	3	0.38
3	20.5	0.22	1.4	14	1.6	0.9	7	0.25
4	25.5	0.22	1.4	18	2.0	0.9	10	0.24
5	30.5	0.22	1.4	21	2.3	1.4	16	0.16
6	35.5	0.22	1.4	27	3.0	1.6	22	0.14
7	40.5	0.22	1.4	26	3.0	1.3	20	0.17
8	45.5	0.22	1.4	22	2.5	0.9	11	0.24
9	50.5	0.22	1.4	18	2.0	0.5	5	0.47
10	55.5	0.22	1.4	12	1.3	0.4	3	0.53

A fault with the EWI method is that its requirement of maintaining a constant transit rate at each vertical may often be incompatible with collecting unbiased samples everywhere across the section. For example, setting the transit rate fast enough so that the sample bottle does not overfill at the critical vertical may result in sample bias at other verticals where the velocity is lower and the transit-rate/velocity ratio is too high. This problem will be indicated by the F values. If these exceed 0.4 only at bank-side verticals carrying only a few % of the total discharge (as in the above example), then the bias is generally not significant. However, if F exceeds 0.4 at most verticals, then SEDGAUGE should be rerun with a sampler combination requiring a slower transit rate.

If you have no prior gauging data, SEDGAUGE requests the offset of WELB and WERB (in m) and estimates of the depth and velocity at the section carrying the greatest partial discharge (usually, the deepest-fasted section). In this case, the output table only indicates the offset and transit rate for each sampling vertical.

Using Both Methods

SEDGAUGE writes all the sampling requirements for the present sediment gauging to an ASCI file called SEDGAUGE.LOG. You can review this using TYPE or BROWSE if you forgot what SEDGAUGE told you. If a file SEDGAUGE.TXT exists, SEDGAUGE will append this information to it; otherwise it creates the file. The date and time (taken from the operating system) are written onto the log file each time it is added to, so you can identify information from a particular gauging. You can check that your computer's date and time are correct using the Dos DATE and TIME commands.

Print out the SEDGAUGE.LOG file when you return to the office, and staple a hard copy of the sediment gauging information to the record form.

Other Notes:

- It is good practice to create a special directory for keeping the RES and VEL files for all your sediment sites.
- These programs are written in TURBO PASCAL, which is very strict on formatting. It will consider any number with a "bare" decimal point as text. Therefore, when entering numeric data, either via the keyboard or via a file, you must ensure that your decimal points are enclosed by digits, e.g.: enter 3 or 3.0 not 3.; 0.3 not .3. The programs have error traps to flag this if it occurs in an input file.
- Pressing the Control and Break keys simultaneously will crash you out of any of the programs.

APPENDIX D: Instructions for Preparing Annual Data Reviews

Annual Data Reviews (ADR's) should be prepared for every active site in the sediment sampling network at the end of each year. One copy should be kept at the field party office and another sent to the study management team. Field teams should use the ADR's to plan their sampling strategies at each site for the coming year. A file of ADR's should be accumulated as the years progress.

An ADR consists of

- a listing of all sediment gaugings for the site
- a page of plots
- a summary page

The task of preparing the ADR's involves listing data-to-hand, running the automated plotting procedure, interpreting the plots, and completing the summary page.

Plots and Listing

Overview

A largely automated routine is used to produce a series of graphs summarising suspended sediment data-to-hand at a given site.

After some data preparation, the sediment data is listed then the PSIM routine SEASONS.SIM is used to scan the site flow data to identify, for each sediment gauging, whether the gauging was rising or falling stage and for what season of the year, writing the results to temporary files. The script file SEDGO.SCF then activates a series of routines to calculate a "working" suspended sediment rating equation, estimate the average sediment yield over the period of sediment data collection, and to prepare data for plotting. The script files SEDPLOT.SCF and SEDSCR.SCF are then used to build plots for a hard-copy plotter or the PC screen respectively. The sediment rating equation is fitted to the log-transformed concentration and flow data using linear least-squares. A non-parametric correction factor (Duan, 1983) is applied to correct for bias in the retransformation of the rating equation from log-values back to linear values.

