National Environmental Monitoring Standard

Measurement of Fluvial Suspended Sediment Load and its Composition

Version: 1.0.0

Date of Issue: October 2020

Disclaimer

The Ministry for the Environment does not necessarily endorse or support the content of the publication in any way.

Copyright

The National Environmental Monitoring Standards

The current suite of National Environmental Monitoring Standards (NEMS) documents, Best Practice Guidelines, *Glossary* and *Quality Code Schema* can be found at www.nems.org.nz .

Implementation

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments shall be followed. The NEMS "Guidelines for Safe Working When Undertaking Environmental Monitoring" also provide useful support material for undertaking monitoring.

Limitations

It is assumed that, as a minimum, the reader of these documents has a basic understanding of environmental monitoring techniques, and a degree of competency in their application. Instructions for manufacturer-specific instrumentation and methodologies are not included in this document.

The information contained in these NEMS documents relies upon material and data derived from a number of third-party sources.

The documents do not relieve the user (or a person on whose behalf it is used) of any obligation or duty that might arise under any legislation, and any regulations and rules under those Acts, covering the activities to which this document has been or is to be applied.

The information in this document is provided voluntarily and for information purposes only. Neither NEMS nor any organisation involved in the compilation of this document guarantee that the information is complete, current or correct and accepts no responsibility for unsuitable or inaccurate material that may be encountered.

Neither the NEMS Steering Group, nor any employee or agent of the Crown, nor any author of or contributor to this document shall be responsible or liable for any loss, damage, personal injury or death howsoever caused.

Development

The National Environmental Monitoring Standards (NEMS) Steering Group has prepared a series of environmental monitoring standards on authority from the regional chief executive officers (RCEOs) and the Ministry for the Environment (MfE).

The development of this Standard involved consultation with regional and unitary councils across New Zealand, industry representatives, and the National Institute for Water and Atmospheric Research Ltd (NIWA). These agencies are responsible for the majority of hydrological and continuous environmental-related measurements within New Zealand. The U.S. Geological Survey (USGS) was also consulted, since USGS equipment and procedures have long underpinned river sediment monitoring in New Zealand.

It is recommended that these Standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately to facilitate data sharing. The degree of rigour with which the Standards and associated best practice may be applied will depend on the quality of data sought.

This document has been prepared by Murray Hicks of NIWA, with input from Martin Doyle of Tasman District Council and the NEMS Steering Group members Jeff Watson of Horizons Regional Council, Nicholas Holwerda of Auckland Council, Barry Lynch from Hawke's Bay Regional Council, and Justin Wyatt, Haydon Jones, and Reece Hill from Waikato Regional Council. External review input provided by John R. Gray of Gray Sedimentology is gratefully acknowledged. Arman Haddadchi of NIWA assisted with securing updated information on samplers.

Funding

The project was funded by the following organisations:

- Auckland Council
- Bay of Plenty Regional Council
- Environment Canterbury Regional Council
- Environment Southland
- Greater Wellington Regional Council
- Hawke's Bay Regional Council
- Horizons Regional Council
- Marlborough District Council
- Ministry for the Environment
- National Institute of Water and Atmospheric Research Ltd (NIWA)
- Northland Regional Council
- Otago Regional Council
- Taranaki Regional Council
- Tasman District Council
- Waikato Regional Council
- West Coast Regional Council

Review

This document will be reviewed by the NEMS Steering Group within one year of its release and thereafter once every two years. Further details on the review process can be found at http://www.nems.org.nz .

TABLE OF CONTENTS

National Environmental Monitoring Standard 1
Measurement of Fluvial Suspended Sediment Load and its Composition 1
The National Environmental Monitoring Standards i
Table of Contents iv
Normative References ix
About this Standard x
Introduction x
Objective xi
Scope xi
Exclusions xii
The Standard – Suspended Sediment xiii
Primary Method xiii
Requirements xiv
Other Methods xvi
Requirements xviii

1 Measurement 1
1.1 Primary Method 3
1.2 Other methods 4

2 Proximity to associated monitoring 8
2.1 Discharge 8
2.2 Surrogate to SSCindex calibration sampling 8
2.3 Deployment 10
2.4 General safety and security issues 12
2.5 Affiliated monitoring/measurements 13
2.6 Metadata 14
2.7 Stationarity 15
2.8 Units 16

3 Data Preservation 18
3.1 Surrogate time-series records 18
3.2 Surrogate to SSCindex calibration 19
3.3 Sediment gaugings for SSCQm calibration 19
3.4 Laboratory analyses 20
3.5 Other methods 21

4 Suspended Sediment Gauging Equipment and Procedures 24
4.1 Purpose 24
4.2 Sampling equipment and procedures 24
4.3 Isokinetic sampler accessories and care 31
4.4 Unmeasured load 34
4.5 Non-isokinetic manual samplers and sampling 35
4.6 Field procedures 35
4.7 Associated measurements 56

5 Fixed-point Sampling to Calibrate and Supplement Surrogate Records 58
5.1 Purposes of fixed-point sampling 58
5.2 Method of collecting fixed-point samples 58
5.3 Where to sample 59
5.4 When and how often to sample 59
5.5 Scheduling auto-sampling 60
5.6 Quality control 61

6 Recording Turbidity as an SSC Surrogate 63
6.1 Instruments and procedures 63
6.2 Managing missing/unreliable turbidity data 64

7 Recording ABS as an SSC Surrogate 66

8 Office Procedures for the Primary Method 67

8.1 Calculating SSCQm from gaugings 67
8.2 Processing turbidity or ABS data to provide a surrogate SSCindex record 69
8.3 Calibrating SSCindex to SSCQm 72
8.4 Managing suspect SSC laboratory results 73
8.5 Assigning quality codes to SSCQm records 74
8.6 Calculating time-averaged suspended sediment load 75

9 Flow-Proportional Composite Auto-sampling 77
9.1 Purpose 77
9.2 Principles 77
9.3 Hardware requirements 77
9.4 Parameter setting 78
9.5 Logging field data 78
9.6 Infilling missing record 79
9.7 Calculating and filing incremental SS load 79
9.8 Calculating time-averaged SS load 80

10 Sediment Rating Method 81
10.1 Preamble 81
10.2 Sediment rating approaches 81
10.3 Sampling strategy for statistical ratings 82
10.4 Fitting sediment ratings 83
10.5 Event sediment ratings 86
10.6 Calculating time-averaged SS loads using instantaneous sediment ratings 87
10.7 Calculating time-averaged SS loads using event sediment ratings 88

11 Laboratory Methods 90
11.1 Sand/mud splits 90
11.2 Suspended sediment concentration 90
11.3 Organic content 97
11.4 Reporting concentration results 97

11.5 Particle size 98
11.6 Other laboratory procedures 99

12 Particle Size Analysis 100
12.1 Overview 100
12.2 Purpose 100
12.3 Variables measured 100
12.4 Method options 101
12.5 In situ vs laboratory measurements 102
12.6 Field sampling requirements for laboratory analysis of particle size 102
12.7 Sample mass requirements for particle size analysis 103
12.8 Converting particle- or volume-based data to mass-based size distributions 104

13 Deposited Fluvial Sediments 105

14 Quality Codes 106
14.1 Site Quality Matrix 108
14.2 SSCindex Value Quality Matrix 109
14.3 SSCQm Value Quality Matrix 110

Annex A – List of Referenced Documents 111

Annex B – Other SSC measurement technologies 115
B-1 Laser diffraction 115
B-2 Pressure differential systems 116
B-3 Other types under development/evaluation 116

Annex C – Isokinetic samplers developed by FISP and their characteristics 117

Annex D – Description of FISP Suspended Sediment Samplers 121
Sampler nomenclature 121

Isokinetic depth-integrating samplers 121

Annex E – Developing calibration functions between turbidity and suspended sediment concentration 126

Annex F – Developing calibration functions between SSCindex and SSCQm 132

Annex G – Example desktop for fitting sediment rating curve 135

Annex H – Quality matrix examples 136

Normative References

This Standard should be read in conjunction with the following references:

- NEMS *Glossary*
- NEMS *Quality Code Schema*

About this Standard

Introduction

The sediment load of a river is typically differentiated by its mode of entrainment: the suspended load comprises fractions fine enough to be dispersed within the water column by turbulence, while the bed load comprises fractions too coarse and heavy to be suspended but which roll, skip, and slide over the river bed. Clay, silt, and the finer grades of sand are typically carried as suspended load, which tends to dominate the total sediment load in most New Zealand rivers, except in steep, headwater streams. This Standard concerns measurement of the suspended sediment (SS) load.

During freshes and floods, when most of the suspended load is transported, the clay and silt fraction (finer than 63 μm) is usually well mixed in the water column and is often termed 'wash load', but suspended sand generally is more concentrated towards the bed and settles and becomes part of the bed load when velocities wane. The wash load tends to be supply limited, meaning its concentration in suspension is determined by its delivery from erosion sites rather than by the river's capacity to carry it. While the suspended sand load may theoretically be capacity limited, it may also be supply limited (at least in gravel-bed rivers) because sand grains in the bed material are censored from the flow by bed-surface armouring. Consequently, the suspended load of a river is usually indeterminable by a physics-based formula and must be measured.

Measurements of suspended loads in New Zealand rivers began in the 1950s in response to soil conservation problems and were undertaken by hydrological survey teams of the Ministry of Works and Catchment Boards. In the 1960s and 1970s, measurements were extended into catchments of interest to hydro-power development to assess potential reservoir sedimentation. These early measurements generally used samplers and protocols developed in the United States by the Federal Interagency Sedimentation Project (FISP), and data were plotted on 'sediment rating curves' to estimate long-term average loads. In the 1980s, measurements were made in smaller catchments to assess the impact of land cover and land use on catchment sediment yields, with growing interest in the contribution of individual storm events, particularly large storms (such as Cyclone Bola in 1988). Measurements in remote and 'flashy' streams became feasible with the advent of automatic samplers. Sensors to measure turbidity as a surrogate for suspended sediment concentration (SSC) also became available in the 1980s, while acoustic backscatter, usually as a biproduct of acoustic current measurement, has provided a similar SSC surrogate in recent years.

The last national network of suspended load monitoring stations was operated by the National Institute for Water and Atmospheric Research (NIWA) until the mid-1990s. Since then, suspended sediment load measurements have been continued on an independent basis by several regional authorities, research agencies, and by NIWA under contracts for water-use industries, notably the hydro-power industry. Regional authorities have used (and continue to use) measurements of suspended load to direct, and assess the effectiveness of, soil conservation efforts. In particular, Horizons Regional Council maintains a strong tradition of suspended load measurements in the Manawatu-Wanganui region that began in the 1950s.

Fine sediment has been recognised as a contaminant of national significance for New Zealand's freshwater and estuarine water bodies, and its mitigation will be addressed by the National Policy Statement for Freshwater Management (NPS-FM). Once implemented, this policy will require quantitative measures of stream suspended sediment loads, including the sediment characteristics

of size grade and mineral or organic composition (since these exert important controls on sediment-related environmental variables such as water clarity).

A manual detailing field, laboratory, and office procedures for measuring the suspended load in New Zealand rivers using depth-integrating samplers was prepared by NIWA in the 1990s (Hicks and Fenwick, 1994), based largely on US Geological Survey (USGS) documentation (e.g. Guy and Norman, 1970; Edwards and Glysson, 1988). This Standard updates that manual (drawing also on updated USGS documents such as Edwards and Glysson, 1999) and includes procedures for generating continuous records of suspended sediment load using turbidity and acoustic backscatter as surrogates for SSC. Procedures for turbidity monitoring per se are detailed in the NEMS *Turbidity Recording*.

Objective

The objective of this Standard is to ensure that data for determining suspended sediment loads in New Zealand's rivers and streams are gathered, processed, and archived in a verifiable and consistent manner and are suitable for 'at site' and comparative analyses.

Scope

This Standard details procedures for collecting and processing data for determining quasi-instantaneous and time-averaged loads of suspended sediment in rivers and streams. It focuses on a primary data collection strategy that (i) uses continuous, instrumented recording of in situ turbidity or acoustic backscatter as a surrogate for SSC at an index location, and (ii) converts this index record to one of cross-section averaged SSC using a relation developed by undertaking depth-integrated sampling at multiple verticals across the stream cross-section. The Standard includes:

- site selection
- application of the turbidity- or acoustic-based surrogate approach, including collection of calibration samples
- description of alternative measurement approaches (e.g. sediment rating curves, composited auto-sampling)
- procedures for determining the cross-section mean SSC
- laboratory procedures for determining SSC, and
- field and laboratory procedures for suspended sediment particle size analysis.

While this Standard lists supplementary or affiliated measurements (including streambed size grading, deposited fine sediment cover on the streambed, and channel hydraulic variables) that may be made to enhance the information value of the suspended sediment monitoring, it does not detail the methodologies for these measurements but, instead, provides references to appropriate methods.

Exclusions

This Standard does not apply to:

- the acquisition and analysis of stream bed load data
- the determination of the sand load in the near-bed zone unsampled by isokinetic samplers
- the acquisition and analysis of stream dissolved load data, including nutrient loads
- the acquisition and analysis of stream water quality data
- application of the suspended sediment data, for example, for:
    - catchment erosion-type classification or model development
    - estimation of streambed sediment deposition rates, or
    - classification of streambed substrate type.

The Standard – Suspended Sediment

Primary Method

For data to meet the Standard and to secure the highest quality code (*QC 600*), the Primary Method shall be adopted and the following shall be achieved:

Measurement objectives	The objectives shall be to determine the measurable, time-averaged load of suspended sediment, its split between sand and mud size fractions, and the volatile organic content of each of these fractions.	
Metadata	Metadata shall be recorded for all measurements and samples collected.	
Primary Method	Time-series records	Use turbidity or acoustic back-scatter sensors to collect a surrogate time-series record of SSC adjacent to the sensor ("point measurements").
	Surrogate sensor calibration to SSC_{index}	Calibrate the point surrogate measurements to SSC adjacent to the sensor (SSC_{index}) by collecting, with an autosampler, point water samples beside the sensor covering the full range of the sensor
	Infill sampling	Particularly if using a turbidity sensor, collect infill samples beside the sensor under high-flow conditions when the sediment concentration is expected to exceed the sensor's operating range, or at baseflows when the turbidity may be dominated by factors other than suspended sediment. Also collect infill samples if the surrogate sensor is too close to the water surface or becomes exposed at baseflows.
	Calibration of SSC_{index} to discharge-weighted, cross-section mean SSC (SSC_{Qm})	Calibrate SSC_{index} to SSC_{Qm} by undertaking suspended sediment gaugings to collect isokinetic,

		depth-integrated SSC samples at multiple sampling verticals whilst collecting concurrent point SSC samples at the index location
	Laboratory analysis	Analyse all of the field samples for their separate mass concentrations of sand and mud and their volatile organic content
Stationarity	The record shall be considered stationary if temporal variability recorded in the suspended sediment load: • is due only to processes or factors associated with the delivery of sediment to the stream from its catchment and/or the stream's capacity and competence to transport this load, and • is not due to drift/change/bias in field or laboratory instruments or procedures	

Requirements

The following criteria apply to the Primary Method procedures:

Field instruments/equipment	Acoustic backscatter sensors	Acoustic backscatter records shall by preference be collected using sensors emitting 8 MHz sound, be calibrated to return equivalent silt-sand concentrations in mg/l, and range between 0 and at least 10,000 mg/l
	Turbidity sensors	Turbidity records shall by preference be collected using sensors that follow the ISO 7027 protocol, and sensors shall range between 0 and at least 4000 turbidity units and be actively managed to inhibit biofouling, by equipping with an anti-biofouling device and/or by manual cleaning as needed
	Auto-samplers	Auto-samplers should contain at least 24 bottles and shall be capable of having sampling triggered by a programmable data logger
Field procedures	Isokinetic samplers	All samplers used for suspended sediment gaugings shall be

		approved by the US Federal Interagency Sedimentation Project
	Acoustic backscatter recording	As specified herein
	Turbidity recording	As specified in the NEMS *Turbidity Recording*
	Point/auto-sampling	As specified herein
Location of measurements	Manual suspended sediment gauging	EDI approach (minimum 5 verticals unless width less than 10 m and sediment shown to be well mixed) by preference or EWI approach (minimum 10 verticals except when width less than 5 m, when 5 can be used)
Timing of measurements	Field turbidity or acoustic backscatter	Logged every 5 minutes
	Point sampling	For high-flow infill: at least 2-hourly For baseflow infill: bi-weekly For sensor calibration to SSC_{index}: collect samples that cover as much of the full range of the sensor as possible at least once/year
	Manual suspended sediment gaugings for SSC_{index} to SSC_{Qm} relationship calibration	At least 4 per year required, at discharges between mean discharge and mean annual flood discharge, until an adequate relation is established; then at least one per year to check stability of relation
Associated data	Discharge	Continuous records of discharge shall be collected at or near suspended sediment monitoring stations, using procedures detailed in the NEMS *Open Channel Flow Measurement*
		Discharge gaugings undertaken concurrently with sediment gaugings shall use procedures detailed in the NEMS *Open Channel Flow Measurement*
Laboratory analyses	Suspended sediment concentration	ASTM D3977-37 SSC Procedure options A, B, or C, with variations permitted as specified herein
		Results on sample sediment mass, volume, and SSC to be reported as

		integer values in units of mg, ml, and mg/l, respectively. Reporting Limits shall be 1 mg for sediment mass, 1 ml for sample volume, and $1000/V$ rounded-up to nearest integer for SSC (where V is sample volume in ml). Results less than Reporting Limit (x) shall be reported as "< x".
	Volatile organic concentration	APHA 2540 E procedure
		Results to be reported as mg/l of volatile organics. Reporting Limit shall be as for SSC. Results less than Reporting Limit shall be reported as for SSC.

Other Methods

The Standard also permits the following Other Methods in certain circumstances, but data collected using these methods can only secure a maximum *QC 300* rating. These Other Methods share with the Primary Method common:

- measurement objectives
- stationarity considerations, and
- requirements for manual suspended sediment gaugings.