The rating is termed "working" since it is the simplest form of rating and is being used in this context primarily as a guide for future sampling. After inspection of the plots, it may become apparent that a better, final estimate of sediment yield would be obtained from a more complex representation of the sediment concentration vs. water discharge relationship - such as using separate ratings for rising and falling stages or for separate seasons, or using different rating equations for different ranges of discharge (see Glysson, 1987, for examples).

The sediment yield is calculated by combining the "working" sediment rating with a flow-duration table for the period of sediment record. The flow-duration table is produced by the TIDEDA process PDIST from the logarithms of the flows, thus the sediment yield calculation is performed on some 45 flow bands separated equally in log-space. The log transformation is used because river flows and particularly sediment loads tend to be log-normally distributed.

Notes:

- A separate ADR directory should be created on your hard disk, and the ADR package should be copied into this directory. When making ADR's, TIDEDA must be launched from this directory. This is because the script-file editing programmes and assorted temporary files needed in the analysis are located there.
- A good 2 Mb of hard disk space should be available for temporary files.
- TIDEDA version 4.33 or later is required; the script files may crash on older versions
- the SETUP utility must be run before using the ADR package for the first time or if the screen or printer/plotter is changed
- A pen-plotter is recommended because colours are better for distinguishing samples collected at different seasons and flow conditions
- If a pen-plotter is used, it must have pens in slots 1-6.
- Sediment data collected since 1 July 1992 should be archived as explained in Section 6.4, i.e. as 15-item kind INSTANT under the same site number but in a different directory or file than the STAGE, RATINGS, and GAUGINGS data for the same site number. This differs from the traditional way that sediment data has been archived, which has involved loading sediment concentration in item 10 of GAUGINGS.
- The instructions below should be followed with great care.

Steps to follow

1. Set the temporary output file:

   OF TEMP.MTD

2. Copy suspended sediment data archived in the new SEDIMENT format (i.e. post July 1 1992) data onto the temporary file. If you have no new format data, bypass this step.

   OF TEMP.MTD

   IF <pathname of TIDEDA file containing sediment data in the new format>

   COPY S

   <site number>

   <enter>

   <enter>

   <enter>

   <enter>

   SITE 1

KIND INSTANT

GO

3. Change the input filename to the file containing stage, ratings, and gaugings data from the site:

   IF <pathname of the file containing stage, ratings, and gaugings for site number> (i.e., the name of your standard archiving file)

4. If you have old suspended sediment concentration data archived in the traditional fashion as item 10 of GAUGINGS, then enter the following commands, otherwise bypass this step:

   PSIM OLD_NEW.SIM

   <site number>G (Don't forget the "G" for GAUGINGS data)

   <enter>

   <enter>

   <enter>

   <enter>

   INT 0

   SITE 1

   KIND INST

   GO

5. Print a listing of all the available sediment gauging data - old and new:

   IF/OF

   LIST 1

   1

   <enter>

   <enter>

   <enter>

   <enter>

   PRON (or PRI)

   GO

6. Run the PSIM routine SEASONS.SIM. Note that this step sets the starting and ending dates and times for use of the discharge record in the scripted commands that follow. These should be selected with some care. The period must extend

from the beginning of the period of record of the sediment data up to the latest data filed (see printed listing for this). If the sediment record period spans less than 10 years, the time period for SEASONS.SIM should be extended to either span 10 years or else the entire record, whichever is shortest. For example, if all your sediment data was collected between 900101 and 930630 while your flow record began in 800101, then set the start date to 830630 and the end date to 930630; if the flow record had begun on 860101, then this should be the start date. (You can use the total length of flow record for sites with more than 10 years of record, but you may find that the analysis takes a long time and/or requires too much hard disk space for the temporary files). The commands are:

IF <pathname of the file containing stage, ratings, and gaugings for site number> (i.e., the name of your standard archiving file)

PSIM SEASONS.SIM

<site number>

start date

start time

end date

end time

NPR

SITE 2

INT 0

RATE

GO

(Running SEASONS.SIM may take a while; it will crash if there is inadequate hard disk space available)

7. Run the script file SEDGO:

   LGO SEDGO.SCF

8. Generate the plots, with either

   LGO SEDPLOT.SCF for hard copy

   or

   LGO SEDSCR.SCF for a screen plot.