In addition, with the Other Methods the following shall be achieved:

Side-looking ADCP	Time-series records	Use a permanently installed side-looking Acoustic Doppler Current Profiler (ADCP) to collect a surrogate time-series record of SSC across a part of the channel cross-section
	Calibration to SSC_{Qm}	Calibrate surrogate record to SSC_{Qm} by undertaking suspended sediment gaugings to collect isokinetic, depth-integrated samples at multiple sampling verticals whilst collecting concurrent side-looking ADCP measurements
	Laboratory analysis	Analyse all of the field samples for their separate mass concentrations of sand and mud

		and their volatile organic content, as detailed above for Primary Method
Flow-proportional composite auto-sampling	Suspended sediment load accumulation within runoff events	Use auto-sampler programmed off stage record to collect samples flow proportionally, compositing multiple samples into auto-sampler containers
	Calibration to SSC_{Qm}	Calibrate auto-sampled SSC record to SSC_{Qm} by undertaking suspended sediment gaugings to collect isokinetic, depth-integrated samples at multiple sampling verticals whilst collecting concurrent auto-samples
	Laboratory analysis	Analyse all of the field samples for their separate mass concentrations of sand and mud and their volatile organic content, as detailed above for Primary Method
Sediment rating	Dataset of concurrently measured SSC and water discharge	Either (1) compile dataset of suspended sediment gaugings using isokinetic, depth-integrated samples at multiple sampling verticals to measure SSC_{Qm}, or (2) compile dataset using an auto-sampler to measure SSC_{index}
	If using auto-sampler, calibrate SSC_{index} to SSC_{Qm}	Calibrate auto-sampled SSC_{index} record to SSC_{Qm} by undertaking suspended sediment gaugings to collect isokinetic, depth-integrated samples at multiple sampling verticals (to measure SSC_{Qm}) whilst collecting concurrent auto-samples (to measure SSC_{index})
	Laboratory analysis	Analyse all of the field samples for their separate mass concentrations of sand and mud and their volatile organic

		content, as detailed above for Primary Method
	Rating development	Ensure dataset and curve-fitting procedures are unbiased, as detailed herein

Requirements

The following criteria apply to the Other Method procedures:

Field instruments/equipment	Side-looking ADCPs	Side-looking ADCPs as described in Landers et al. (2016)
	Auto-samplers	Auto-samplers shall be capable of having sampling triggered by a programmable data-logger
	Isokinetic samplers	All samplers used for suspended sediment gaugings shall be approved by the US Federal Interagency Sedimentation Project
Field procedures	Side-looking ADCPs	As specified in Landers et al. (2016)
	Auto-sampling	As specified herein
	Manual suspended sediment gauging	EDI approach (minimum 5 verticals) by preference or EWI approach (minimum 10 verticals except when width less than 5 m, when 5 can be used)
Timing of measurements	Side-looking ADCP records	Logged every 5 minutes
	Flow-proportional composite auto-sampling	Flow volume and stage thresholds set to ensure at least 16 composite samples per event
	Auto-sampling to compile sediment rating dataset	At least 6 runoff events auto-sampled per year for at least 5 years
	Manual suspended sediment gaugings to calibrate auto-sampler or side-looking ADCP records to SSC_{Qm}	At least 5 suspended sediment gaugings required between mean discharge and mean annual flood discharge to establish relation; then at least one per year to check stability of relation
	Manual suspended sediment gaugings to compile sediment rating dataset	At least 6 suspended sediment gaugings per year during runoff events, for at least 5 years

Associated data	As per Primary Method for associated discharge records and gaugings
Laboratory analyses	As per Primary Method for SSC and organic volatiles analysis

1 Measurement

The suspended sediment load (L, mg/s) of a river is the product of SSC (c, mg/l) and water discharge (Q, l/s), both of which can vary significantly with depth and across-channel. The SSC variation depends on both the sediment fall speed (a function of water temperature and grain size, shape, and density) and the vertical and lateral variation in turbulence intensity. Determining the suspended load passing a river cross-section thus requires an integration of the spatially varying SSC and velocity (v, m/s). This can be expressed as:

$$L = \iint c_{xz} v_{xz} dz dx = \int \left[\int c_z v_z dz \right] dx$$

Where xz denotes variation laterally (x-direction) and vertically (z-direction) above the streambed. Note that the water discharge is:

$$Q = \iint v_{xz} dz dx$$

L/Q is the ratio of the sediment and water discharges and is termed the discharge-weighted mean SSC (SSCQm, mg/l), also referred to as the cross-section mean SSC. Determining SSCQm is the end-result of any suspended sediment load measurement, since it can be readily converted to the cross-section's suspended load simply by multiplying it by the water discharge (whether measured or determined by stage-discharge rating).

By sampling isokinetically (i.e. by collecting a water sample such that the flow entering the sampler nozzle is at the ambient flow velocity), depth-integrating samplers, as they are traversed across the flow depth, perform a mechanical integration of the ∫cz·vz dz and ∫vz dz integrals at a sampling vertical, with the mass of sediment in the sample being proportional to the unit sediment load passing the vertical and the volume of the sample being proportional to the unit discharge. Accumulating the results from depth-integrated sampling at multiple verticals across the channel (termed a suspended sediment gauging), after appropriate weighting by the discharge represented by each vertical, thus provides the total cross-section suspended load (L).

Generally, suspended sediment gaugings must be undertaken manually [1] and require substantial time and effort, so cannot be done on a continuous basis. Figure 1-1 outlines possible methodological pathways for arriving at a CQm record of high temporal resolution.

Alternative approaches involve collecting water samples at a fixed (index) location, often beside the stream bank, and calibrating a relationship between the SSC at the index point (SSCindex) and the SSCQm. One index-sampling option is direct measurement of SSC in samples collected, for example, by a bank-mounted automatic sampler (hereafter auto-sampler) programmed to trigger at frequent intervals and/or key times during runoff events.

Another index-monitoring option is to measure, at the index-point, an SSC surrogate that can be readily recorded by an instrument. Example instruments include optical backscatter (OBS, or turbidity), acoustic back-scatter (ABS), and water-density sensors. Index monitoring with surrogate sensors requires calibration relationships to be

[1] *While the equivalent to a depth-integrated gauging result can be obtained by analysis of acoustic backscatter intensity from ADCP measurements of water discharge (since, once corrected for range, this provides a surrogate of the local SSC) or by laser-diffraction instruments, these technologies still require manual sampling to calibrate their output to mass-based SSC.*

developed between the SSC surrogate (e.g. turbidity) and SSCindex (as well as between SSCindex and SSCQm).
Figure 1-1 outlines possible methodological pathways for deriving an SSCQm record of high temporal resolution. Section 1.2 outlines the Primary Method pathway from Figure 1-1 that is recommended in this Standard. Other method pathways that may be acceptable under certain conditions (albeit sometimes with compromise regarding result quality) are outlined in Section 1.3.

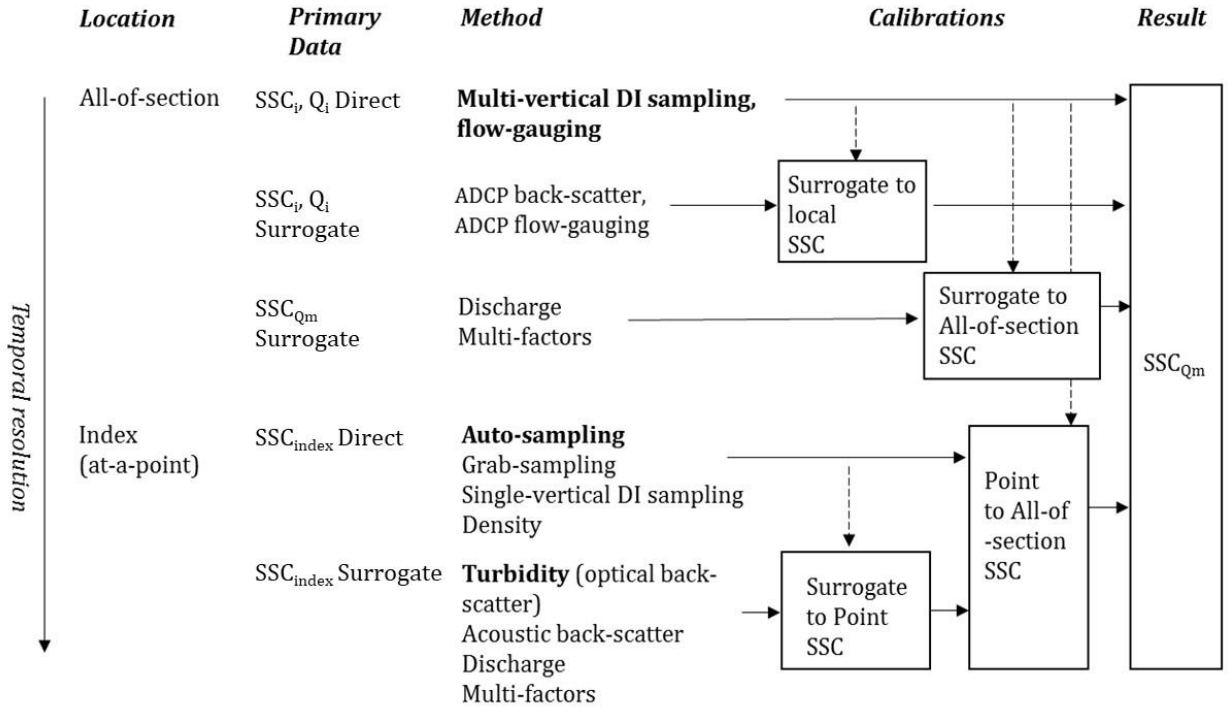


Figure 1-1 – Method pathways for determining flow-weighted, cross-section mean SSC (SSC_{Qm}) for the purpose of recording suspended sediment load.

Bold font shows components of the method pathway based on use of a turbidity sensor as an SSC surrogate. i-suffixes indicate measurements made across multiple verticals or flow sections.

1.1 Primary Method

The Primary Method pathway (from Figure 1-1) recommended in this Standard for collecting continuous SSC_{Qm} records involves the use of a surrogate instrument to derive SSC_{index}, either:

- a turbidity / optical backscatter (OBS) sensor, or
- an acoustic backscatter (ABS) sensor.

These surrogates have been adopted because they:

- generally provide a more reliable surrogate for SSC than does water discharge,
- provide a record of higher temporal resolution than allowed by auto-samplers, and
- require less frequent field servicing than auto-samplers (e.g. when used to collect a continuous SSC record, an auto-sampler must be kept with a supply of empty sample bottles).

Note: While the acoustic surrogate instruments offer several advantages over optical (turbidity) instruments (including higher SSC ranges and invulnerability to biofouling), there is yet little experience around their use for SSC monitoring in New Zealand – whereas turbidity sensors have been widely used for many decades. Thus, the choice of a single primary surrogate instrument is currently left "open" in this Standard until adequate experience with acoustic instrumentation is accumulated.

1.1.1 Calibration and data streams

In the Primary Method pathway, the SSC surrogate record shall be converted to discharge-weighted, cross-section mean SSC (SSC_{Qm}) in two steps:

- calibration of at-a-point turbidity/ABS to at-a-point SSC (SSC_{index}), and
- conversion of SSC_{index} to SSC_{Qm}.

The main justifications for this two-step calibration (instead of relating point turbidity/ABS directly to SSC_{Qm}) are:
The at-a-point turbidity/ABS vs SSC relationship depends on the size mixture of the suspended load and may vary substantially (up to a factor of ten) within events and over time. Thus, a relatively large number of samples is required to establish and maintain this relationship, and these are expediently collected with auto-samplers.
The SSC_{index} to SSC_{Qm} ratio depends on the lateral and vertical extent of sediment mixing, which depends on both the sediment size grading and flow turbulence.
The Primary Method pathway therefore requires collection of three data streams:

- turbidity/ABS records
- point samples collected beside the surrogate sensor to calibrate turbidity/ABS to SSCindex, and
- concurrent point samples and suspended sediment gaugings to calibrate SSCindex to SSCQm.

Note: The same point samples may be applied to both calibration steps. Point samples may also be collected to "infill" spans of unreliable turbidity/ABS record.

1.1.2 Procedures

When using turbidity as the SSC surrogate, turbidity records shall be collected, processed, and preserved as specified in the NEMS *Turbidity Recording* and as expanded on in Section 8 of this document. After processing, the turbidity records shall be converted to SSC_{Qm} records by application of the two-step calibration relations.
When using ABS as the SSC surrogate, ABS records shall be collected, processed, and preserved similarly to turbidity records as in Section 9 of this document. After processing, the ABS records shall be converted to SSC_{Qm} records by application of the two-step calibration relations.

1.1.3 Fixed-point sample collection

Fixed-point samples collected beside the surrogate sensor are used for three purposes:

- calibrating the surrogate measure to SSC_{index}
- calibrating SSC_{index} to SSC_{Qm}, and
- providing infill records of SSC_{index} beside the surrogate sensor under conditions when the sensor's record is unreliable (more so when using turbidity sensors).

Fixed-point samples should generally be collected by auto-sampler. Procedures for auto-sampler operation for these purposes are detailed in Section 7.

1.1.4 Suspended sediment gaugings

Suspended sediment gaugings using isokinetic samplers shall be used to collect data for relating SSCindex to SSCQm. Equipment and procedures for undertaking suspended sediment gaugings are detailed in Section 6.

1.2 Other methods

Other method combinations are shown in **Figure 1-1**. They may be used under appropriate circumstances, but (because of issues such as acuracy, reliability, temporal resolution, maturity of technology, etc) they cannot be assigned *QC 600*. These methods include:

- other types of SSC sensor
- side-looking acoustic doppler current profilers (ADCPs)
- flow-proportional composite auto-sampling
- sediment ratings, and
- multiple-sensor deployment.

1.2.1 Other types of SSC sensors

Other instruments for measuring SSC include laser diffraction and pressure differential systems. Laser diffraction instruments can measure both SSC and particle size at-a-point, but these measurements are based on particle volume, not mass, and so are not directly equivalent to SSC. Pressure differential instruments relate SSC to water density, measuring the density with ultra-sensitive pressure sensors which can be deployed at-a-point or in a vertical array. Neither technology is widely used. Further details, including advantages and limitations, are included in Annex B.

1.2.2 Side-looking ADCPs

The acoustic backscatter intensity returned from permanently installed, bank- or bed-mounted (i.e. side-looking or up-looking) ADCPs is related to SS concentration, and so ADCPs can also be used to provide continuous surrogate records of SSC. They collect data from multiple locations along the acoustic beam over the cross-section (or in the vertical if deployed in up-looking mode), so their measurement remains only an index of the cross-section average SSC; nonetheless, they return a result more representative of the cross-section average SSC than does a point sensor, and so they should be directly calibrated to SSC_{Qm}.

An advantage of this technology is that the same instrumentation provides an index of both discharge and SSC. Indeed, discharge monitoring is usually the intended purpose of an ADCP installation, with the SSC-surrogate record a by-product.

While used overseas (notably by the USGS, see Wood, 2014), there is limited experience with using side-looking ADCPs to monitor SSC in New Zealand. Thus, if using ADCP backscatter records as the SSC surrogate, such records shall be collected, processed, and preserved as described in Landers et al. (2016), or Topping and Wright (2016) if using two instruments with different acoustic frequencies in tandem.

Note: The distinction between ABS sensors, which are "point" sensors that measure the acoustic backscatter from a single small water volume adjacent to the sensor (analogously to how optical sensors measure the light back-scattered from the near-sensor volume), and ADCPs, which resolve the back-scatter from multiple "bins" spaced along directed sound beams.

1.2.3 Flow-proportional composite auto-sampling

An SSC record compiled from discrete auto-samples collected during runoff events typically has inadequate temporal resolution to provide an accurate, continuous measure of SS load. This results from the limited number of sample bottles in the auto-sampler magazine (typically 24–28), the need to service the sampler whenever the magazine is full, and break-downs associated with a mechanical sampling device. Also, the cost of sample laboratory analysis is high.

To help resolve the sampling frequency issue, composite auto-sampling involves combining, within runoff events, multiple (typically 6 or 8) smaller samples into each auto-sample bottle or into one large bottle. This is permissible providing the sampling is scheduled on a flow-proportional basis – such that each sample represents a given volume of water passing the site. In this case, the sediment mass in the composite sample is proportional to the sediment load accumulated over the sampling period.

This is a workable option providing the auto-sampler can be serviced immediately as required (e.g. as soon as all bottles have been filled or a malfunction is detected) to maintain the continuous record.

Like the OBS and ABS surrogate methods, this method provides an index-sample SSC record at a fixed point (SSC_{index}) which must be related to SSC_{Qm} by developing a calibration relation.
Procedures for collecting data using the flow-proportional, composite auto-sampling method are detailed in Section 11.

Note: Two key differences in the mode of operation of an auto-sampler for this method compared with auto-sampler use to collect samples to calibrate surrogate instruments to SSC_{index} are: the auto-sampler must be operated continuously (as it is the source of the temporal record), and the composite samples indicate a temporally averaged SSC, not an instantaneous SSC.

1.2.4 Sediment ratings

The sediment rating method uses the discharge record as an SSC surrogate, with the sediment rating curve effectively being the surrogate calibration relation. This approach has historically been used for estimating time-averaged suspended load in New Zealand rivers. However, the rating relation can vary considerably within events (e.g. producing "hysteresis loops"), between events (e.g. due to variation in the activity of sediment sources, such as due to seasonal effects), and year to year (e.g. due to the legacy effects of large, rare storms). Thus, unless this variability is sampled without bias and the sediment rating is adequately fitted, the method often produces imprecise and/or biased results that may be inaccurate by a factor of two or more. Also, because of this variation, the method is only appropriate for estimating the long-term average (e.g. annual average) sediment load.

The rating curve may be developed directly with SSC_{Qm} derived from sediment gauging or with SSC_{index} from index samples (e.g. collected by an auto-sampler at a fixed point). In the latter case, a calibration relation with SSC_{Qm} must also be developed.

"Event sediment ratings" can also be developed. These relate the sediment load totalled over discrete runoff events to some easily determined index of the hydrological magnitude of the event (e.g. peak discharge, runoff volume).

Procedures for collecting data for the sediment rating method are detailed in Section 12.

1.2.5 Multiple-sensor deployment

Deployment of multiple surrogate sensor types at the same site (e.g. an OBS and ABS or two ADCPs with different sonic frequencies) can give information on the concentrations of the sand and mud fractions of the suspended load. This is possible because of the varying sensor response with particle-size (e.g. OBS sensors are more sensitive to mud rather than sand, ABS sensors are more sensitive to sand, and ADCP backscatter depends on particle size and sonic frequency). While such cases have been trialled (e.g. Topping and Wright, 2016), they are not yet "mainstream", and so are not detailed further in this Standard.

A sediment monitoring site is defined as the location of the primary instrumentation that captures the time-series record used to determine the suspended load. Usually this will be an SSC-surrogate sensor.

Site selection and instrument/sampler deployment are critical to measuring suspended sediment loads accurately. Key considerations are:

- proximity to associated monitoring (e.g. river/stream discharge);
- channel and bank characteristics;
- accessibility;
- deployment, including practical and safety issues associated with suspended sediment gauging;
- general safety issues;
- affiliated monitoring; and
- metadata.

The extent to which any operational/existing sediment monitoring site does not meet the criteria in the following sub-sections shall be recorded in the Site Quality Matrix.

2 Proximity to associated monitoring

Associated monitoring is that required to enable the data collected by the primary instrumentation to be converted into sediment load.

2.1 Discharge

River/stream discharge is a key component for integrating sediment load over time, therefore:

- sediment load measurements shall be located at, or within 500 m of, a discharge monitoring station, and
- measurable water inflows (e.g. tributaries or drains) or outflows (e.g. water withdrawals for irrigation, seepages) shall not occur between the discharge monitoring station and the sediment measurement site.

2.2 Surrogate to SSCindex calibration sampling

In situ SSC-surrogate sensors (e.g. turbidity sensors) must be calibrated to SSCindex in water samples drawn (usually by auto-sampler) as close as possible to the measurement space of the sensor. Generally, this sampling point (e.g. the instream end of the auto-sampler intake hose) should be within 0.1 m of the sensor vertically and 1 m laterally. Furthermore, there should be no feature (e.g. woody vegetation) between the sensor and the sampling point that creates a significant variation in the local hydraulic conditions between the sampling point and the sensor.

Note: Should the primary SSC-surrogate instrumentation require relocating (e.g. because of bank stability issues or channel changes following a flood), then the new location is deemed to be a new site, and the surrogate to SSCindex calibration should be re-established.

2.2.1 Sediment gauging section

The river cross-section at which the SSCQm is gauged (e.g. to develop a relationship between SSCQm and SSCindex) shall be located as close as practicable to the surrogate sensor and its calibration sampling location; however, it may be located up to 200 m away providing that:

- no water gains or losses occur in the intervening reach of channel
- no riparian sediment sources (e.g. eroding banks, scouring beds) are observed in the intervening reach, and
- no suspended sediment deposition is observed in the intervening reach (e.g. due to deposition along a backwater, entrapment in rank riparian grasses).

The above requirements notwithstanding, the suspended sediment gauging section may be shifted to different locations if necessary to ensure safe and practicable measurements at different discharges (e.g. wading-based sampling may be done at a suitable access point during low to medium discharges, but bridge-based sampling may be required at high discharges).

2.2.2 Channel and bank characteristics

Access and instrument security during floods generally dictate that surrogate sensors (and associated auto-sampler intakes) are deployed from a stream bank (or, rarely, from a bridge pier). The following characteristics of the channel and banks shall be considered when locating instrumentation:

- turbulence and velocity characteristics, and
- channel and bank conditions.

2.2.2.1 Turbulence and velocity characteristics

Ideally and where practicable, surrogate sensors shall be deployed where turbulence is sufficient to maximise the mixing of the suspended load over the cross-section (laterally and vertically), so that the monitoring location is representative of the cross-section.

Surrogate sensors and associated auto-samplers should never be deployed where the local velocity is so low that sediment resuspended by the auto-samplers during their purge cycle is:

- subsequently sampled during their sampling cycle, or
- registered by the surrogate sensor.

2.2.2.2 Channel and bank conditions

Bank conditions at, and immediately upstream of, surrogate sensor and point-sampling sites shall be stable over time. For example, the bankside vegetation should not change over time from grass to progressively larger trees because this would change the bankside roughness and turbulence characteristics, which could then alter the sediment mixing characteristics at the site.

Bank and channel characteristics to avoid include:

- banks that are eroding or are prone to slips;
- banks with trees or shrubs that create low-velocity backwaters that trap sediment;
- sections that have unstable beds (for example, pools and beaches) where mud, sand, gravel, or organic debris can build up and bury or otherwise foul a surrogate sensor or auto-sampler;
- sharp bends and morphological features that induce strong lateral asymmetry in streamwise velocity, secondary currents, and large eddies (including locally reversing flows); and
- sites accessible by livestock, since wading stock can stir-up sediment plumes.

2.2.3 Accessibility

The following accessibility factors shall be considered when selecting a site:

- general access and legal requirements
- instrument servicing, and
- collecting sensor calibration samples.

2.2.4 General access and legal requirements

If a new station is to be established, the following general access issues shall be considered:

- Is safe site access possible all year round at all discharges?
- Can materials and equipment be suitably and safely used during installation?
- Is it possible to obtain a long-term access agreement with any landowners whose land may be crossed when accessing the site?
- What are the environmental effects and resource requirements (from local/regional authorities) and/or other special permit requirements (e.g. from DoC for sites in DoC reserves)?
- Does the site provide security against vandalism?

2.2.5 Instrument servicing

The surrogate sensor shall be accessible over most of the site stage range for:

- servicing
- cleaning biofilm fouling from the lens of a turbidity sensor, and
- clearing flood debris (which can alter the local hydraulic conditions and so alter the calibration relationship between the surrogate and SSCindex).

2.2.6 Collecting point calibration samples

If surrogate to SSCindex calibration samples are collected by auto-sampler:

- the auto-sampler shall be located where it is secure from flood damage at high stages, and
- the auto-sampler's intake hose should be located on the downstream side of the SSC-surrogate sensor so that bed sediment resuspended by the auto-sampler's purge cycle is not registered on the sensor.

If such calibration samples are collected manually, then access shall permit these to be collected as close as practicable to the sensor.

2.3 Deployment

2.3.1 Surrogate sensors

Deployment of turbidity sensors to acquire surrogate SSC records at index points shall be accomplished as detailed in the NEMS Turbidity Recording.

2.3.1 Auto-samplers

Deployment of auto-samplers to collect water samples for calibrating SSC-surrogate sensors to SSCindex shall be as detailed in Annex B of the NEMS Turbidity Recording.

2.3.2 Sediment gauging

When undertaking suspended sediment gaugings, including for rating SSCindex to SSCQm, a key consideration is the infrastructure available to deploy depth-integrating samplers safely and practicably. Deployment options include:

- wading;
- bridges;
- manned cableways;
- slackline cableways, and
- boats.

2.3.3 Wading

Wading, using a wading-rod-mounted depth-integrating sampler, is only an option under flow conditions that may be safely waded. Refer to NEMS Safe Acquisition of Field Data in and Around Fresh Water for further information.

Generally, samplers designed for wading-rod deployment have depth and velocity operating range limits that align with safe wading conditions. However, depth-integrating samplers should not be operated in water less than 0.25 m deep. An open bottle may be used for sampling shallower depths.

2.3.4 Bridges

Bridges provide a stable platform from which to deploy depth-integrating samplers by rod, handline, or cable and reel. Rod or handline deployment is suited for small, low bridges that may not have a handrail. The gauging reel may be mounted on a portable A-frame (a hand-railed bridge) or on a trailer crane (vehicular bridge). A trailer crane mount is required for samplers heavier than 30 kg.

A Traffic Management Plan shall be prepared and implemented for sediment gaugings from vehicular bridges.

2.3.5 Manned cableways

Manned cableways require use of a sampler deployed by cable and reel.

2.3.6 Slackline cableways

Slackline cableways require use of a cable-and-reel sampler. Long slacklines may require an extended cable length.

2.3.7 Boats

Deployment from a boat requires:

- a cable-and-reel sampler;
- a suitable boat (typically jet boats are used in New Zealand);

- a Boating Safety Plan;
- a boat launching ramp that permits handy and safe navigation to the sampling cross-section;
- a means to navigate and remain on-station whilst collecting samples – either a tagline or GPS plotter accurate to 1 m in horizontal positioning; and
- an assistant on-board to change sample bottles. If the type of boat (e.g. a jetboat) prevents safe servicing of the sampler from within the boat, then a handy, safe and navigable bank location is required for the assistant to service the sampler from the bank.

Usually, and certainly in fast flow, the most suitable and stable deployment configuration is off the bow of the boat, using a sampling boom that overhangs the bow and positions the gauging reel in the cockpit for easy operation by a boat crew member (Figure 2-1).

Samplers should not be deployed:

- from boats "on the plane";
- over the sides of narrow, unstable boats; or
- close to boat sterns and propulsion units.

Figure 2-1 – A 48-kg US P-61 point sampler deployed from a jetboat using a bow-boom and gauging reel.

Note GPS antenna to assist navigation across the sampling section.

2.4 General safety and security issues

2.4.1 Site access

Site access shall be secure and safe for the complete period of monitoring.

2.4.2 Safety

Hazards (for observers, the public, livestock, and wildlife) related to the location and measurement activity shall be identified and eliminated (if possible), or at least mitigated to acceptable levels.

A safety plan shall be developed for servicing the site and undertaking gauging activities under all envisaged conditions. This should include appropriate safety procedures and training for staff, including safe operation of (often heavy) sampling and associated deployment equipment.

Boating Safety Plans shall be required for all manned boat deployments and Traffic Management Plans shall be required for all operation on public bridges carrying motor vehicle traffic.

2.4.3 Hazard review

On selection of a final site, a hazard review shall be carried out in accordance with relevant guidelines or best practice.

The potential for human activity to affect the monitoring, e.g. vandalism, shall be minimised.

Where the site is accessed through private property, communication with the landowner is required before site visits to ensure no new hazards are present.

2.5 Affiliated monitoring/measurements

Affiliated monitoring or measurement involves collecting data complementary to, but not essential for the determination of, suspended sediment loads. Such affiliated data may, for example, help develop relationships between suspended sediment load or concentration and other environmental variables (e.g. water clarity, deposited sediment). Affiliated measurements at the suspended sediment monitoring site may occur:

- concurrently with the suspended load measurements, or
- at a subsequent time when flows are lower, access to the channel is safer, and the channel bed and banks are visible, such as during recession flows following a flood that was sampled for sediment. (Post-flood measurements can provide qualitative indications of what might have occurred during floods; for example, the grain size of fine sediment drapes left on the banks after high-flow events will indicate the composition of the suspended load which, in turn, will give an indication of how well mixed the load was over the cross-section.)

2.5.1 Concurrent affiliated measurements

Concurrent affiliated measurements may include:

- water clarity;
- water temperature;
- water colour;

- water salinity or conductivity;
- dissolved load and nutrients;
- sediment tracers (to fingerprint sediment sources);
- hydraulic data such as water surface level or slope; and
- photographs, including of water surface features such as standing waves.

2.5.2 Subsequent affiliated measurements

Subsequent affiliated measurements may include:

- deposited fine sediment cover on streambed ;
- bed surface size grading;
- bed subsurface size grading;
- periphyton cover;
- channel morphological features (e.g. bed long-profile, cross-sections);
- observations (e.g. of flood debris, sediment deposits on the streambed and banks, channel morphology change); and
- photographs.

2.5.3 Archiving affiliated measurements

All affiliated measurements, including photographs, should be archived or referenced with the primary measurements.

2.6 Metadata

Metadata include information that:

- informs on the location and timing of the measurements/samples collected for each variable;
- captures key details of the methods and instrumentation being used;
- explains the purpose of the monitoring;
- places the data collected at the site in a broader (e.g. catchment-scale) context; and
- informs on the stationarity of the record (see Section 3).

For every site at which suspended sediment data is collected the following metadata shall be recorded:

- date and time of the measurement/sample-collection;
- river name;
- site identification (name and/or number);
- site location (New Zealand Transverse Mercator coordinates);
- SSC-surrogate instrument type, serial number, certified operating range, expected over-range behaviour, installed location, installation history, calibration history, and maintenance history;

- auto-sampler location (particularly the location of the in-stream intake), type, sampling strategy (e.g. time/stage/turbidity/flow-proportional control), threshold changes in time/stage/turbidity/flow-volume to trigger a sample, threshold values to begin and end sampling, and history of alterations to these operating parameters;
- manual sampler deployed, including sampler type, nozzle size, bottle size, deployment method (e.g. bridge, cableway);
- manual sampling strategy employed (EDI or EWI) and number of verticals;
- laboratory analyses performed on samples (e.g. SSC, particle size analysis);
- list of associated variables (e.g. discharge) and affiliated variables (e.g. water clarity) measured on site, and their measurement location if different from the surrogate-instrument measurement location; and
- comment files associated with particular events or actions.

In addition, the following metadata should be recorded:

- site purpose (e.g. to monitor effectiveness of catchment erosion mitigation works, benchmark monitoring site);
- catchment characteristics (e.g. area, soil types, geology, land use) – particularly those that indicate the expected sand/mud proportions of the suspended load;
- bed-material composition – particularly the proportion of the bed that is sand-covered – and the history of any significant changes observed (e.g. after significant storm event);
- comments relating to:
    - significant storm events that may relatively abruptly change the catchment sediment yield;
    - the implementation of catchment management plans that may change the sediment yield over time; and
    - changes in land cover or land use (e.g. conversion to pasture, forest harvesting) that may change the sediment yield over time;
- site plan diagram including auto-sampler/sensor location relative to the sediment gauging cross-section;
- comments on unavoidable siting issues or compromises (e.g. potential bank stability issues).

2.7 Stationarity

Stationarity of measurements shall be maintained so that any temporal variability recorded in the suspended sediment load is caused only by processes or factors associated with the delivery of sediment to the stream, including the stream's capacity and competence to transport this load. Such processes/factors causing load variability can be natural or human induced.
Natural causes include large storms, earthquakes, fires, naturally driven climate change, and random spatial variation in the activity of erosion sites.

Human-induced causes include land-use and land-cover change, accelerated erosion or erosion mitigation works, alteration of river flow regime (e.g. water storage and

diversions), alteration of connectivity of sediment transport pathways (e.g. dams, sediment extraction), river channel earthworks, and human-influenced climate change.

Measurement-induced non-stationarity (or bias) in sediment load records can result from changes in:

- the instrument (e.g. turbidity sensor) used for collecting a surrogate SSC record, by:
    - instrument calibration drift;
    - fouling of turbidity sensor lenses;
    - changing instrument type (or even instruments of the same type) without instrument re-calibration;
    - moving the location of the sensor or intake of an auto-sampler without re-calibration; and
    - undetected change in the surrogate variable vs SSC calibration relationship (e.g. changes in the suspended sediment particle size grading alters the turbidity vs SSC calibration).
- the type of depth-integrating sampler and nozzle used, if they were deployed in conditions or in a way that violated the requirements of isokinetic sampling;
- the sampling strategy, for example, by changing from all-of-cross-section sampling (with depth-integrating samplers at multiple verticals to measure SSCQm) to bankside point sampling (e.g. using an auto-sampler to measure SSCindex) without applying a SSCindex:SSCQm adjustment; and
- the laboratory procedure used to determine SSC (e.g. changing from the total suspended solids (TSS) to the SSC procedure without adjusting for bias present in the TSS procedure – refer Section 9.2).

2.8 Units

The suspended sediment concentration (SSC) has units of sediment mass per unit volume of water and shall be reported as mg/l (equivalent to g/m^3).

Note: This applies to SSC_{index} sampled at-a-point, the velocity-weighted SSC sampled by a depth-integrating sampler, and the SSC_{Qm} derived from a sediment gauging.

The "instantaneous" suspended sediment load passing a cross-section, associated with a single measurement or record, has units of mass per unit time and shall be reported as g/s.

The time-averaged load shall be reported in units consistent with the time-base of the averaging, e.g. t/day for daily average load, t/yr for annual average load.

Sediment yield is the average annual load per unit catchment area and shall be reported as $t/km^2 \cdot yr$.

Note: Yield is sometimes also expressed as t/ha·yr. It may be converted to denudation rate by assuming a sediment density.

Units for turbidity data collected as a surrogate for SSC shall be reported according to the measurement protocol of the turbidity instrument, as described in the NEMS *Turbidity Recording*:

- data collected using the NEMS standard turbidity protocol (ISO 7027 standard) shall be reported in Formazin Nephelometric Units (FNU);
- data meeting the EPA 180.1 standard shall be reported in Nephelometric Turbidity Units (NTU); and
- data from instruments meeting neither the ISO 7027 nor EPA 180.1 standards but using a backscatter-type detection system and using formazin as the calibration standard shall be reported in Formazin Backscatter Units (FBU).

Raw SSC-surrogate data output by an acoustic backscatter (ABS) sensor shall be reported with units of mg/l providing the sensor has been factory calibrated to a reference sediment.

Note: The raw output records from an ABS sensor still require a field calibration as there is no guarantee that the field sediment characteristics will match those of the reference sediment mixture used for the factory calibration.

3 Data Preservation

This section describes the preservation of data that are required to be retained by the collecting agency. The objectives of data preservation are to:

- secure, on an electronic archive, as complete a record of SS load as possible
- provide an audit trail of all field procedures used, and
- provide an audit trail of data transformations required to convert the raw field record to the final archived record.

It covers:

- preserving time-series data while it is being collected (e.g. by site inspection, telemetry)
- preserving linked data streams and intermediate results such as calibration data and calibration relationships
- data editing logs
- laboratory results, and
- data archiving.

The main focus in this section is on the data streams associated with the Primary Method. Data preservation for the other methods listed in Section 1.2 is addressed at outline-level only.

3.1 Surrogate time-series records

3.1.1 Surrogate time-series data acquisition and recovery

High-quality data-streams from SSC-surrogate sensors shall be ensured, wherever practical, by:

- telemetering the surrogate data, filing the raw data at regular intervals (daily–weekly);
- regular (at least weekly) remote inspection of the telemetered data, to be alert for:
    - evidence of sensor fouling (notably with turbidity sensors)
    - sensor burial under deposited sediment
    - power supply condition, or
    - other types of instrument malfunction;
- regular (at least monthly if not telemetered, bi-monthly if telemetered) site inspection, including:
    - sensor checks against reference sensors (for turbidity); and
    - checking for site issues that may compromise data acquisition (e.g. channel shifts, vegetation growth).

Issues detected by remote or site inspection shall be rectified as soon as practical.

3.1.2 Data editing

Surrogate data shall be edited as appropriate to manage fouled or missing records, as detailed in the following sections. A log of data editing shall be compiled and maintained.

3.2 Surrogate to SSCindex calibration

3.2.1 Sample Acquisition

When using an auto-sampler:

- the triggering of auto-samples shall be logged;
- the numbers of filled and remaining empty bottles in the auto-sampler shall be monitored via telemetry, to indicate when the auto-sampler requires servicing; and
- samples should not be left in an auto-sampler for longer than two weeks.

Note: Scheduling auto-samples off the same logger as used to record surrogate data ensures time synchronisation of both. Independent control requires synchronisation checks.

3.2.2 Calibration relationships

The surrogate record to SSC_{index} calibration relationship at a given site may change over time for multiple reasons (e.g. sensor drift, change of sensor, relocation of sensor, change in sediment size mixture). Thus, it is important to keep records of:

- the type and a unique identifier (e.g. serial number) of the surrogate sensor;
- the parameters defining the fitted function;
- key statistics of the fitted function, including its standard error and r2; and
- the start and end dates of the period over which it is applicable.

3.3 Sediment gaugings for SSCQm calibration

3.3.1 Acquisition

All information relating to sediment gauging field choices and operations shall be recorded on a field form, as detailed in Section 6.6.14. Key information summarising these field choices shall be compressed into a "Methods code" for archiving with the gauging results.

For example, for the NIWA field form (Hicks and Fenwick, 1994 – see Figure 6-12), a 9-character string (SSNCInnMF) records the sampler type (SS), nozzle size (N), container size (C), integration mode (I), number of verticals (nn), vertical selection method (M), and source of concurrent flow data (F).

3.3.3 Calibration relationships

The following information shall be recorded for the SSC_{index} to SSC_{Qm} calibration relationship(s):

- the locations of the at-a-point sampling and the sediment gauging cross-section;
- for each data pair, the times over which the sediment gauging was conducted and the sampling times of the matched SSCindex samples;
- key information on each sediment gauging, including sampler/bottle/nozzle choice, EWI or EQI method, and number of sampling verticals;
- the parameters defining the fitted function;
- key statistics of the fitted function, including its standard error and r2; and
- the start and end dates of the period over which it is applicable.

3.4 Laboratory analyses

3.4.1 At the laboratory

Issues can occur with laboratory-despatched samples before and during laboratory analysis. Examples include:

- uncertain/unclear labelling
- sample leakage/spillage in transit or during analysis
- algal growth
- filter-clogging, and
- situations where standard laboratory procedures were not applied or where their application limits were exceeded.

Knowledge of such issues clarifies the value of the laboratory result. Results returned from the laboratory shall therefore include appropriate comments against any compromised samples, and results shall be reported as detailed in Section 13.4.

3.4.2 Back in the office

Laboratory-supplied comments regarding compromised analyses shall be filed with the data, with the data assigned an appropriate quality code.

Further use of compromised data (e.g. in calibration relationships) shall be considered carefully. Such data plotting as outliers on calibration plots shall generally be discarded from function fitting, noting this accordingly (see Section 10.4 for further detail).

3.4.3 Data archiving

Raw and edited SSC-surrogate records shall be archived along with the final transformed, QC assessed record of SSC_{Qm}.

3.5 Other methods

3.5.1 Side-looking ADCPs

As there is yet little experience in New Zealand with use of side-looking ADCPs for SS monitoring, refer to Landers et al. (2016) for data preservation guidelines.

3.5.2 Flow-proportional composite auto-sampling

3.5.2.1 Acquisition

The flow-proportional composite auto-sampling method for obtaining SSC_{index} records requires samples to be collected through all runoff events. Thus, it is imperative the status of the auto-sampler (including the bottle-filling status) is monitored regularly via telemetry and site visits and the sampler is serviced expediently if issues arise.

The following data must be logged electronically on an ongoing basis:

- time when each sample is initiated;
- the bottle number where the sample is direct; and
- the accumulated runoff volume between subsequent samples.

In addition, the following "operating settings" shall be documented:

- the number of sub-samples placed into a sample bottle;
- the sub-sample volume;
- the runoff volume threshold that triggers an auto-sample;
- the stage thresholds at which sampling is initiated and stopped during runoff events; and
- the stage-discharge function coded into the data-logger (used to calculate runoff volume on-the-fly).

Any changes to these operational settings shall be noted, including the time period over which each combination of settings applies.