9. When finished with a site, delete the temporary files thus:

   RUN DEL TEMP*.*

   RUN DEL *.TMP

RUN DEL *.OUT

(if deleting from DOS rather than inside TIDEDA, omit the RUN command).

Problems

- Usually, if a problem is encountered during the running of these automated routines it will be because the above instructions have not been followed exactly.
- Alteration of the script files should be avoided, since these are written-to during the process. If you must fiddle with the files *MAS.SCF, always make a back-up and never add or delete lines without compensating.
- Pen numbers (for colour plotters and displays) are set up as follows:

Pen 1:	Axes and labels
Pen 2:	Rating curve and % of yield
Pen 3:	Rising stage, summer, and particle size data; discharge time series, number of sediment gaugings
Pen 4:	Falling stage and autumn data
Pen 5:	Winter data
Pen 6:	Spring data

- "UNRECOGNISED COMMAND" messages that appear while the scripts are running can be ignored, since these are simply responses to comments inserted in the script files.

Interpreting plots

The ADR plots should be used to help decide the optimal sampling strategy for the site in the coming year. A sample ADR plot for the Shotover River at Bowens Peak site is shown in Figure D.1.

The top-left plot shows the sediment rating plot (log sediment concentration vs log water discharge[1]) with data differentiated according to whether the samples were collected on rising or falling stages. The aim is to get a good range of samples from both rising and falling stages. This is particularly important if it appears that rising and falling stage data plot in different zones; if this is the case, then it will probably be best to define separate sediment ratings for rising and falling stages. Thus, for example, if almost all of the data to hand are from falling stages, then sampling efforts in the coming year should be focussed on collecting rising stage samples.

The top-centre plot differentiates the sediment rating data by season (summer is December to February, autumn is March to May, winter is June to August, and spring is September to November). If it appears that there is a seasonal spread to the data, then an effort should be made to obtain approximately equal amounts of data from the different seasons. When interpreting these first two plots, care should be taken to not confuse seasonal and rising/falling stage effects. For example, summer data might