Note: Even though a telemetered record indicates an auto-sample has been triggered, an auto-sampler mechanical malfunction may result in no physical sample – thus regular site visits to test auto-sampler functionality remain important.

There is a "trade-off" in deciding on the type of compositing container. Compositing into standard auto-sampler bottles (e.g. giving a capacity of 24×8 =192 50-ml sub-samples across 24 bottles before a change of bottles is required) provides reasonable temporal resolution of load over a runoff event and samples "in the bag" should a malfunction develop, but still typically requires sampler servicing between most events. In comparison, compositing into a large container (e.g. 2000 50-ml sub-samples into a 100-l container) allows a longer time before servicing but minimal temporal resolution and greater risk of corrupting the composite sample through a mechanical issue.

3.5.2.2 Data editing, SSCindex to SSCQm calibration, laboratory analysis

Sections 5.1.1.2, 5.1.3, and 5.1.4 also apply to flow-proportional composite auto-sampling for data editing, SSC_{index} to SSC_{Qm} calibration, and laboratory analysis, respectively.

3.5.2.3 Data archiving

Raw and edited SS load increments developed from flow-proportional composite auto-sampling records shall be archived along with the final record transformed to the cross-section averaged load.

Note: The SS load data records generated from flow-proportional composite auto-sampling are incremental – i.e. they indicate the SS load passing the site over the period during which the sub-samples are composited into the sampling container.

3.5.3 Sediment rating method

Data preservation considerations of the sediment rating method centre around the data acquisition, rating curve fitting, and result archiving.

3.5.4 Data acquisition

Sediment rating curves are typically derived from SSC_{Qm} measured by sediment gaugings and so Sections 5.1.3.1 and 5.1.4 apply equally to the acquisition of data for the sediment rating method. If auto-samplers are used for the rating, then Sections 5.1.2.1 and 5.1.3.2 are also relevant (since a correction is required to convert the result to a cross-section average load).

3.5.5 Rating curve development

The following documented records relating to rating curve development shall be kept:

- whether or not the data were log-transformed;
- a comment on whether or not the degree of data scatter increases as discharge increases;
- the parameters defining the fitted function;
- key statistics of the fitted function, including its standard error and r^2;
- the log-bias correction factor (if applied); and
- the start and end dates of the period over which the data were collected.

In addition, "working" results / comments shall document:

- the proportion of time-averaged load transported at flows greater than the maximum sampled discharge;
- the predicted SSC at the maximum discharge on record;
- if rising/falling-stage and seasonal separations of data occur and the proportions of data in each group; and

- if there is a temporal trend in the residuals of the rating.

These give an indication of:

- potential sampling bias in the rating dataset, and therefore the reliability of the results; and
- flow conditions to be targeted for future sampling to reduce such bias.

3.5.6 Data archiving

The sediment rating approach is generally applied to estimating the long-term (multi-year) average sediment load; it is not recommended for generating continuous SSC records if those are required to have reasonable accuracy. Thus, it is generally only necessary to archive the sediment gauging datasets and documents containing the information in Section 5.2.3.2.

4 Suspended Sediment Gauging Equipment and Procedures

4.1 Purpose

The purpose of a suspended sediment gauging is to measure the "quasi-instantaneous" suspended sediment load and discharge-weighted, cross-section mean suspended sediment concentration (SSC_{Qm}).

In the context of the Primary Method pathway pursued in this Standard, the purpose of suspended sediment gaugings is to develop a relationship between SSC_{Qm} and the index or surrogate-derived SSC (SSC_{index}).

4.2 Sampling equipment and procedures

The suspended sediment gauging equipment and procedures detailed below are adapted from Hicks and Fenwick (1994), which, in turn, were adapted from those of the USGS (Edwards and Glysson, 1988, which has subsequently been superceded by Edwards and Glysson, 1999, and augmented by Diplas et al., 2008, Gray et al., 2008, and Gray and Landers, 2015).

The sampling equipment prescribed in this Standard shall be as developed and approved by the United States' Federal Interagency Sedimentation Project (FISP) (Gray and Landers, 2015).

4.2.1 Sampling strategy

The sampling strategy is designed to manage spatial variation in SSC over the measurement cross-section – both across-channel and with depth. Across-channel variation is managed by sampling at multiple verticals and weighting the SSC value from each sub-sample by the percentage of sub-section discharge the sub-sample represents. Vertical SSC variation is managed using isokinetic samplers, either by collecting a single, depth-integrated sample, a series of samples integrated over depth-segments, or a series of point samples at specific depths in the vertical.

4.2.2 Isokinetic samplers

Isokinetic samplers are designed and operated so that the streamflow enters the sampler nozzle at the ambient horizontal water velocity at the location of the sampler intake. Isokinetic sampling ensures that the rate of sample collection is velocity weighted. It also avoids selective sampling of different sediment grain sizes. Sand grains in suspension tend to be under-sampled if the inflow velocity is faster than the ambient velocity – this occurs because, while the water flow lines curve into the sampler nozzle, the greater momentum of sand grains causes them to travel straight past the nozzle. Conversely, a relatively slower intake will over-sample sand.

Isokinetic samplers are also designed to:

- permit the sampler nozzle to reach a point as close to the bed as possible without gouging the bed;
- minimise disturbance to the flow pattern, particularly at the nozzle; and
- fill smoothly, so that air exhausting from the sample bottle does not hinder the entry of the sample.

When an isokinetic sampler is submerged with its nozzle pointing upstream, streamflow enters the nozzle at the same time as air in the sample bottle exhausts. This air exhaust is driven by:

- the positive dynamic head at the nozzle inlet, 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.

Note: Over-filling an isokinetic sampler will result in selective capture of different grain sizes. 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, with streamflow exiting through the air exhaust. The bottle then preferentially traps coarser sediments in suspension, potentially resulting in a positively biased SSC value, even for silt-grade sediment. Section 6.6.7 provides guidance on appropriate sample volumes.

Isokinetic samplers are either:

- depth-integrating samplers, or
- point samplers.

4.2.3 Depth-integrating samplers

Depth-integrating samplers have an inlet nozzle that is always open. Thus, by traversing the sampler through the stream depth at a uniform rate, from the surface to the bed and immediately back again, the sampler collects and accumulates a water sample that is correctly velocity weighted and has an SSC equal to the discharge-weighted mean SSC in the vertical.

Depth-integrating samplers collect their samples either into rigid bottles or flexible bags.

4.2.4 Point samplers

Point samplers differ from depth-integrating samplers by having a solenoid-activated valve that opens and closes the inlet nozzle, enabling them to collect samples over a period of time from discrete depths in a vertical. The results from discrete depths may be used to plot a vertical SSC profile, which can then be combined with a velocity profile to derive a load profile and hence the cross-section sediment load and SSC_{Qm} value.

While their inlet valve is kept open, point samplers may also be traversed in the vertical to collect depth-integrated samples – over the whole depth or over partial spans of depth. This provides flexibility to collect depth-integrated samples under deep, fast flow conditions that would result in over-filling of a standard depth-integrating sampler equipped with a rigid bottle. For example, with a point sampler, a sample may be

integrated only between the surface and the bed or vice-versa, not from the full surface-bed-surface traverse as required with a depth-integrating sampler. The depth range may also be sampled in parts.

Note: Relatively newly developed depth-integrating samplers that use flexible sample bags overcome many of the limitations of the earlier-generation depth-integrating samplers that use rigid bottles, negating the need to use the more cumbersome point samplers when the objective is to collect a single depth-integrated sample from the vertical.
Point samplers only have rigid sample bottles.
Point samplers are sometimes termed "point-integrating samplers" because they can integrate a sample over a period of time at a point.

4.2.5 Prescribed samplers

The sampling equipment prescribed in this Standard shall generally be isokinetic depth-intergating or point samplers, as developed and approved by the FISP. The only exception shall be for exceptionally shallow or slow flows where use of isokinetic samplers is impractical (Section 6.5).

Various isokinetic samplers developed by the FISP are suited to different river conditions and deployment systems. These are summarised in Figure 6-1 and are detailed in Annex C and Annex D. Several of the samplers are upgrades or improvements over earlier versions, and should be purchased by preference. The current versions of FISP samplers are listed in Gray and Landers (2015).

Some isokinetic samplers are also suited to water quality and/or sediment quality sampling by virtue of the use of autoclavable plastic sample containers.

Note: Water quality rated samplers are not required for suspended sediment sampling directed at determining sediment load.
The formal names of the FISP samplers in Figure 6-1 begin with the letters US. Henceforth in this section the US prefix is omitted.

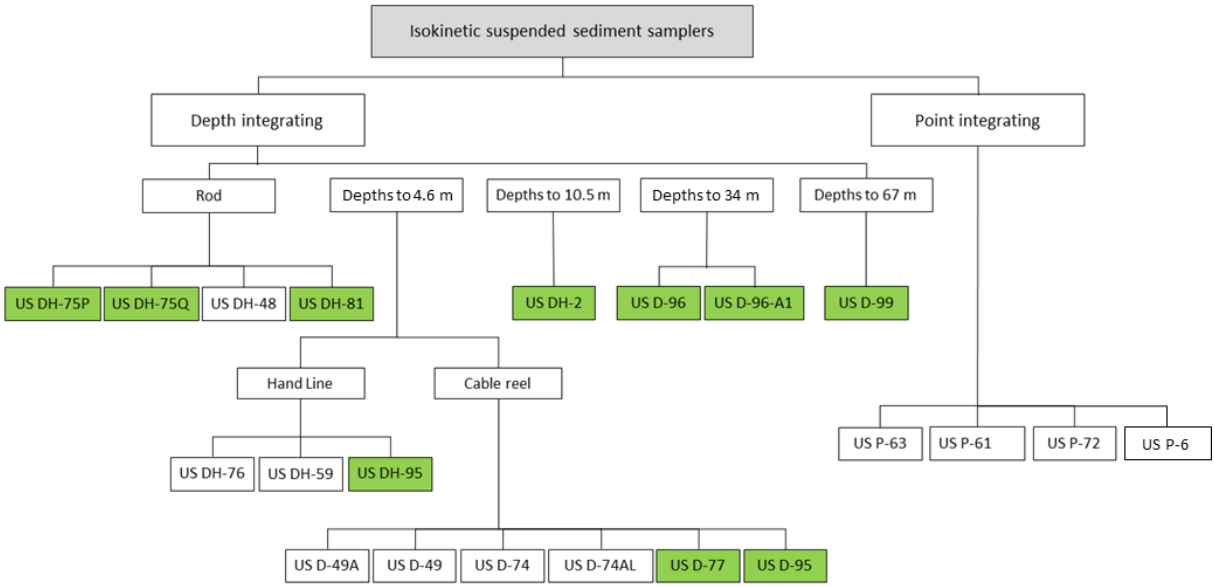


Figure 6-1 – Isokinetic suspended sediment samplers classified by type of deployment system and effective sampling depth. Green filled boxes indicate samplers that can be used for trace-element water quality sampling as well as suspended sediment measurements.

Deployment options include:

- rod mounted
- handline suspended, and
- cable and reel suspended.

Samplers typically suited to and/or commonly used in New Zealand rivers are described below. These samplers should suit most situations, but some applications may require use of more specialised samplers, in which case a suitable sampler should be selected using Annex C and Annex D.

4.2.6 Rod-mounted depth-integrating samplers

The rod-mounted DH-48 (Figure 6-2) has been commonly used in New Zealand for depth-integrated sampling in wading situations. It comprises a lightweight, streamlined aluminium body which partially encloses a 470-ml (1 U.S. pint – hereafter termed "pint") glass bottle, and mounts on a standard 12.5-mm-diameter wading rod. With rod extensions, the sampler can be deployed from a low bridge. The bottle is held in place by a spring-tensioned pull-rod assembly, which is readily operated by hand. It has a screw-in 6.4-mm brass nozzle. The sampler can be used in velocities that range from 0.5 to 2.7 m/s.

The DH-48 is now superseded by the DH-81 (Figure 6-2), which is made of plastic components. The DH-81 sampler can use screw-in, interchangeable nozzles and sample bottles (U.S. Mason jar thread) of different sizes but is usually used with a 7.9-mm nozzle and a 940-ml (1 U.S. quart – hereafter termed "quart") bottle (often loosely referred to as a 1-litre bottle). Depending on the nozzle and bottle size, the sampling inflow efficiency is acceptable in stream velocities ranging from 0.6 to 2.3 m/s and depths up to 2.7 m.

Note: Because the objective is usually to sample sediment during high flows, safe sampling by wading is typically limited to small streams.

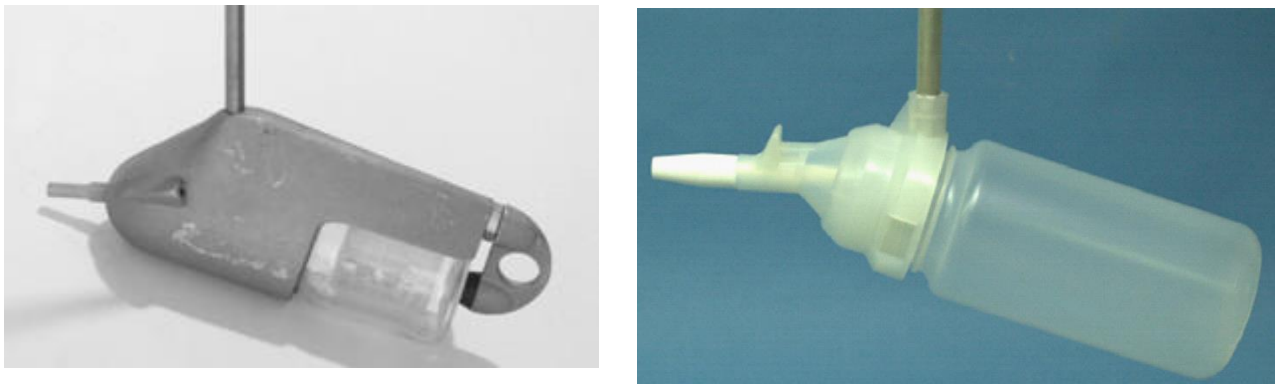


Figure 6-2 – Left: a DH-48 depth-integrating suspended sediment sampler mounted on a wading rod. Right: a DH-81 depth-integrating suspended sediment sampler mounted on a wading rod (photos: Gray and Landers, 2014).

4.2.7 Handline-suspended depth-integrating samplers

Handline-suspended depth-integrating samplers tend not to have been used to date in New Zealand, but they are useful for small to medium-sized, shallow, low velocity streams that are unsuitable for wading or must be sampled from bridges that are too high to deploy a rod-mounted sampler from. The most generally suitable sampler of this type is the DH-76 (Figure 6-3). The DH-76 is a medium-weight handline sampler that has a quart glass sample bottle. Its tail assembly extends below the body of the casting to ensure sampler alignment parallel to the flow direction. It uses 3.2-, 4.8- or 6.4-mm nozzles, but the 3.2-mm nozzle is no longer sanctioned by the FISP. It is suitable for depths up to 4.6 m and for velocities in the range 0.46 to 1.53 m/s.

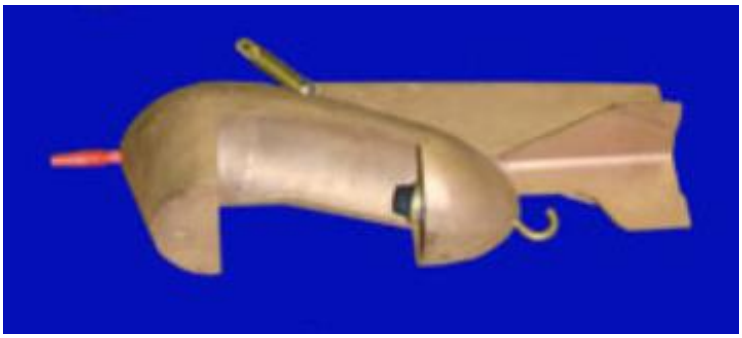


Figure 6-3 – DH-76 handline-suspended depth-integrating sampler.

4.2.8 Cable-and-reel-suspended depth-integrating samplers

The D-49 sampler and its updated version the D-74 sampler (Figure 6-4) are almost identical, 28-kg samplers designed to be suspended from standard gauging reels for deployment in non-wadeable conditions. They differ mainly in that the D-49 uses only the standard 470-ml round glass bottle, while the D-74 can hold either a 940-ml or 470-ml bottle. While still commonly deployed in New Zealand and sanctioned by the FISP, the D-49 has been superseded by the D-74.

The D-49 and D-74 have a cast bronze body and a stainless-steel hanger-bar for connection to the reel cable. The sample bottle is installed by opening the sampler's downward-swinging hinged head.

They come equipped with three nozzle options, with bore diameters of 3.2, 4.8 and 6.4 mm. The nozzle size influences the rate of bottle filling.

Note: The maximum operating depth of D-49 and D-74 samplers is 4.7 m. At greater depths, water pressure inhibits their isokinetic performance, and a point sampler is required (see below).
In high velocities, the 28-kg D-49 or D-74 sampler may be swept too far downstream. In such cases, a heavier sampler (such as a P-61) may be required or the sampler may be mounted below a Columbus sounding weight.
6.4-mm nozzles for D-49 and DH-48 samplers are not interchangeable but are often confused. Look for the flat section on the D-49 nozzle. A DH-48 nozzle has no flat section.
The 3.2-mm nozzle is no longer sanctioned by the FISP and should only be used if there are no other sampler/nozzle options available.

Figure 6-4 – D-74 cable-and-reel depth-integrating sampler.

4.2.9 Cable-and-reel-suspended depth-integrating samplers with large sample volume

The D-77 (Figure 6-5) is a 37-kg depth-integrating sampler that collects a 3-litre sample. It is particularly suited for situations requiring a large water volume or sediment mass (e.g. for particle size analysis) since it makes collection of a large volume of water easier and faster than collecting multiple samples with a small-volume sampler such as the D-49. The D-77 sampler is constructed without a head assembly to cover the mouth of the container. Instead, a cap, nozzle, and air-exhaust assembly, made from autoclavable plastic, is screwed onto the mouth of the sample container at the front of the sampler. The sample is accommodated in either a 3-litre autoclavable sample bottle or a collapsible bag inside a special rigid container.

Nozzles with diameters of 3.2, 4.8, 6.4 and 7.9 mm are available for the D-77, but the 7.9-mm nozzle is generally recommended for use with this sampler; moreover, the 3.2-mm nozzle is no longer sanctioned by the FISP and its use should be avoided.

The autoclavable bottle is also suitable for water quality sampling, but it limits isokinetic behaviour to depths less than 4.7 m. Use of the collapsible sample bag avoids this limit, but the sampler is still limited to a depth of 5.2 m by other considerations. The D-77 may be used in most streams with low to moderate velocities (from 0.3 to 2.1 m/s).

Where a large sample volume is desired from faster-flowing, deeper streams (beyond the limits of the D-77), the 60-kg **D-96** sampler, also with a 3-litre collapsible sample bag, is an option. The D-96 can sample isokinetically at velocities between 0.6 and 3.8 m/s and at depths up to 34 m (when used with a 4.8-mm nozzle).

A valve-assembly can be attached to the head of the D-77 sampler to enable it to operate as a point sampler.

Note: The use of collapsible sample bags in samplers requires special quality-assurance field tests of the intake efficiency before each set of samples is collected (documented in FISP, 2013).

Figure 6-5 – D-77 cable-and-reel depth-integrating sampler.

4.2.10 Cable-and-reel-suspended point samplers

The P-61 (Figure 6-6) and its updated version the P-6 are 48-kg, cable-and-reel-hung point samplers. They have a solenoid-activated inlet valve which is connected via the co-axial gauging cable to a control box with a 24–28 v battery pack. The P-6 differs from the P-61 mainly by having an improved valve system. The samplers can be used to collect point samples at discrete depths, but are often used in depth-integrating mode (with the inlet valve kept open) in flows too deep or fast for use of a D-49 or D-74. This is by virtue of the P-61 and P-6 being heavier and because they are not subject to the 4.6-m depth limitation of the D-49/D-74. They are used only with a 4.8-mm nozzle, and may be used with either a pint- or quart-sized glass sample bottle. They can be used in depths up to 37 m with the quart bottle and 55 m with the pint bottle. They can be used in velocities ranging from 0.5 to 3.0 m/s.

The P-72, weighing 18.6 kg, is a light version of the P-61 and is limited to velocities in the range 0.5–1.6 m/s. It can be used to a depth of 22 m with a pint sample bottle and 16 m with a quart bottle. These maximum depths are less than one-half of the maximum usable depths for the P-61 with the same bottle sizes. The P-72 also uses a 4.8-mm nozzle.

Note: When using a P-61, P-6 or P-72 sampler with cables longer than 30 m (e.g. with extended-length reels), the high voltage drop may require use of a voltage source greater than the 24–28 v of the standard battery pack.

Figure 6-6 – P-61 cable-and-reel point sampler.

Note the blue plastic nozzle is colour-matched to the blue plastic button in the tail.

4.2.11 Sampling extremely shallow or fast flows

Occasionally, flows may be too shallow (depth < 0.25 m, which renders the unsampled zone large compared to the sampled zone) and/or sluggish (velocity < 0.2 m/s) for satisfactory operation of isokinetic samplers. In such situations, a sample may be collected with a small diameter sample bottle, using fingers across the inlet to regulate the inflow rate.

In extremely fast flows, a surface sample may be collected with a weighted or dipped bottle.

In such cases, the compromised sampling method must always be noted.

4.3 Isokinetic sampler accessories and care

Care should be exercised in using and maintaining sampler accessories (nozzles, seals, bottles).

4.3.1 Nozzles

4.3.1.1 Interchangeability

Each suspended sediment sampler uses nozzles specifically designed for that type of sampler. The nozzles are cut and shaped internally and externally to ensure isokinetic flow though the nozzle. Thus, nozzles from different samplers should not be used interchangeably. There are two exceptions: D-49 and D-74 nozzles are interchangeable, and P-61, P-6, and P-72 nozzles are interchangeable.

DH-48 nozzles can be distinguished from D-49 nozzles by the DH-48 nozzle not having a flat (for a spanner) on the knurled section of the nozzle.

4.3.1.2 Composition

Nozzles were originally made of brass, but for several decades were made of teflon plastic which was often colour coded to a specific sampler. A plastic insert of the same colour in the sampler tail fin helped ensure the correct match of sampler and nozzle. Brass nozzles have since returned to favour. This is because, although both materials are prone to being deformed by “bashing”, which corrupts sampling efficiency, the deformation – and the need to replace the nozzle – is usually more apparent with brass nozzles. Therefore, brass nozzles are required with this Standard.

4.3.1.3 Diameter

A choice of three nozzle diameters (selected from 3.2, 4.8, 6.4 and 7.9 mm) is generally provided for depth-integrating samplers. The exceptions are the DH-48 (6.4 mm) and D-77 (7.9 mm) which have only one nozzle diameter.

Note: The 3.2-mm nozzles are no longer sanctioned by the FISP for any sampler. This is because of sampling efficiency issues, notably for sand grade sediment. Thus, use of 3.2-mm nozzles should be avoided where other options exist.

Inflow rate to the sample bottle depends on the ambient velocity and the nozzle diameter, whilst the total sample volume collected when depth integrating depends on the inflow rate, transiting rate, and water depth. Limits on the transit rate (see later section) mean that a nozzle size should be chosen to ensure the sample bottle is not over-filled.

In general, the largest nozzle that does not over-fill the bottle should be chosen. This ensures maximum sample volume and mass.

Bottle over-filling is less of an issue with the D-77 because of its large (3-litre) sample container volume.

Point samplers are equipped with only the 4.8-mm nozzle as they must match the opening of the valve mechanism. In their case, when used as depth-integrating samplers, over-filling is avoided by limiting the depth range traversed in the vertical.

4.3.1.4 Damage

Any damage to the tip or body of nozzles will degrade isokinetic performance of the sampler. Thus, damaged nozzles should be discarded and replaced immediately.

4.3.1.5 Seals

A neoprene (or semi-soft plastic) gasket in the head of an isokinetic sampler seals the mouth of the sample bottle against the head of the sampler. This not only precludes river water from leaking into the sample bottle, but ensures that the water-entry and air-exhaust ports that terminate inside the sampler are the sole means of water entry and air exhaust during sampler operation. This gasket should be kept clean and free of dust, which can both contaminate the sample and impair the seal. With use, the gasket tends to become compressed and too thin to seal effectively. The gasket seal should be tested with the "blow test" prior to each use (see section 6.6.11.1). At least one spare gasket shall be kept with each sampler.

4.3.2 Sample containers

4.3.2.1 Rigid sampler bottles

A variety of rigid bottles may be used, providing they are matched to the samplers being used. The standard 0.47- and 0.94-litre sample bottles, used for many years in isokinetic samplers, are glass, round, and with a wide mouth. They were originally derived from standard U.S. pint and U.S. quart milk bottles. Bottles with square sections are also available. The glass bottles are sealed either with rubber bungs or push-on plastic caps. A plastic version of the 0.47-litre glass bottle is available with a screw cap. Plastic 1-litre bottles are used in the DH-81 and some other newer samplers. While plastic bottles are more robust, sample inspection is less easy than with a clear glass bottle.

Note: Rubber bungs, plastic caps, and even screw-on caps (particularly those that are old and/or in poor condition) can all leak water, thus it is important to ensure filled bottles are transported and stored upright.

4.3.2.2 Collapsible bag sample containers

Collapsible/flexible plastic bag sample containers are used in several relatively modern samplers (e.g. D-96, D-99). These typically enable sampler operation at greater depths than rigid bottle samplers, and they also permit collection of larger sample volumes (e.g. 3 litres with D-96, 6 litres with D-99).

4.3.2.3 Transferring and compositing samples to other bottles

Once collected from the river, samples collected in rigid bottles may be transferred to other bottles. This is commonly done when compositing multiple samples into one larger container. In appropriate circumstances, sample compositing reduces the cost of expensive laboratory analysis. Typically, 2- or 5-litre plastic bottles are used for compositing samples.

Compositing may be done when:

- using the Equal Width Increment (EWI) sampling technique, necessarily using the same transit rate at each vertical (see Section 6.6.12)
- point samples from multiple equispaced depths in a vertical are combined to create the equivalent of a depth-integrated sample (this requires the same sampling duration at each depth)
- samples collected with a point sampler in depth-integrating mode from multiple partial depths are combined to create the equivalent of a depth-integrated sample (this requires the same transit rate for each sample), or
- a large sediment mass is required, e.g. for particle size analysis.

Individual samples may also be transferred from the original glass sampling bottle to a 1-litre plastic bottle. This may be required when many samples are to be collected but few glass bottles that fit the sampler are available.

Transfer bottles should ideally be of clear plastic, since this facilitates sample inspection.

Procedures for compositing samples and transferring samples between containers are detailed in Section 6.6.12.

4.3.2.4 Storage and transport of samples

Empty sample bottles used in samplers should be cleaned, inspected, then stored with their bungs or caps on to prevent contamination with dust, dirt, etc. Empty plastic transfer bottles should be similarly treated.

Full bottles must be kept upright, to prevent bungs from falling out of glass bottles or to prevent leakage through the threads of screw-capped plastic bottles.

Bottles containing water samples should be kept in robust and water-resistant boxes (wooden, metal, or hard plastic but not cardboard) for transport from field to laboratory.

4.3.2.5 General care of samplers

Isokinetic suspended sediment samplers are expensive, precisely manufactured instruments, and the quality of the samples collected by them is, in part, determined by the samplers and their accessories being kept in good condition. To help achieve this:

- each sampler shall be stored and transported in its purpose-built box;
- the sampler box shall be labelled with the sampler type;
- the sampler shall be dried before storing (to avoid mould growth);
- all accessories and fittngs shall be stored in the sampler box, including (as appropriate for the sampler type):
    - a full range of nozzles;
    - hanger bar and threaded pin;
    - spare gasket; and
    - instruction sheet;
    - a laminated list of essential fittings and accessories should be kept in the box;
- any lost or damaged nozzles shall be replaced by the correct type;
- any damage to, or deformation of, the sampler, such as a bent tail-fin, is likely to alter the sampler performance. The sampler shall be sent to an appropriate facility for repair and testing;
- the sampler shall be kept ready for use at short notice, with batteries charged (for point samplers), maintenance attended to, and complete with accessories; and
- each sampler shall be identified with a serial number.

4.4 Unmeasured load

The isokinetic suspended sediment samplers in routine use can only sample to within 75-100 mm of the riverbed, because when the sampler base contacts the bed the intake nozzle is perched above the bed. It is a design factor that helps to prevent the sampler scooping-up bed material, thus biasing its sample. This near-bed span of the flow is termed the "unmeasured" or "unsampled" zone. The mean SSC of the sampled part of the vertical is always less than or equal to the true mean SSC 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 generally highest in concentration in the unmeasured zone. In contrast, the silt and clay fractions tend to be uniformly mixed and their sampled SSCs are representative of their concentrations in the unmeasured zone.

The assumption implicit in most suspended sediment load calculations is that the discharge-weighted SSC in the unmeasured zone equals that in the measured zone. Thus, the suspended sediment load across the full depth, spanning measured and unmeasured zones, is determined from the product of the total discharge and the measured discharge-weighted SSC.

A more refined approach may be required in sand-bed streams where sand comprises a substantial proportion of the suspended load or where there is particular interest in the

sand load. In such cases, the suspended sand load carried in the unmeasured zone may be:

- Sampled with a "bed load" sampler with an intake height that spans this zone and a sample-bag mesh fine enough to trap the suspended sand.
- Calculated using information on the suspended sediment concentration and size distribution in the measured zone, plus information on the mean velocity and bed material size distribution. A procedure ("Modified Einstein Procedure") to adjust the mean measured concentration and size-distribution of the suspended load to incorporate the unmeasured zone was developed by Colby and Hembree (1955). This procedure is summarised in Vanoni (1975) and has been captured in the BORAMEP software (Holmquist-Johnson and Raff, 2006).
- Measured using appropriately calibrated ADCP backscatter methods.

Note: Correcting the measured suspended sediment load for the unmeasured load is not part of this Standard.

4.5 Non-isokinetic manual samplers and sampling

Isokinetic samplers are impractical to operate at verticals that are too shallow (< 0.25 m depth) or too slow (< 0.2 m/s velocity). In these situations, a non-isokinetic sampler may be used.

Non-isokinetic samplers include:

- Hand-held, open-mouthed bottles. These may be used to collect surface grab-samples (shallow flow) or "pseudo depth-integrated" samples (with the water entry regulated by placing fingers across the bottle mouth)
- Handline-suspended weighted bottles. The WBH-96 weighted bottle sampler is an example (Annex D). It consists of a stainless-steel housing that secures an open-mouthed 1-litre bottle. The housing has holes drilled near the top for a rope line that is used to secure the bottle and deploy the sampler.

Note: Samples and results collected with a non-isokinetic sampler must always be labelled and archived as such.

4.6 Field procedures

4.6.1 Overview

For every sediment gauging, decisions are required on:

- the location of the gauging section;
- the number and location of sampling verticals;
- 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 depth and velocity variation across the section and, if available, prior information on the proportion of sand in the suspended load.

The depth and velocity information should be obtained from the following sources in priority order (first is best):

- a current-meter / ADCP gauging performed immediately beforehand;
- data compiled from previous gaugings at similar discharges; or
- visual estimates.

As the latter two data sources will only provide approximate information, some trial-and-error experimentation will likely be required to optimise sample collection.

4.6.2 Location of gauging section

The suspended sediment gauging section at the sediment monitoring site shall be located as described in Section 1.1.3 and shall, if practicable, coincide with the section used to gauge the water discharge. (Co-locating the sediment and discharge gaugings allow the depth and velocity information from the discharge gauging to be used to guide the selection of sampling specifications, particularly with the EDI sampling method.) Often, the sampling location will be constrained by the availability of sampling infrastructure (e.g. bridge, cableway) or safe and accessible parts of the channel.

Where there is choice available (e.g. when wading or using a boat), the sampling section shall be one that is located:

- as close as practicable to proxy sampling equipment and/or sensors (e.g. turbidity sensor);
- at a section that is as uniform and well-mixed across-channel as possible;
- where there are no significant eddies; and
- where the gauging operation can be undertaken safely.

Within the constraints set out in Section 1.1.3, ideally the same section should be used for gauging sediment over the full flow range, but it is permissible to locate the gauging section differently under different flow conditions if these demand a different deployment method (e.g. the best section for wading at lower flows may not be the best section for sampling from a boat at higher flows). However, subsequent sediment gaugings at the same site should occupy the same gauging sections as used previously under similar flow conditions.

4.6.3 Method of selecting sampling verticals

Across-stream variations in SSC are managed by sampling at multiple verticals. Two main methods are available for distributing sampling verticals (**Figure 6-7**):

- the Equal Discharge Increment (EDI) method, which involves sampling at the centroids of sub-sections carrying equal portions of the total discharge; or
- the Equal Width Increment (EWI) method, which involves sampling at the mid-point of sub-sections of equal width.

The choice between these two methods influences:

- the need for concurrent flow gaugings;
- the time required for sampling;
- the number and location of sampling verticals;
- the number of samples collected; and
- the flexibility to bulk samples before laboratory analysis to save costs on laboratory analysis.

The two methods have different advantages and disadvantages. This Standard permits either method but generally recommends use of the EDI method. This is because the EDI method:

- requires fewer sampling verticals and so can be accomplished more quickly;
- permits greater flexibility to adapt sampling details (e.g. transit rate) to local hydraulic conditions, thereby reducing the risk of non-isokinetic sampling and makes collecting an optimal sample volume easier; and
- does not bulk samples from multiple verticals, and so the risk of corrupting the cross-section average concentration by excessive sand content (due to the sampler scuffing streambed sand) is lessened because "outlier" concentrations identifed from the laboratory results can be discarded.

However, the EDI method does require prior knowledge of the cross-channel discharge distribution, ideally from a preceding flow gauging.

Circumstances where the EWI approach might be preferred include:

- when there is no discharge data available at the sampling cross-section to underpin the EDI method;
- when there is insufficent time available to do both sediment and discharge gaugings;
- when a series of sediment gaugings is required during a flood; or
- when a composited sample is required to minimise laboratory-analysis costs.

The EWI approach, which requires using the same sampler transit rate at all verticals (and in the down and up transit directions), should be avoided where the cross-channel velocity distribution is particularly non-uniform. This is because the sampler transit rate required to avoid bottle over-filling at the highest velocity vertical may induce sampling bias at verticals with lower velocities (typically by breaking the "0.4 rule" – see Section 6.6.8.1).

4.6.4 Number and location of verticals with the EDI method

4.6.4.1 Number of verticals

The number of verticals required with the EDI method depends on the SSC variation across-channel and the accuracy sought. The cross-channel SSC variation increases the less uniform the section and the greater the proportion of sand in the suspension. Almost all cross-sectional variation in SSC results from sand-sized material; finer sediment is uniformly dispersed. Sampling to date in New Zealand rivers (Hicks et al., 2004) indicates that the proportion of sand in the suspended load is strongly influenced by catchment lithology, and is typically less than 50% except from catchments

dominated by volcaniclastic rocks (e.g. pumice, tephra), granites, gneiss, and marble (all of which largely reduce to sand grains when eroded).

Analysis by the USGS (using data from Colby, 1964, and reported by Edwards and Glysson, 1988, 1999) showed that for sand percentages up to 50%, sampling at five verticals produced no more than a 15% error in the cross-section mean suspended sediment concentration, even for non-uniform cross-sections (in regard to depth and velocity distribution).

Based on the above considerations, for this Standard, five verticals shall generally be used with the EDI method. There are three exceptions to this rule:

- as few as three verticals may be used on small streams (less than 10 m wide) if re-sampling of past gauging results (originally with five or more verticals) indicates the standard error of the SSC_{Qm} result would be less than 15% if only three or four verticals were used
- six to ten verticals shall be used where substantial cross-channel variations in sediment concentration are perceived, and/or
- six to ten verticals shall be used at sites where significant sand deposition is observed on the stream bed and/or the catchment is dominated by sand-producing lithologies (i.e. tephra/pumice, unconsolidated sandstone, granite, gneiss, marble); both types of information shall be included in the site metadata.

Note: In flashy streams and rivers, particularly in small catchments, SSC can change quickly over the time of the sediment gauging, which adds further uncertainty to the SSC_{Qm} result. In such situations, a trade-off may need to be made between sampling the required number of verticals and minimising temporal variation. Such situations should be logged as comments.

4.6.4.2 Location of verticals

For the EDI method with n sampling verticals, the verticals should be located at the centroids of sub-sections each carrying $1/n^{th}$ of the total water discharge, Q. The sub-section centroids are located where the cumulative discharge equals $(1, 3, 5, \ldots 2n\text{-}1)Q/2n$. For example, with 5 verticals, the verticals should be located at sections where the cumulative discharge equals $Q/10$, $3Q/10$, $5Q/10$, $7Q/10$ and $9Q/10$ **(Figure 6-7 top).**

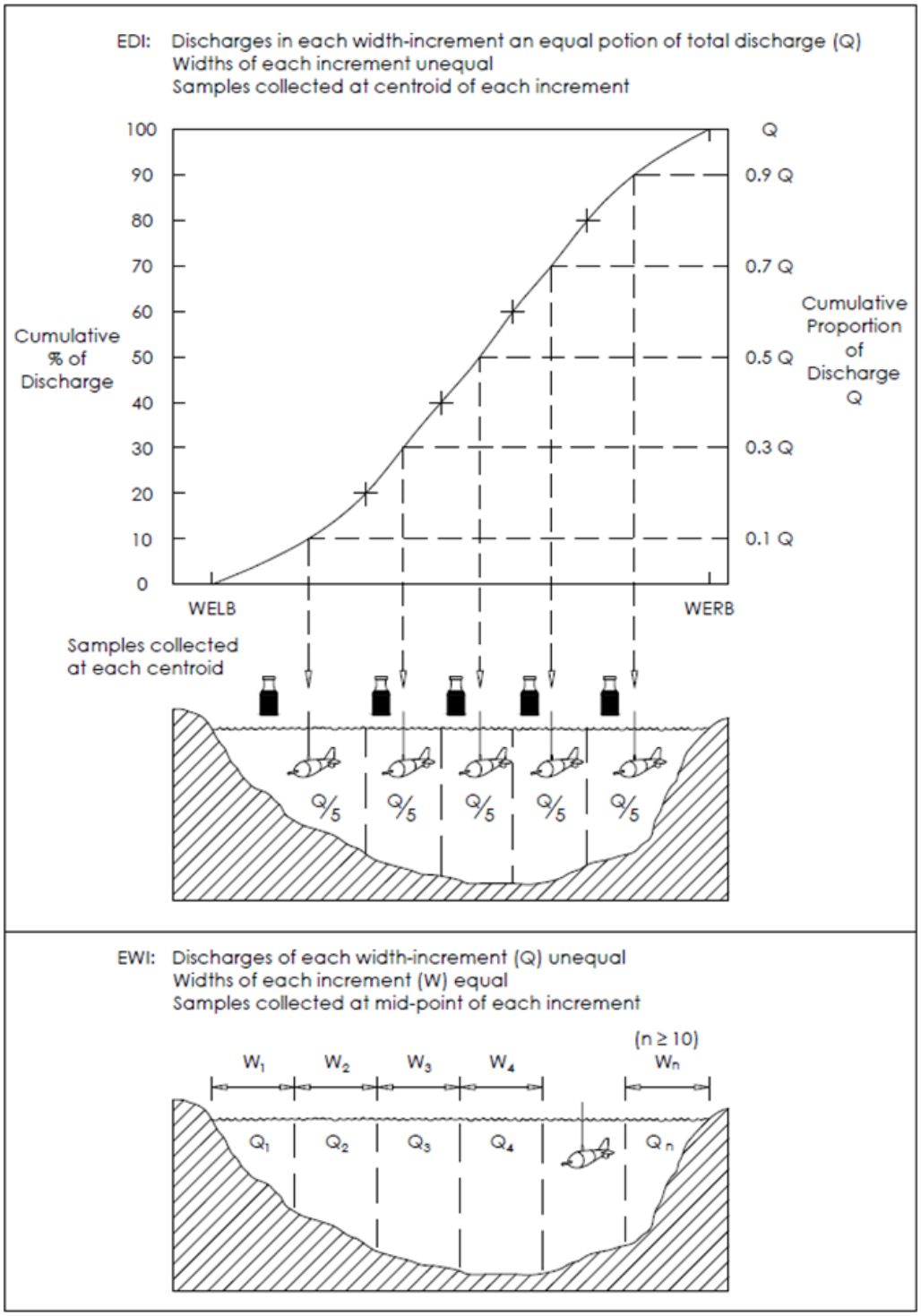


Figure 6-7 Location of sampling verticals using the EDI and EWI methods. With EDI method (top), verticals are located at the centroids of sub-sections carrying equal portions of the total discharge. For EWI method (bottom), verticals are located at the midpoints of sub-sections that are equal in width.