1 For example, where log discharge = 3, discharge = 10^3 = 1000

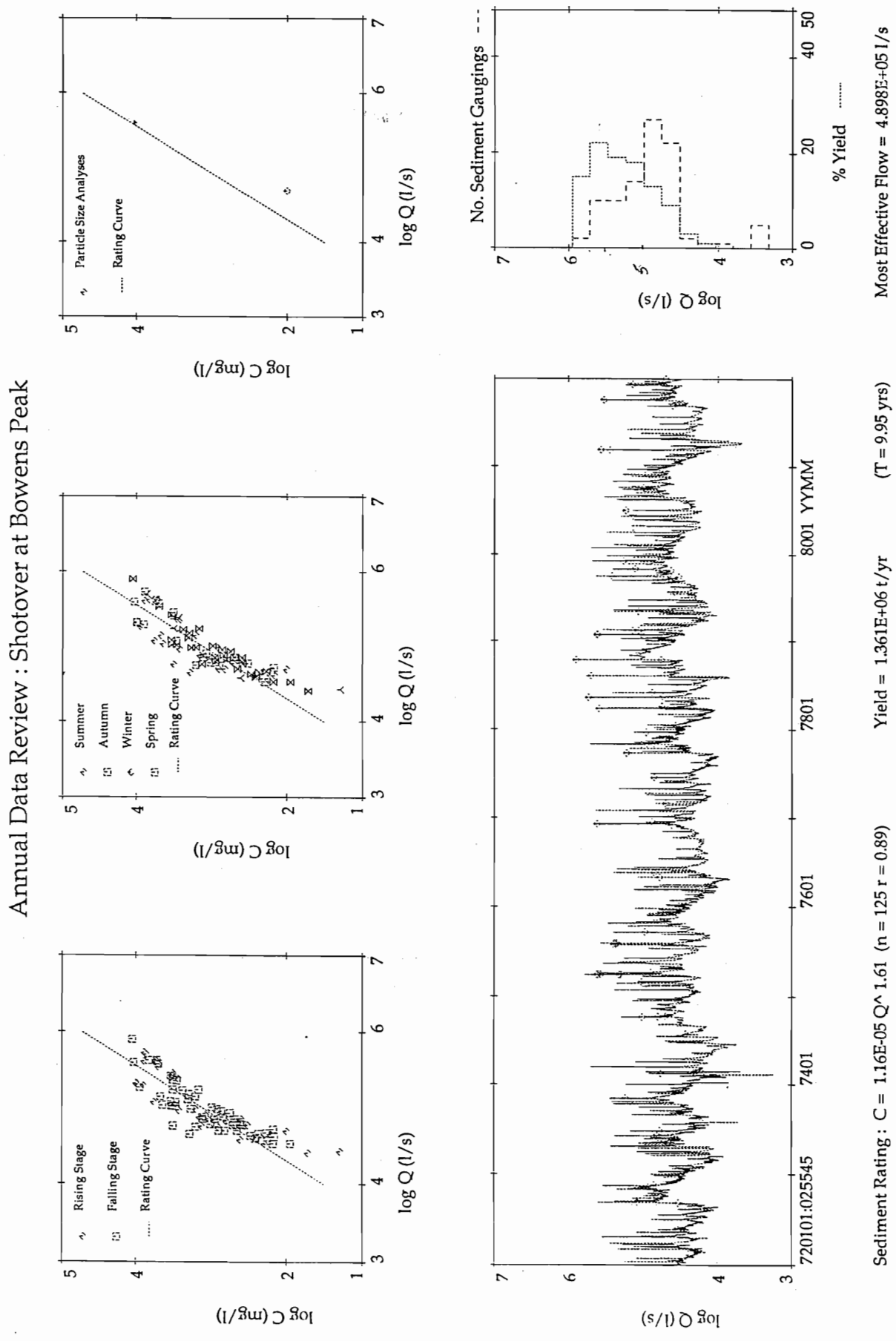

Figure D.1. *An example of the annual data review plots, in this case for the Shotover River at Bowens Peak for 1981*

plot in a different zone from other seasons' data because the summer data are from rising stages.

The top-right plot shows sediment gaugings for which particle size information was collected. Approximately one fifth of all sediment gaugings should include size analysis, so if the data on this plot are sparse, then an effort should be made to collect samples for particle size analysis.

The bottom left plot is a time-series of the logarithm of the water discharge, with the sediment gaugings overlain (as diamonds). This shows how the sediment gaugings to date are distributed in time. An effort should be made to collect an approximately equal number of samples per year (flood flows permitting) - about 5-6 per year on average is the target. It also shows how many gaugings were done in the current year, and, possibly, what opportunities were missed. Thus if the site has had few sediment gaugings in the most recent year or two, then it should receive greater sampling efforts.

The bottom-right plot compares the proportions of the long-term sediment yield carried per discharge band (dotted line) with the number of sediment gaugings per band (dashed line). Note that the bands are for equal increments in the base-10 logarithm of discharge - this is because discharges tend to be log-normally distributed in time. Ideally, the most samples should be collected for the discharges that carry the most sediment, so the two distributions should match. If, for example, most of the sediment gaugings to date have been collected at lower discharges but most of the load is carried by higher discharges (as in Fig. 1), then sampling efforts should be focussed on the higher discharges.

The bottom line lists the suspended sediment rating equation, the average sediment yield over the analysis period, and the most effective flow at transporting sediment over that period. The rating equation is derived by least-squares regression of the log-transformed data, and has been corrected for log-transformation bias using Duan's non-parametric approach. The error on the yield is the 95% standard error. Note that a sediment rating curve won't be determined if there are fewer than 5 data pairs, and so the rating coefficients and sediment yields will all appear with zero values.