The horizontal offset of EDI sampling verticals across the section should ideally be derived from output of the software used to calculate the gauged discharge. Alternatively, the locations can be calculated manually from the vertical-by-vertical results of a prior current-meter gauging, for example as entered on a current-meter gauging card. The steps for this manual method are:

i. List cumulative discharges from the left bank water's edge (WELB) to each current-meter vertical.

ii. Label position of appropriate cumulative discharges for sampling verticals between figures on this list.
iii. Interpolate corresponding horizontal positions of sampling verticals.

Note: It is important that the sampling verticals be located as above, rather than at the nearest vertical used in the prior current-meter gauging. If this is not done, then the calculation of SSC_{Qm} becomes more complex and non-standard; also, and more importantly, any compositing of samples, e.g. for particle-size analysis, will no longer be done in the correct proportions.

4.6.5 Number of verticals with the EWI method

More verticals are required with the EWI method (compared to the EDI method) to allow for the likelihood that some verticals will only represent a small proportion of the discharge. The required number of verticals should be determined by visually assessing the width of the narrowest span of channel conveying 20% of the flow and dividing the total width by this value.

Notwithstanding this estimate, a minimum of 10 verticals but no more than 20 verticals are required for the EWI method.

4.6.6 Location of verticals with the EWI method

For the EWI method with n sampling verticals, the verticals should be located at the centres of sub-sections each $1/n^{th}$ of the total width, W. The sub-section centres will occur where the offset from water's edge equals $(1, 3, 5,... 2n\text{-}1)W/2n$. For example, with 10 verticals, they should be located at $W/20$, $3W/20$, $5W/20$, …$19W/20$ (Figure 6-7 bottom).

Steps for locating EWI verticals are:

i. Measure the total width (ignoring any small back-eddies or still-water zones at either bank)
ii. Visually inspect the stream from bank to bank, observing the velocity and depth distribution.
iii. Estimate the width of the smallest partial section that conveys 20% of the total discharge (generally the deepest, fastest-flowing section).
iv. Decide the sampling interval:
    a. if the partial-section width estimated in (iii) is less than $1/10^{th}$ the total width but greater than $1/20^{th}$ the total width, then use it as the sampling interval, or
    b. if the partial-section width estimated in (iii) is greater than $1/10^{th}$ the total width, then use $1/10^{th}$ the total width as the sampling interval, or
    c. if the partial-section width estimated in (iii) is less than $1/20^{th}$ the total width, then use $1/20^{th}$ the total width as the sampling interval.
v. Locate the first vertical at half the sampling interval from the water's edge.
vi. Space subsequent verticals by this interval.

4.6.7 Sampler/nozzle combination

4.6.7.1 Sampler selection

Primarily, the choice of sampler will depend on the flow depth and velocity at the gauging section. An additional consideration is the deployment method (e.g. by wading with a rod-mounted sampler or suspending the sampler with a handline or gauging reel).

The recommended depth-velocity operating ranges of the commonly used samplers described in Section 6.2 are shown in Figure 6-8. Outside these depth and velocity limits, the isokinetic performance, sampling efficiency, accuracy, and/or practicality of the samplers becomes unsatisfactory.

Figure 6-8 may be consulted when selecting the optimal sampler/container/nozzle combination at a site.

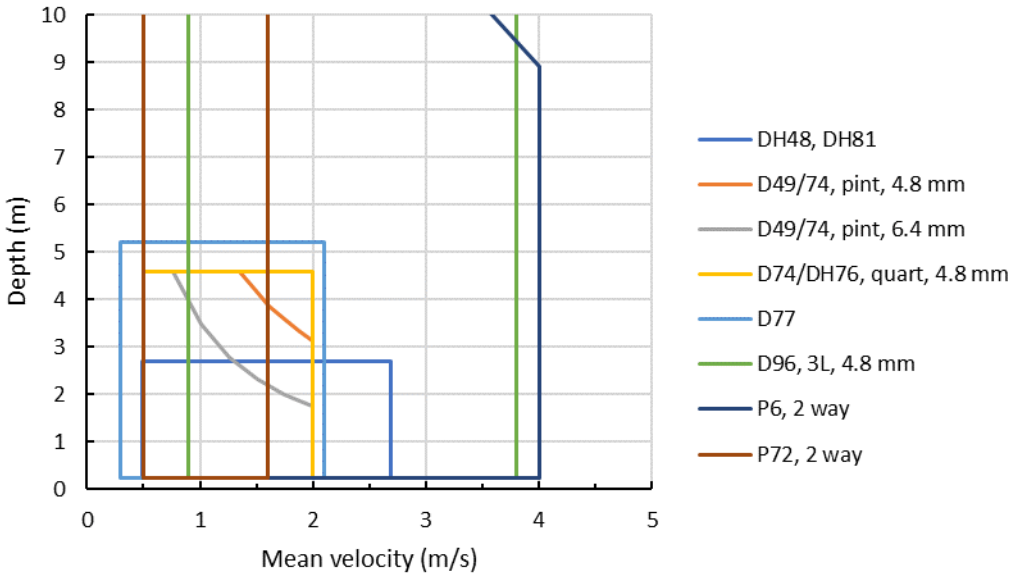


Figure 6-8 Operating ranges of the more commonly used depth-integrating isokinetic sampler/nozzle/operating-mode combinations in terms of depth (*D*) and mean velocity (*v*) at-a-vertical, after Hicks and Fenwick (1994). See Annex C for the depth and velocity limits.

The $D \times v$ product bounds (curved segments) are constrained by the maximum allowable sample volume, nozzle diameter, and the "arm-strength" limitation on transit rate when using an A-reel with cable-and-reel samplers. These ranges assume two-way traverses are done using all samplers.

The depth limit on the depth-integrating samplers with a rigid sample container (DH-48, DH-96, D-49, D-74) is related to air compression in the sample bottle. As the sampler is moved deeper, the increasing hydrostatic pressure at the air exhaust port controls the escape of air as the sample enters the bottle. Beyond 4.6 m depth, compression of the air remaining inside the bottle becomes excessive and prevents the sampler from operating isokinetically. Samplers with collapsible sample bags (e.g. D-77, D-96, D-99) are not so affected. Point samplers (e.g. P-6, P-61, P-72) are also not limited in this way because they have a special chamber that equalizes the air pressure in the sample bottle with the external hydrostatic pressure.

The velocity limit is largely determined by the weight of the sampler – samplers that are too light are deflected downstream in a looping trajectory or "swim" laterally. Both cases result in the sampler integrating a longer section than double the depth.

The depth × velocity product (equal to the unit discharge at the vertical) is also limiting, since this affects the amount of water collected into the sample bottle and hence limits the rate that the sampler must be transitted in the vertical to avoid over-filling the sample bottle. As explained in the next section, this transit rate is limited by the mean velocity and by arm-strength for cranking the gauging reel (unless a power-drive is available for the gauging reel). The depth × velocity product limitation determines the curved segments of the sampler application range on Figure 6-8.

Considering these constraints, in general:

- If the section is wadeable, then a rod-mounted DH-48 or DH-81 should be used.
- If the section has low velocity (< 0.5 m/s) and is accessible from a low bridge, then by preference a weighted-bottle sampler, such as a WBH-96, should be used; if this is not available then an extended-rod-mounted DH-48 or a cable-hung DH-76 should be used.
- If the section has depth greater than 0.25 m and is accessible from a low bridge, then an extended-rod-mounted DH-48 or a cable-hung DH-76 should be used.
- If a cable-and-reel sampler is required, use a D-49 or D-74 provided the depth at the critical sampling vertical (i.e. the sampling vertical where the velocity × depth product is highest) is less than 4.6 m and/or the mean velocity at that vertical is within the range 0.5–2 m/s.
- At any depth less than 37 m and providing the velocity does not exceed 4 m/s, a P-6 point sampler can be used in either two-way, one-way, or partial-depth depth-integrating mode.
- If a large sample volume or sediment mass is required, such as for analysis of particle size, a D-77 is recommended if the velocity is less than 2.1 m/s; at higher velocities, a D-96 or D-99 bag sampler may be used by preference, otherwise multiple samples may be collected using a P-series point sampler.
- For very shallow, wadeable sections where the velocity exceeds 3 m/s, it is permissible to take a surface sample.
- Otherwise, for velocities higher than 4 m/s and/or for very large depths, a specialist sampler should be selected from Annex C and Annex D.

Note: All instances where sampler operating limits are exceeded should be documented in the field and added as comments when archiving results.

4.6.7.2 Nozzle selection

Different nozzle diameters provide a means to regulate the fill-rate of the sampler, and hence the volume of sample collected. Changing the nozzle size is an option for most isokinetic samplers, but is not an option for the DH-48 and D-77 depth-integrating samplers and for all (P-series) point samplers.

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, fastest-flowing sampling vertical is neither too fast to be impractical nor

exceeds the maximum permissible rate for the particular combination of intake nozzle and mean velocity at the vertical.

Figure 6-8 provides broad guidelines on choice of nozzles to use with a given sampler at different velocity and depth combinations. The impact of varying nozzle size on transit rate is covered in Section 6.6.8.

With the EDI method, sample collection should aim for the optimal volume range. Similar volumes should certainly be collected at each vertical if samples are to be composited. Generally, this is best achieved by choosing the optimal nozzle size for the deepest, fastest vertical, then using that nozzle at all verticals whilst adjusting the transit rate to achieve the desired sample volume.

With the EWI method, the same nozzle size and same transit rate must be used at each vertical. Thus, nozzle selection and transit rate must be set for the deepest, fastest-flowing vertical.

The 3.2-mm nozzle should generally be avoided and certainly should not be used where there are:

- significant quantities (i.e. > 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), or
- abundant small roots and plant fibres suspended (which may clog the small bore of this nozzle).
- 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, a bag sampler or P-series point sampler should be used.

4.6.8 Sample volume

Sample bottles should never be overfilled because:

- 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 in which SSC exceeds the ambient concentration
- a filled bottle is bound to spill some of its sample during sampler retrieval and bottle unloading, and
- one can never be sure where in the vertical it became full or how much spilled after the sampler left the water.

Thus, any sample bottle filled beyond its maximum level should be discarded and the sample collected again.

The maximum fill-level is set by the shape and size of the bottle, and is the maximum level at which water does not spill back out of the bottle and nozzle when the sampler is being retrieved.

Note: The best indicator of an over-filled bottle is an absence of bubbles coming from the exhaust port as the sampler returns to the water surface.
When discarding samples and re-using the sample bottle, use the swirling procedure described in Section 6.6.12 to ensure that no sediment remains in the bottle after the discarding process.

With the EDI method, it is generally desirable to collect as much sample as possible whilst not exceeding the maximum volume limit. This is to ensure adequate sample volume and sediment mass for laboratory analysis.

Collecting a precise volume is difficult; therefore, in practice, an optimal sample volume range is targeted. The optimal range is between a mimimum acceptable volume and the maximum allowable volume:

- For standard pint bottles (**Figure 6-9**), the maximum sample volume is 370 ml, and the optimal sample volume to aim for is 300–370 ml. While a sample marginally smaller than 300 ml is acceptable, it may yield insufficient mass of sediment for analysis and so should be avoided. The minimum acceptable sample volume is 250 ml
- For standard quart bottles, the maximum sample volume is 740 ml, and the optimal sample volume to aim for is 600–740 ml
- For 1-litre bottles, the maximum sample volume is 800 ml, and the optimal sample volume to aim for is 600–800 ml
- For 3-litre bottles, the maximum sample volume is 2700 ml, and the optimal sample volume to aim for is 2400–2700 ml.

Note: Sampling staff should be familiar with where the levels are on their containers that align with these upper and lower sampling volumes. Novices may care to mark these levels with a marker pen.

With the EDI method, the optimal volume range should be targeted at each vertical.

With the EWI method, in which the transit rate is fixed, the optimal volume range is only targeted at the deepest, fastest vertical and lesser volumes will be collected at other verticals. While these may be less than the minimum acceptable volume described above, this is less of an issue with the EWI method because samples from multiple verticals are typically composited before laboratory analysis.

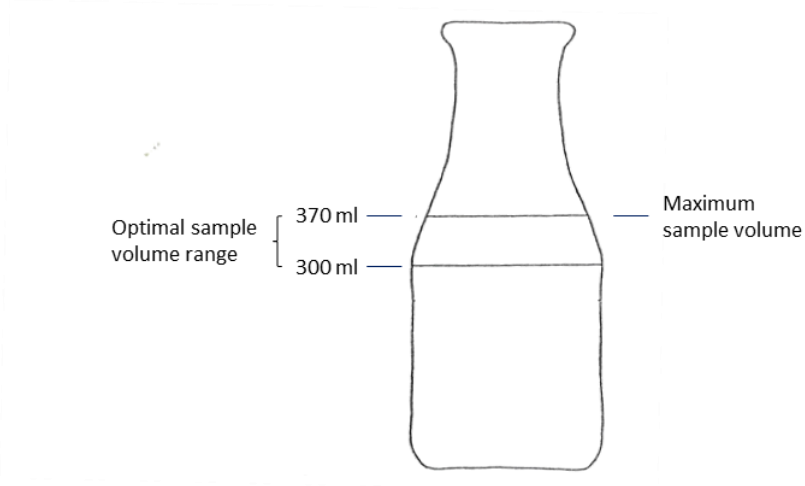


Figure 6-9 – A standard 470-ml glass pint bottle, indicating the maximum fill level (370 ml) and the optimal fill range (300–370 ml).

4.6.9 Transit time and rate

For a given sampling vertical and intake nozzle, the volume of sample (V, ml) is determined by the time taken to move the sampler from the surface to the bed and back again. This time is termed the "transit time" (t, s). Thus:

$$V = \pi \emptyset^2 v t / 4$$

where v is the mean velocity in the sampling vertical (m/s), and $\emptyset$ is the diameter of the intake nozzle (mm).

This equation can be re-arranged to predict the transit time required to collect a target sample volume:

$$t = 4V / v\pi\emptyset^2$$

The rate of lowering and raising the sampler, called the "transit rate" (t_R, m/s) is:

$$t_R = 2D / t \quad = \quad \pi D v \emptyset^2 / 2 V$$

where D is the flow depth (m).

With the EDI method, appropriate transit times and rates should be selected for each vertical so that the sample volume from each vertical is optimal while maintaining efficient and practical operation of the sampler.

With the EWI method, the same, steady transit rate must be used at each vertical, so it must be selected for the deepest, fastest vertical. The sampling time at any particular vertical will then be a consequence of the depth at that vertical.

Note: Whether using either the EDI or EWI method, the sampler must be lowered and raised at a steady transit rate, since this is a fundamental condition of the mechanical integration process – see Section 1.1. However, with the EDI method different steady rates may be used for lowering and raising the sampler.

4.6.9.1 Maximum transit rate

The maximum transit rate (or minimum transit time) is limited by two factors:

1. 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 (which is why it has recently been discarded by the USGS). To avoid these problems, the ratio of transit rate to mean velocity in the vertical should never exceed 0.4 times the mean velocity in the vertical (the "0.4 rule").

2. How fast the sampler can physically be raised – or how fast the gauging reel crank can be turned by arm. A maximum of two revolutions per second on a gauging reel has been assumed for this, equating to a transit rate of 0.61 m/s for an A-reel, 0.91 m/s for a B-reel, and 1.2 m/s for an E-reel.

With the EWI method, since the same transit rate must be used at each vertical and this must be set for the deepest, fastest vertical, a consequence is that the "0.4 rule" may often be broken at other verticals where the velocity is slow. Typically, though, this compromise has minor impact on the overall result for the cross-section since the slower-flowing sub-sections make less contribution to the overall sediment load.

4.6.9.2 Determining transit time and rate

The appropriate transit time (and rate) required to obtain the optimal sample volume should ideally be predetermined for each sampling vertical when using the EDI method.

This is particularly important for the samples collected for particle size analysis, since the compositing procedure assumes they are of approximately equal volume. The minimum transit time corresponding to the maximum permissible transit rate should also be predetermined and checked against the actual transit time taken during sampling.

Transit time and rate can be determined expediently using field computers or nomographs using depth and mean velocity measurements/estimates at the sampling vertical.

Figure 6-10 (updated from Hicks and Fenwick, 1994) provides nomographs for selecting the optimal and minimum permissible transit times for a vertical with given mean velocity and depth, for common nozzle and sample container combinations. Transit times can be converted to transit rates using the nomograph in **Figure 6-11**. In practice, it may be easier to assess transit rates in terms of the rotation rate of the gauging reel (either revolutions per second or seconds per revolution).

Note: In practice, during sample collection using the EDI method, different transit rates may be used when raising the sampler compared with lowering the sampler – so long as the transit rate is steady in each leg, the overall average transit rate is close to the target rate, and the "0.4 rule" is not broken. For example, it may take longer than estimated to reach the riverbed on the downward leg, thus to return the sampler to the surface within the target time to avoid overfilling the sample container the transit rate can be increased on the upward leg. With the EWI method, however, the same transit rate must be used when traversing up and down at all verticals.

With experience, hydrographers may find their on-site observations and test deployments adequate to replace these nomographs.