Recommendations for sampling at the site in the coming year, based on these plot interpretations, should be listed in the appropriate space on the summary page.

Summary Page

An example summary page, completed for Shotover at Bowens Peak site for the year ending 811231, is shown as Figure D.2.

The *Data-collection Authority* will usually be the NIWA Environmental Data field team.

Sediment Network(s) identifies the network(s) for which sediment data is being collected at that site. Since data-collection networks, by definition, have specific data-collection objectives and procedural requirements, identifying the networks specifies what the data is being collected for and how it should be collected. For example, if the site belongs to the National Flood Gauging Network, then it is implicit that the data are to be collected in order to determine the long-term average sediment yield (employing the sediment rating approach) and its grain-size distribution, and so appropriate sampling strategies, equipment, and methods should be employed. A site may also belong to the ECNZ sediment network, which has slightly different requirements.

Form SADR 930630

NIWA ENVIRONMENTAL DATA
SUSPENDED SEDIMENT ANNUAL DATA REVIEW SUMMARY

Site : Shotover at Bowens Peak Site number: 75276

Data-collection authority: Alexandra E.D.

Sediment Network(s) National Flood Gauging ECNZ

Data-collection objectives at site:

Overall: Long-term average yield and size distribution using rating method; at least 30 gaugings, 6 with particle-size analysis

Annual target (average): 5 gaugings including 1 particle-size

Current year

Data archived in last 12 months ending 820630

All sediment gaugings: 3

Gaugings including particle-size analyses : 1

Data-to-hand

All sediment gaugings: 99

With particle size analyses: 6

Ave % Sand (> 63 microns):

Ave % > 250 microns:

Comments on meeting annual target in past year:
Relatively dry year; few floods

Other Comments : –

Recommendations for coming year:

Continue site? Yes

Flow range to target: 100–500+ m³/s

Focus on rising/falling/both stages: Both

Seasons to target: All

Number of ordinary sediment gaugings to aim for: 5

Number of particle size analyses to aim for: 1

Other: Sampling could cease once higher flow range has been better sampled

Completed by : JRB. Date: 820731

Figure D.2. *An example summary page, completed for the Shotover River at Bowens Peak, for the year ending 811231.*

The *Data-collection Objectives* should be obtained from the network specifications. Listing these every year is one way to ensure that the reason for collecting the data is not forgotten. The *Overall* objective defines what is required of the site before it can be closed. The *Annual Target* sets out what is required in an average year.

The *Current Year* box inventorises the data collected and archived both in the current year and to date. If the actual number of gaugings strays much from the target, a comment is required. Example comments might be that: the year was abnormally dry, with few flood flows; inadequate resources (equipment and/or human); difficulties with the site (e.g. access difficult during storms); and so on. One purpose of these comments is to identify operational problems to be addressed in the coming year.

The *Average % Sand* should be used during future sampling to help identify the total volume of sample required for particle size analysis. The Ave % >250 microns should be used to indicate if a 3.2 mm sampler nozzle is permissible - if more than 16% of the suspended load exceeds 250 microns (0.25 mm), then this nozzle should not be used since it causes a decrease in the sampling efficiency of larger-sized sand grains.

Other Comments can include anything pertinent to the collection of sediment data at the site or to the study objectives. An example comment might be that the catchment upstream experienced a significant change in landuse over the past year, causing an apparent change in the sediment regime.

The *Recommendations for Coming Year* box draws largely on interpretation of the plots, as detailed above. The *Number of Ordinary Sediment Gaugings* and those with Particle Size Analyses should reflect both the average annual targets and the progress on meeting these in previous years. The *Other* recommendations should generally relate to the comments made in the *Current year* box.

When assessing whether to continue sampling sediment at the site, the error on the sediment yield, the length of record, the number of sediment gaugings and their distribution in terms of rising/falling stage, season, time, and flow band, the number of samples analysed for particle-size analysis, and any severe logistical constraints should all be considered.