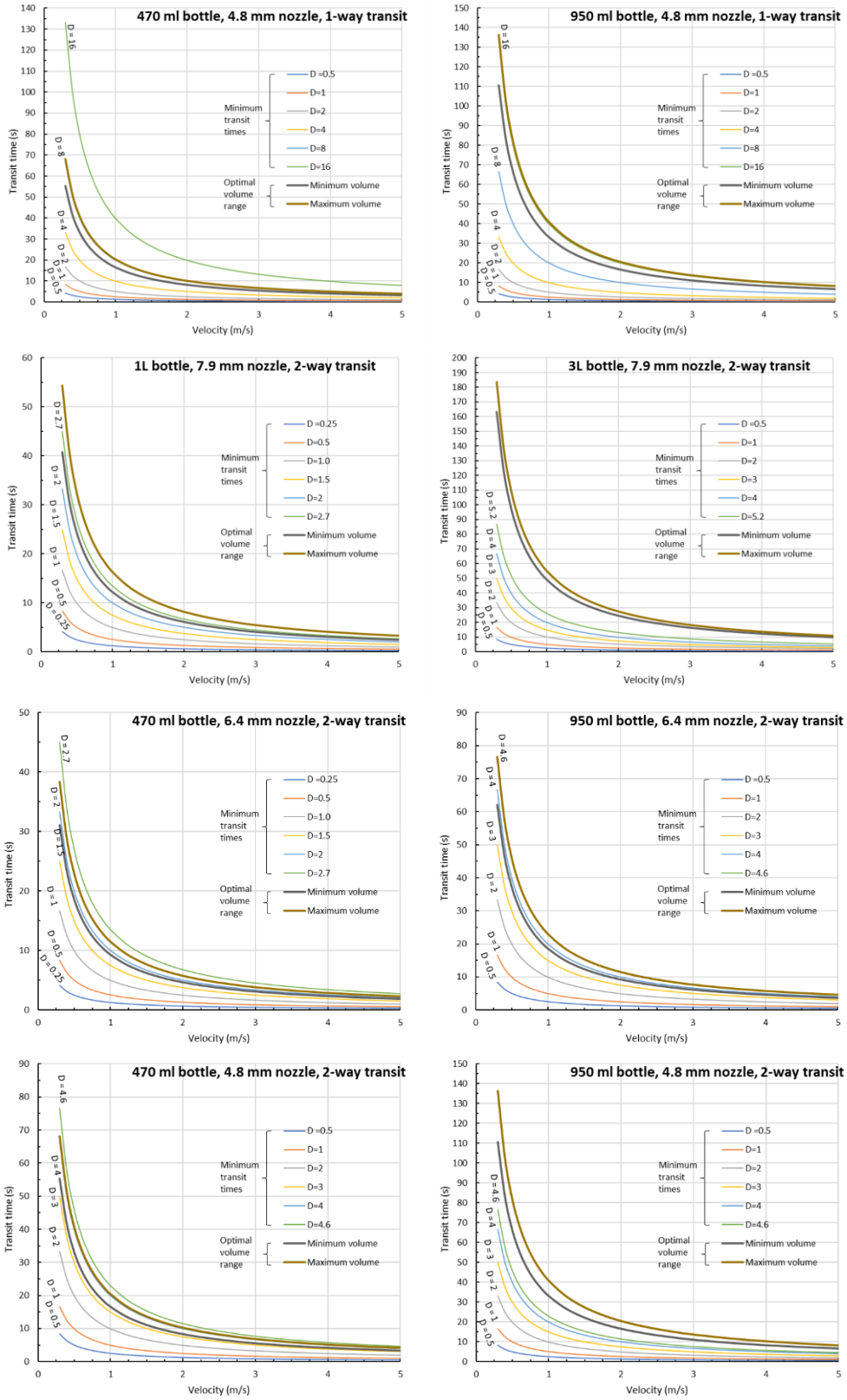


Figure 6-10 Nomographs for determining optimal and minimum permissible transit times (*t*) for given flow depth (*D*) and velocity (v) and for different nozzle and sample container sizes. Example: for case where *v* = 1.0 m/s, *D* = 2.0 m, and 4.8-mm nozzle with 470-ml bottle, from lower-right graph, optimal range of *t* is 17–20 s (thick grey curve and thick brown curve, respectively) and minimum permissible *t* is 10 s (thin grey curve).

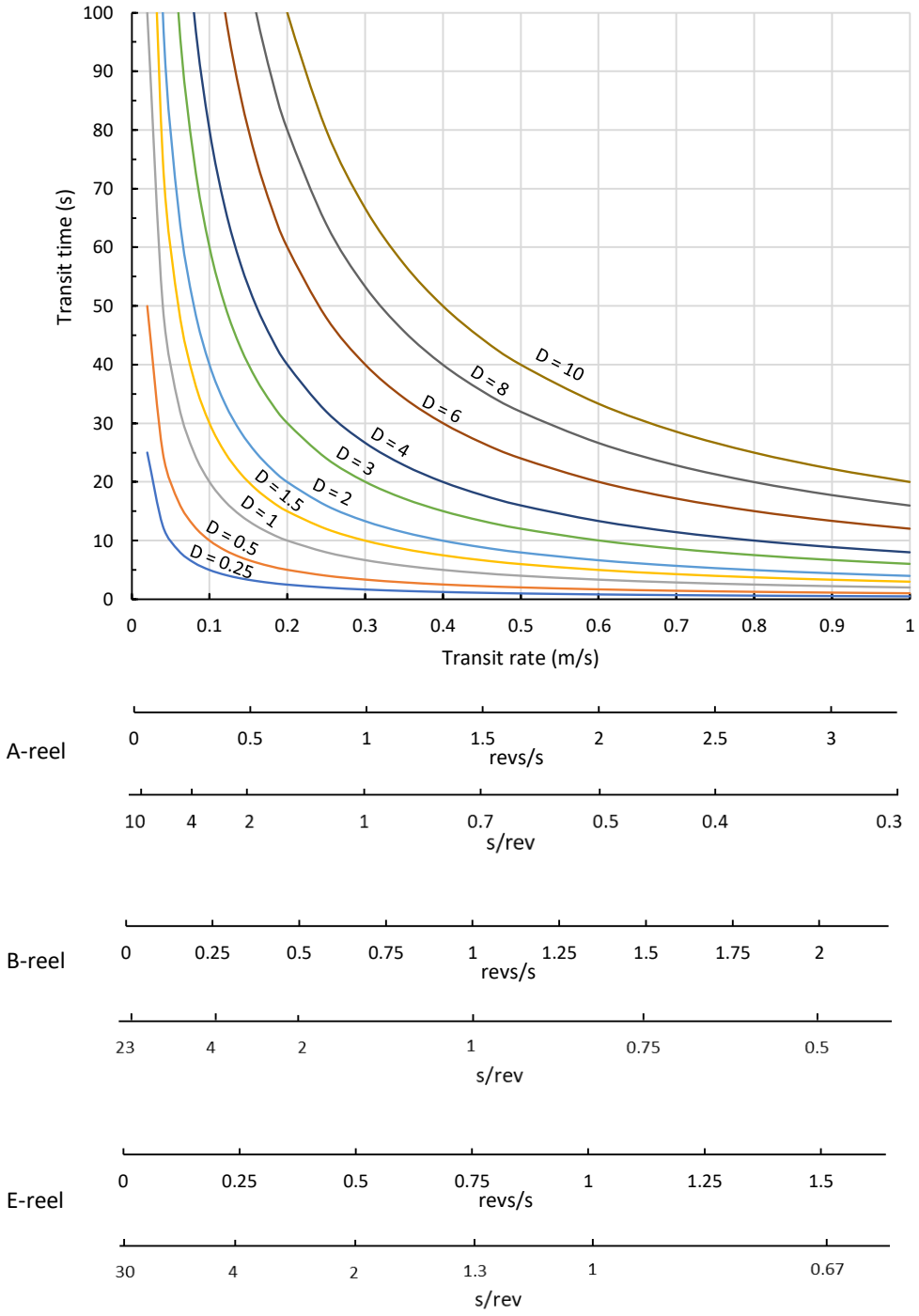


Figure 6-11 Nomograph for converting transit time (t) to transit rate (*t*R) for a two-way traverse over different depths (D) using different sounding reels. Example: for t = 12 s and D = 2.0 m, R = 0.34 m/s, which is equivalent to 1.1 revolutions per second or 0.9 seconds per revolution for an A-reel. Note: when using a point sampler in a one-way integration, halve the depth value.

4.6.9.3 Using point samplers for two-way or one-way depth integration

When using the P-6 series or P-72 point-samplers (which are always equipped with a 4.8-mm nozzle) in depth-integrating mode, **Figure 6-10** can be used to estimate the optimal transit time, taking care to distinguish whether a pint bottle (bottom-left graph) or quart bottle (bottom-right graph) is used. This time will be the same whether transit

is one-way or two-way, but for one-way transits the value of *D* to be used in the nomographs should be one half the total depth. The operating depth range of these samplers is limited only by the maximum permissible transit rate.

Note: When using point samplers for one-way depth-integation, two samples should be collected: one from the surface to the bed and the other from the bed to the surface. Providing the same transit rate and time is used for each sample, the two samples may then be composited for laboratory analysis. This should be checked by timing both traverses with a stop-watch.

4.6.10 Partial-depth integration using point samplers

When the depth-velocity conditions are such that even using a P-series point sampler in one-way mode does not meet the requirements of an isokinetic sample (Figure 6-8), and no other special-purpose sampler is available, then a P-series sampler may 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.

4.6.10.1 Number of depth segments

The number of depth segments to sample, *m*, can be found by dividing the total depth, *D*, until D/m falls within the operating range of the sampler in one-way mode (as shown on **Figure 6-8**). For depths less than 9 m, two depth segments should suffice.

4.6.10.2 Transit time and rate

The transit time (and rate) should be the same for each depth segment and should be keyed to the segment conveying the fastest velocity – which should invariably be the upper segment, nearest the surface. The mean velocity of the upper segment may be estimated as 1.2 times the mean velocity in the vertical. This velocity and half the partial depth are used in **Figure 6-10** (bottom nomographs) to estimate the required transit time.

A stop-watch should always be used to time the traverse of the depth segments, which should coincide with the opening and closing of the the sampler's inlet valve.

4.6.10.3 Compositing samples

Samples from individual depth segments can be composited for SSC analysis provided the transit times recorded for each sample are the same (to within 20%). Otherwise, each sample will need to be analysed separately and the mean SSC for the vertical determined by inversely weighting each individual concentration by its transit time.

Before compositing samples that have been collected from the streambed depth segment, always closely inspect the sample for excessive sand. If in doubt, collect another sample from the streambed segment.

4.6.10.4 Example

Sampling is required at a vertical where the depth is 6.0 m and the mean velocity is 3.0 m/s. **Figure 6-8** shows that dividing the depth into two 3.0-m segments will permit operation of a P-61 sampler in partial-depth mode: thus, four samples should be collected: surface to 3 m, 3 m to bed, bed to 3 m, 3 m to surface. Use $v = 3.0 \times 1.2 = 3.6$ m/s to determine (from **Figure 6-10**, bottom left or right graph depending on bottle size) the optimal transit time for the top depth segment, and use $D = 3/2 = 1.5$ m to find the minimum permissable transit time. Use the same transit time (and rate) for the lower segment.

4.6.11 Isokinetic point-sampling

P-series point samplers, such as the P-61, can be used to collect isokinetic samples at discrete depths. Collection of a series of samples in a vertical will provide an SSC profile if each sample is analysed separately for SSC. This concentration profile can then be combined arithmetically with a velocity profile to calculate the discharge-weighted mean concentration in the vertical.

If each sample is to be analysed for SSC separately, then the sample collection times may vary. Alternatively, the samples from different depths may be composited before analysis to provide the equivalent of a depth-integrated sample, provided that:

- the samples are collected from equal depth increments
- the samples are collected over the same time period (i.e. the period over which the nozzle is opened) at each depth, and
- at least 5, ideally 10, samples are collected from a vertical.

As with partial depth sampling, the sampling time interval for point sampling (to avoid bottle over-filling) should be determined using the estimated maximum velocity in the vertical, assumed equal to 1.2 times the mean velocity in the vertical.

If the EDI method is used to define the location of the verticals within the cross-section, the sampling time may be varied among the verticals. If the EWI method is used, a constant time for collecting samples from all verticals must be used.

4.6.12 Procedure at each vertical

4.6.12.1 Testing seals

It is crucial to seal the sample bottle mouth against the sampler for correct sampling. A poor seal can result from the absence/wear/damage/compression of the neoprene or white plastic seal, or from a bottle being of incorrrect length or shape.

The “blow test” should be used to test the seal:

- install a bottle and close the sampler head
- block the air exhaust oriface with a finger
- if using a point sampler, operate the solenoid to open the valve and hold it open

- seal a short length of rubber or plastic tubing over the intake nozzle and blow into the tubing, then
- check for escaping air or a lack of blow-pressure; if heard or felt, check for issues and replace gasket or bottle as appropriate.

Do this test at the beginning of each sampler run or whenever a different bottle type is used.

Note: To avoid an electric shock, never blow directly into the nozzle of a point sampler.

4.6.12.2 Loading and unloading bottles

Key points are:

- all sample bottles shall be labelled with a unique identifier, and note the number associated with the sampling vertical
- ensure bottles are clean
- insert bottles in sampler and close the head, ensuring the bottle lip is in contact with the sealing gasket (a lightly forced twist of the seated bottle, by about 10 degrees, should assist sealing)
- keep bottle bung/screw-cap secure and clean whilst sampling, and replace securely as soon as bottle is removed, and
- tilt the sampler tail downward while unloading the bottle, to avoid spilling.

4.6.12.3 Lowering and raising

When lowering and raising a depth-integrating sampler:

- lower the sampler to just above the water surface
- with cable-suspended samplers, observe the reel-depth counter and set to zero if necessary
- align the sampler pointing upstream (with cable-suspended samplers, the orientation can be corrected by just dipping the tail fin, but not the nozzle, into the current)
- begin the integration by steadily lowering the sampler to the bed at the calculated transit rate, ensuring the transit rate is constant (transit rate metronomes may be purchased to assist this)
- when the sampler base touches the streambed, immediately reverse direction; mentally note (i) the firmness of the contact with the bed (a soft contact warns of the possibility of the sampler nozzle 'scuffing' a sand dune or sinking into mud) and (ii) the elapsed time vs half that pre-calculated, and decide if the upward transit rate needs to be faster or slower to ensure the desired filling time is achieved
- continue raising the sampler to above water level, and
- check that the bottle has not overfilled by (i) checking for bubbles coming out of the air exhaust when the sampler is near the surface, and (ii) checking whether water is spurting out of the nozzle after the sampler is above the surface - if no bubbles are seen or water spurts from the nozzle, the bottle was overfilled and the sample must be discarded and re-collected.

When lowering and raising a point sampler using one-way integration:

- lower the sampler to just above the water surface
- observe the reel counter and alter to zero if necessary
- lower the sampler to the streambed keeping the intake valve closed, and note the depth to the bed
- begin raising the sampler at the required transit rate, opening the valve at the same time
- continue raising the sampler to above water level and check whether water is spurting out of the nozzle; if so, the bottle was overfilled and the sample shall be discarded and re-collected
- close the inlet valve and raise the sampler
- unload the bottle and check its volume, and
- repeat the procedure at the same vertical, but sampling from the water surface to the bed, closing the valve immediately as the bed is contacted (or anticipated, if the bed is known to be covered with sandy bedforms).

When lowering and raising a point sampler using partial-depth integration:

- determine the number of partial depths required, and the filling time and transit rate required for the surface depth segment; use this filling time for all samples from that vertical
- for each depth segment, with the valve closed, lower the sampler to the required starting depth (this will be the surface for the first sample, and the reel counter should be zeroed at this stage)
- open the valve and traverse to the required stopping depth, always at the transit rate determined for the surface segment
- raise the sampler fully, but
- before opening, open the solenoid valve briefly to check if water spurts out of the nozzle; if it does the bottle is overfilled and the sample shall be discarded and re-collected. Take a second sample at each partial depth, traversing in the opposite direction.

When point sampling with a point sampler for compositing into a pseudo depth-integrated sample:

- determine the number of point samples required, their evenly spaced depths, and the filling time required for the sample nearest the surface; use this filling time for all samples from that vertical
- for each depth in turn, lower the sampler to the target depth with the valve closed
- open the valve for the required filling time then close it
- retrieve the sampler, but
- before opening, open the solenoid valve briefly to check if water spurts out of the nozzle; if it does the bottle is overfilled and the sample shall be discarded and re-collected.

Note: Point sampling with a point sampler may also be done to collect samples for SSC profile plotting or to collect samples at reference depths (e.g. for research applications). In such cases, the same procedures as above should be used, but all samples should be analysed individually for SSC

and ideally for size statistics; also, the filling time may be optimised to the velocity at the target depth.

4.6.12.4 Checking samples

Samples unloaded from samplers should be immediately checked for:

- overfilling: if the water level in the bottle is above the maximum permissible level for the bottle/sampler combination the sample shall be discarded and re-collected (usually the sample will have failed the "bubble check" if this is the case)
- underfilling: a sample volume of at least 250 ml is required unless samples are to be composited before laboratory analysis (e.g. as is the usual case with samples collected with the EWI method)
- large particles and extraneous matter: if particles larger than 2 mm are present, or there are particles that are neither sediment nor organic matter (e.g. plastic "beads"), the sample shall be discarded and repeated (possibly to a slightly higher distance above the bed), and
- seemingly abnormally high (compared to other samples) sand quantities and perhaps abnormally coarse particles at the bottom of the bottle: this suggests that the sampler nozzle has dipped into the bed (which is an elevated risk when ripples and dunes are present), and the sample should be discarded and re-collected.

4.6.13 Compositing samples

Sample compositing (also termed "bulking") limits the number of laboratory analyses required and also increases the mass of sediment available for analysis. However, compositing into one container places the whole gauging exercise in jeopardy of being corrupted by a single badly collected sample (typically one where the sampler nozzle has scuffed a sandy streambed). This risk shall be minimised by:

- carefully checking each sample for abnormally high sand content before adding it into the compositing container. If excess sand is suspected, discard and recollect the sample
- collecting a duplicate set of samples for compositing.

Generally, samples will be composited in three circumstances:

- across verticals for all EWI gaugings
- across verticals when collecting duplicate samples for particle size analysis using the EDI method, or
- at-a-vertical when using point samplers in one-way, partial-depth, or point-sampling modes (providing the partial-depth and point samples have been collected over/at equal depth intervals and over the same sampling time) to collect multiple samples that, when composited, are the equivalent of a depth-integrated sample.

When using the EWI method, transfer the sample from each vertical into the compositing container before moving on to the next vertical. Never accumulate a sample from multiple verticals into the sampler. This means that when collecting EWI samples by wading, a compositing container must be carried across the section.

The following procedure should be used for transferring samples into a compositing container:

- inspect the original samples (as in 4.6.12.4) before undertaking the transfer;
- ensure the compositing container is clean;
- swirl the bottle (being careful not to allow coarser particles to accumulate at the bottom-centre of the sample bottle) and transfer most of the sample;
- swirl again and transfer the remainder;
- inspect the original bottle for remaining sediment grains;
- as necessary, either:
    - return some sample water to the original bottle and repeat the final swirl until no sediment grains are observed in the original bottle, or
    - sluice lingering sediment grains from the original bottle using a wash-bottle filled with clean water, noting the volume of wash-water added to the transferred sample.

Note: Transfer of a single, badly collected sample into a compositing container can corrupt the composite sample. If in doubt, re-sample.
The same transfer procedure should be used if transferring samples from the sampler bottle to another bottle, even without compositing.

4.6.14 Duplicate samples

When using the EWI approach and the samples collected across the transect are composited, it is standard practice to repeat the transect, collecting a duplicate composite sample which should also be forwarded for laboratory analysis. The composite sample with the lower sand content should be the one archived. This further reduces the risk of the sample being corrupted by sand scuffing.

When using the EDI approach and when not pressed for time, it is good practice to collect duplicate samples from each vertical. After completing sampling, all sample bottles should be lined up and inspected for consistency and, especially, for anomalously high sand content. The duplicate sample should be selected for laboratory analysis if the original sample appears irregular. Unused samples may then be discarded.

Gray and O'Halloran (2015) detail the value of duplicate samples in reducing the risk of potentially corrupt field samples.