References:

Duan, N. 1983. Smearing estimate: a non-parametric retransformation method. Journal of the American Statistical Association, V. 78 (383), 605-610.

Glysson, G. D. 1987. Sediment transport curves. U.S. Geological Survey Open-File Report 87-218, 47 p.

Appendix E: Initial comments for sediment gauging file

The following is the standard format for initial comments for each site on the SEDIMENT file. Sample data (*in italics*) have been included to assist clarity.

Site ***64602***

Comment

Initial comment for *Waiau* River at *Marble Point*

Site number ***64602*** on river number ***646000***

The station is situated at grid reference ***N32:914408*** and drains ***2030*** sq km

Items and their units of measurement are:

1) Discharge-weighted mean concentration in mg/l

2) Standard deviation of concentrations in mg/l

3) Discharge at mid-time gauging in l/s 4) water surface slope in mm/km

5) Method code 6) Quality control code

7) Cumulative % of sample finer than 0.004 mm 8) Cum. % finer than 0.016 mm

9) Cum. % finer than 0.031 mm 10) Cum. % finer than 0.063 mm

11) Cum. % finer than 0.125 mm 12) Cum. % finer than 0.25 mm

13) Cum. % finer than 0.5 mm 14) Cum. % finer than 1.0 mm

15) Particle-size method code

The sediment gaugings are filed at the mid-time of each gauging

The recording agency is *Environmental Data - Christchurch*

Date ***930416*** Hour ***093000***

Appendix F: Table of density factors, D_t

This table gives values for the relative densities of the total sample (water plus sediment) to be used as D_t in the formulae for calculation of net volume of sample following laboratory analysis. The reason for using this factor is to correct results from the laboratory expedient of measuring the weight of the total sample instead of its volume (or, in effect, the conversion of concentration in parts per million to milligrams per litre).

It makes the following assumptions:

- the density of water is 1.000 ± 0.005
- the range of temperature is 0 °C to 29 °C
- dissolved solids concentration is between 0 ppm and 10,000 ppm
- the specific gravity of the sediment is 2.65

Suspended sediment concentration in ppm		Factor D_t
0 -	15,900	1.00
16,000 -	46,900	1.02
47,000 -	76,000	1.04
77,000 -	105,000	1.06
106,000 -	132,000	1.08
133,000 -	159,000	1.10
160,000 -	184,000	1.12
185,000 -	209,000	1.14
210,000 -	233,000	1.16
234,000 -	256,000	1.18
257,000 -	279,000	1.20
280,000 -	300,000	1.22
301,000	321,000	1.24
322,000 -	341,000	1.26
342,000 -	361,000	1.28
362,000 -	380,000	1.30
381,000 -	398,000	1.32
399,000 -	416,000	1.34
417,000 -	434,000	1.36
435,000 -	451,000	1.38
452,000 -	467,000	1.40
468,000 -	483,000	1.42
484,000 -	498,000	1.44
499,000 -	513,000	1.46
514,000 -	528,000	1.48
529,000 -	542,000	1.50

Reference

Vanoni, V.A. (Editor), 1975. Sedimentation Engineering. American Society of Civil Engineers, New York, 745p.

Suspended Sediment Laboratory Analysis Form

Form SSL 941010

To:

Attention :

Date sent to lab: ..... by: .....

Date analyses completed: ..... by .....

Please conduct the ticked analyses on the enclosed samples, enter the results on this form, add any necessary comments over-page, and return form and cleaned sample bottles (as indicated), to:

The Manager
Environmental Data
NIWA

For enquiries, contact:
Phone
Fax

Charge costs to: Project no. .....

Analyses required: (tick the appropriate indicator columns)

Sample No.	Site No	Date Collected	Net Sample Vol. (ml)	Net Mass (mg) Sand	Fines	Organics	Total Solids	Dissolved Solids	Particle Size (cum % finer) 0.002	0.004	0.008	0.016	0.031	0.063	0.125	0.25	0.5	1.0	2.0mm	Method Code	Return Bottles? Y/N