4.6.15 Field record form

Field records of suspended sediment gaugings should be logged on a paper or electronic form. This form should contain detail adequate to fully document the equipment and procedures used. Most of the information should be logged before actual sampling commences, then used to guide the sampling.
The records should comprise:

- general information: river and site, gauging party, date, accompanying discharge reference and measured discharge

- initial information: method of locating verticals (EDI or EWI), sampler type, nozzle size, integration mode (i.e. two-way, one-way, partial depth, point sample), start and end times
- vertical information: vertical number, offset, mean velocity and depth, optimal and limiting transit time and transit rate
- sample information at each vertical: depth range sampled, sample label, actual sampling time
- compositing of samples: source samples for composite samples, composite sample labels, volume of wash-water added during sample transfer, and
- additional comments/observations/photographs: e.g. unusually high algae or other organic content or sand content, ripples on bed, etc.

Figure 6-12 shows an example record form developed by Hicks and Fenwick (1994) for NIWA.

Suspended Sediment Gauging Record Form — Form SSR 930629

FIELD — Date 14·4·93

River Waiau at Marble Pt Site no. 64102 Party Fenwick Hicks Lwin

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 DH-48 /D-49 /D-74 /D-77 /P-61 (circled) /P-72 /Bucket or bottle

Nozzle: 3.2 /4.8 (circled) /6.4 /7.9 Container: pint (circled) /quart/3l bottles/3l bags

Integration mode (at crit. vert) surface /1-way /2-way /part. depth (circled) /point integ.

METHOD CODE SSNCleanMF – 614130511

Verticals: No Verticals 05 Selection Method: EDI (circled) /EWI/Single vert./Other

Flow data source: gauging (circled) /resource file / table / none

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

Time of start 1100 NZST Slope reach SG 1 start 1·492 m SG 2 start 1·292 m Slope Reach length 797 m

Vertical No.	Distance (m)	v̄ (m/s)	D (m)	T_{min} (s)	T_{opt} (s)	R	Bottle No.	T_{act} (s)	Comment	Mass (mg)	Vol. (ml)	Conc (mg/l)
1	26·4	2·22	2·81	4	8	1·0	YP9	9	Up } Bulked	890	710	1253
					8		YP8	8	Down } added +10 ml H_2O			
2	36·9	2·35	4·25	7	8	0·6	YX7	7	Up } bulked	855	700	1221
					8		YX6	8	Down } +10 ml 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 +20 ml 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			
			2·6–5·2		7	0·8	YP5	6	Up +25 ml 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 } +10 ml	780	680	1147
					Σ 106			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: ......

Figure 6-12 Example suspended sediment gauging record form, complete with columns to summarise concentration results after laboratory analysis.

4.6.16 Forwarding samples for analysis

Samples shall be forwarded to nominated laboratories for analysis in batches at the earliest opportunity, certainly within three weeks of the date of collection. However, where there is a likelihood of high algal content they should be despatched to the laboratory within three days of collection.

To avoid the spread of unwanted algae such as Didymo, the laboratories should always be forewarned about the origin of the samples and have procedures in place to render sample material and containers environmentally safe after analysis has been completed.

Sample containers must always be transported and stored upright. Rubber bungs, plastic caps, and even screw-on caps (particularly those that are old and/or in poor condition) can all leak. If sample leakage is suspected (e.g. water in the base of the carry-box/crate, unexpectedly small samples volumes), then this should be noted and laboratory results from the suspect sample, or batch of samples, should be checked for abnormalities.

4.6.17 Sample storage

Algae growth in stored samples can impact laboratory analysis by adding solid mass and causing premature blockage of filters during filtration. This is less likely to be a problem with flood samples; nevertheless the following safe-guards should be taken when storing samples:

- samples should be stored in the dark and kept cool at 4°C or less (Oudyn et al., 2012), ideally in a refrigerator
- samples should be sent to the laboratory at the earliest opportunity, and laboratory staff should be notified of any samples likely to have significant algae concentrations
- a preservative may be added.

4.7 Associated measurements

4.7.1 Stage and time

Stage and time shall be noted at the start and end times of the suspended sediment gauging and any associated discharge gauging.

4.7.2 Discharge

If using the EDI sampling method:

- if at all possible, discharge shall be measured immediately prior to the sediment gauging (to inform sampling selections), and
- if the stage has changed between the end-times of the discharge and sediment gaugings, the discharge at the mid-time of the sediment gauging shall be adjusted from the measured prior discharge using the rated discharge change (this is to provide a discharge time-synchronised with the sediment gauging – such as when used with sediment rating curves).

If using the EWI sampling method, discharge may be estimated from the rated stage at the mid-time of the sediment gauging.

4.7.3 Fixed-point samples

When a suspended sediment gauging is undertaken for the purpose of developing a relationship between SSC_{index} and SSC_{Qm}, then:

- fixed-point samples shall be collected at the start and end of the suspended sediment gauging, and
- the averaged SSC_{index} of the two point samples shall be related to the SSC_{Qm} result of the suspended sediment gauging and the associated discharge at the sediment gauging mid-time.

Note: When the point samples are collected by an auto-sampler, the auto-sampler shall be manually triggered at the start and finish of the sediment gauging.

5 Fixed-point Sampling to Calibrate and Supplement Surrogate Records

5.1 Purposes of fixed-point sampling

To underpin the Primary Method pathway of deriving a suspended sediment load record using an SSC surrogate measured at a fixed (or index) point (e.g. turbidity, ABS), point sampling beside the surrogate sensor shall be carried out for three purposes:

- calibration sampling: to develop a relation between the surrogate record and the local SSC (SSC_{index}) in the sampling volume of the surrogate sensor, for use in converting the surrogate record to an SSC_{index} record
- high-flow infill sampling: to collect data during high-flow events to fill gaps in the surrogate-generated SSC_{index} record resulting from over-ranging of the sensor (this applies mainly to turbidity sensors, which typically have lower SSC ranges than ABS sensors), and
- baseflow infill sampling: to collect data during baseflow periods to fill gaps in the surrogate-generated record (again, this applies more to turbidity, which at low turbidities may be dominated by factors other than suspended mineral sediment).

5.2 Method of collecting fixed-point samples

Sample collection options include:

- hand-collected grab sampling, using a rod-mounted, wide-mouth bottle or DH-48 sampler, or
- auto-sampling, using an automatically triggered pumping sampler.

Different collection approaches may be used for the different purposes, providing they meet the proximity to surrogate sensor requirement.

Unless impractial (e.g. excessive head required), auto-sampling shall be the standard approach for all three purposes because:

- most importantly, it provides a consistent sampling location and method
- samples can be triggered automatically through night and day, under all weather conditions, and
- high-flow samples can be collected safely.

Note:

- *Commonly available auto-samplers are limited to a 6-m lift between the water surface and the auto-sampler. This limits their usefulness in rivers with high banks that are inundated frequently. In these latter situations, pump rigs may be designed and installed, provided mains power is available at the site.*
- *Avoid dips in the auto-sampler intake hose as these may trap sediment that contaminates subsequent samples – the sample hose should drain after after a sampling cycle.*
- *Generally, the auto-sampler intake should point across the flow (as should the surrogate sensor being calibrated).*

- *Isokinetic sampling requirements do not apply for fixed-point sampling for the purposes listed above (Section 7.1). This is because the fixed-point samples are only index samples, and their SSC_{index} values (and the SSC_{index} records derived from the calibrated surrogate record) require calibrating to SSC_{Qm}.*

5.3 Where to sample

For all three purposes, the fixed-point sampling shall be undertaken:

- as close as practicable to, or in the sampling volume of, the surrogate sensor, ideally within 0.1 m, and
- always at the same location.

Note:
When using an auto-sampler:
- *Planning the positioning of the auto-sampler intake hose should be coordinated with the positioning of the surrogate sensor – remember it is there primarily to calibrate the surrogate record collected by the sensor. Ideally both should be placed where good sediment mixing occurs (see Sections 1 and 8).*
- *The auto-sampler intake hose shall not be placed in a low-velocity location such that the sampler collects sediment stirred-up by the sampler's pre-sampling purge cycle. Re-suspension effects of the auto-sampler shall be checked for when it is installed, and the bed around the sampler intake shall be checked periodically for surface mud that could be resuspended.*

5.4 When and how often to sample

5.4.1 Calibration samples

Samples for developing the surrogate to SSC_{index} calibration relationship shall be collected during freshes and floods:

- over the full range of the sensor or the range experienced at the site, whichever is smaller
- during at least one, preferably three, freshes or floods per year, including on rising and falling stages of the same event, and
- more frequently during the first year that the surrogate sensor is installed, in order to quickly:
    - identify typical, site-specific characteristics of the surrogate–SSC_{index} relationship, and
    - establish an initial surrogate–SSC_{index} calibration function.

Note: Scatter in the surrogate to SSC_{index} calibration relationship is determined largely by variation in the particle size of the suspended sediment passing the surrogate sensor (more so with turbidity sensors than ABS sensors). Particle size can vary systematically with discharge (e.g. more sand suspended as turbulence increases) and/or between rising and falling stages and season as sediment delivery from different sources varies. Thus, it is important, particularly for turbidity sensors, that calibration samples are collected over a range of discharges, both rising and falling stages, and throughout the year.

5.4.2 High-flow infill samples

At least in the case of when a turbidity sensor is used as the SSC surrogate, high-flow infill samples shall be collected during all events when the sensor is at high risk of over-ranging.

5.4.3 Baseflow infill samples

Baseflow infill samples shall be collected during baseflow periods whenever:

- there is evidence that the sensor signal is being dominated by factors other than sediment (e.g. by a 'noisy' calibration plot that does not pass through the origin) – which is much more likely with turbidity sensors
- the water level falls below the sensor sampling volume (i.e. the lens of a turbidity sensor, the end of an ABS), exposing it to the air, or
- persistent sensor fouling is occurring (more likely with a turbidity sensor).

5.5 Scheduling auto-sampling

When using an auto-sampler, the scheduling of auto-sampling shall be done using a programmable data logger to activate the auto-sampler. The data logger shall receive data input from a stage sensor and the surrogate sensor and shall send a sampling pulse to the auto-sampler when certain thresholds are passed. The data logger programme can manage sampling for all sampling purposes (calibration, high-flow infill, and baseflow infill).

Only one auto-sample shall be collected into each sample bottle (i.e. sample compositing should be avoided).

5.5.1 Calibration sampling

For calibration sampling during freshes and floods:

- sampling shall be initiated and terminated when the stage exceeds and falls below, respectively, a given site-specific threshold
- by preference, samples shall be scheduled on a flow-proportional basis, but may be collected at fixed intervals of change in the surrogate sensor measurements.

Note: Flow-proportional sampling:

- *triggers a sample when a fixed volume of water has flowed past the site*
- *requires a programmable data logger that has the current stage–discharge rating registered into it*
- *collects more samples the higher the flow rate, and*
- *increases the number of samples collected during the most influential periods of sediment transport.*

Note: Stage thresholds, water-volume thresholds for flow-proportional sampling, and time intervals for fixed-time sampling shall be set so that – as often as possible – there are enough sample bottles for samples to be collected over both the rising and falling limbs of high-flow events. Running out of

auto-sampler bottles during an event is not critical for the purpose of collecting calibration samples, but it is important to have, whenever possible, bottles available to receive high-flow infill samples. Most currently available auto-samplers have 24 to 28 bottles available. Site-specific simulations over hydrographs for variously sized events are helpful for optimising auto-sampling thresholds to make the best use of the bottles available.

5.5.2 High-flow infill sampling

For high-flow infill sampling, which is typically needed for turbidity sensors, auto-sampling:

- shall be initiated when the turbidity sensor reading is within 100 turbidity units of its known upper range limit for two successive data-logging periods
- thereafter shall be triggered on a fixed-time basis, and
- shall be continued for two hours or until the turbidity sensor reading falls below 100 turbidity units of its known upper range limit, whichever is longer.

Note: The two-hour minimum duration of high-flow infill sampling is required because some turbidity sensors, when over-ranging, return lower readings even though the actual turbidity continues to increase. The two-hour minimum duration may be adjusted with knowledge of:

- *the over-ranging behaviour of the sensor, and*
- *the maximum likely duration of over-ranging periods, based on inspection of turbidity data to hand.*

5.5.3 Baseflow infill sampling

For baseflow infill (to substitute for periods when a turbidity sensor calibration with SSC_{index} may be confused by other sources of turbidity or when any surrogate sensor is exposed above water), auto-sampling shall be:

- initiated at a pre-determined, fixed lag period after the stage has fallen below a threshold value
- continued on fixed time control, at approximately bi-weekly intervals, and
- terminated immediately after the stage threshold has been exceeded.

Note: The lag period before initiating infill sampling should be set for each site based on its stage-recession characteristics and may be 'tuned' based on inspection of subsequent data.
The stage threshold for infill sampling may be the same as, but no higher than, that used to initiate calibration sampling during freshets and floods.

5.6 Quality control

A quality code shall be assigned to the SSC_{index} result associated with each fixed-point sample. As detailed in the SSC_{index} Value Matrix (see Quality Codes section), this considers:

- proximity of sampling point to the sampling volume of the surrogate sensor; and
- whether standard laboratory procedures (as detailed in Section 13) have been used to determine the sample SSC.

In brief, the codes are:

- *QC 600*: The SSC_{index} result meets all field and laboratory standards
- *QC 500*: Sampling location between 0.1 and 1 m from surrogate instrument; or non-standard laboratory procedures used but any bias corrected using site-specific empirical relation
- *QC 400*: Sampling location varies between samples or is >1 m from surrogate instrument; or non-standard laboratory procedures have been used without empirical adjustment; or results have been inappropriately truncated/rounded-up.

6 Recording Turbidity as an SSC Surrogate

6.1 Instruments and procedures

Instrumented recording of at-a-point turbidity as a surrogate for SSC shall generally follow the procedures detailed in the NEMS *Turbidity Recording* except where the details that follow diverge from those in the NEMS *Turbidity Recording* – in which case the details below should be followed. See also Anderson (2005) for further information on turbidity recording.

6.1.1 Instruments

Key points regarding instrument type are:

- generally, it is recommended that the instrument shall follow the ISO 7027 protocol for determination of turbidity (since this is optimised for sediment monitoring)
- if the sensor record is to be used to provide an archived record of turbidity for use other than as an SSC surrogate, then the ISO 7027 protocol must be strictly observed
- if the sensor record is only to be used as an SSC surrogate, then the instrumentation protocol may be relaxed, and
- the instrument shall cover a turbidity range that extends at least to 4000 FNU.

Note: Many commonly available turbidity sensors have a maximum range of 1000–2000 turbidity units. However, many New Zealand rivers and streams have turbidity exceeding this range during floods. The phases of maximum turbidity are commonly associated with those of highest flow; thus, a significant portion of the suspended sediment load may be missed when a sensor over-ranges. A high-range sensor (0–4000 FNU) is required to minimise this risk and the need for infill sampling. Note that few ISO 7027 turbidity sensors range higher than 4000 FNU, which typically relates to an SSC of 4000–8000 mg/l. This range is exceeded during floods in many New Zealand rivers. Most turbidity sensors are rated to provide a linear response to the concentration of a reference suspension (e.g. formazin) up to a maximum value, but some sensors may still provide a useful, albeit non-linear, response over a higher concentration range. It is therefore important to understand the response characteristics of the sensor being used as turbidity increases beyond its stated upper limit.

6.1.2 Units

Turbidity records shall have units consistent with the instrument's measurement protocol, as defined in the NEMS *Turbidity Recording*. See also http://water.usgs.gov/owq/turbidity/TurbidityInfoSheet.pdf.

Data output from ISO7027-compliant instruments are assigned Formazin Nephelometric Units (FNU).

6.2 Managing missing/unreliable turbidity data

Turbidity-based SSC recording typically becomes unreliable at low and high SSC values.

6.2.1 Over-range turbidity

Turbidity sensors have an upper turbidity limit above which the sensor response becomes non-linear. Beyond this threshold, with increasing SSC, the sensor response eventually "saturates" around a maximum value, or even declines (if light absorption dominates over back-scattering).

Sensors used for SSC-surrogate monitoring should have an upper limit of at least 4000 FNU.

During large runoff events at some sites, however, very high SSC values may cause the sensor to over range, producing results that are substantially underestimated. These situations should be planned for and managed by:

- knowing the factory-defined operating limit of the turbidity sensor in use and the nature of its response beyond that limit
- identifying when the sensor has over-ranged, and
- infilling the SSC_{index} record for the period that the sensor has over-ranged.

Note: It is important that the over-range span of turbidity data is discarded and the consequent gap in the record is infilled after converting the turbidity record to SSC_{index}. This is because the turbidity sensor will only have been calibrated against SSC_{index} up to its maximum operating limit, and the calibration relationship (which may be non-linear) should not be extrapolated beyond that limit.

Two options exist for infilling SSC_{index} data:

- The recommended, proactive approach, detailed in Section 7.5.2, is by using a data logger to schedule auto-samples if the sensed turbidity exceeds the operating limit. This requires the auto-sampler and turbidity sensor to be controlled by the same programmable data logger.
- An alternative, or back-up – should the auto-sampler not be available, e.g. it has run out of sample bottles – is to extrapolate the calibrated SSC_{index} record over the gap, using the equivalent procedure defined for over-range records in the NEMS *Turbidity Recording*.

6.2.2 Low SSC values

At baseflows, when SSC tends also to be low, turbidity may be determined more by non-sediment causes (e.g. dissolved colour, phytoplankton), thus turbidity vs SSC_{index} relationships may show high data scatter and/or "saturate", with non-zero turbidity at very low SSC values. This may corrupt the derivation and application of calibration curves (e.g. over-predicting SSC_{index} during baseflows). Calibration datasets should therefore be examined carefully for these effects.

Where such effects are observed, there are three management options:

- fit a separate calibration curve to the low SSC range (identified by inspection)
- schedule infrequent (e.g. weekly or bi-weekly) "infill" auto-samples or manual grab samples during baseflow periods for direct measurement of SSC_{index}, and use these to replace the baseflow turbidity-generated SSC_{index} record, or
- assume zero SSC_{index} at baseflow – but this should only be done if available data indicate this is a reasonable approximation and calculations of the time-averaged SS load indicate that the contribution of baseflows is less than 5%.

At baseflows, the turbidity sensor may become exposed above the water surface, producing corrupt data. Even if the lens is submerged, light contamination can occur during daylight hours if the lens is too close to the water surface. Staff should therefore be aware of the minimum deployment depth of their sensor and the level of the sensor lens relative to the stage level. Turbidity records collected during periods when the sensor is exposed, or in water that is too shallow, should be deleted.

In small streams, sensor exposure at baseflows may be unavoidable, in which case infill sampling should be undertaken.

6.2.3 Infill sampling to replace unreliable turbidity data

Procedures to secure water samples for infilling gaps in the turbidity-derived SSC_{index} record due to unreliable turbidity data are detailed in Section 7.

7 Recording ABS as an SSC Surrogate

Instrumented recording of at-a-point acoustic backscatter (ABS) as a surrogate for SSC is a relatively new approach, thus no instrumentation protocols have been established. Operating principles and procedures for ABS sensors are essentially the same as with a turbidity/OBS sensor. However, important differences include:

- ABS sensors are less prone to signal degradation from biofouling
- they are not calibrated to a reference suspension (as an intermediate step, as are OBS sensors), therefore establishing and maintaining a direct field calibration is the main protection against potential instrument drift
- they are more responsive to suspended silt and sand, and less responsive to clay (which is the opposite of OBS sensors), although the grain size response also depends on acoustic frequency, and
- they measure a higher range of SSC, so should generally not require over-range (high-flow) infill sampling.

Note: The low sensitivity of ABS sensors at very low SSCs may require baseflow infill sampling (as with OBS sensors).

An example off-the-shelf instrument (LISST-ABS) is shown in **Figure 9-1**.

Figure 9-1 Example ABS and OBS sensors, and their relative response to a given concentration of suspended sediment for different sediment sizes. The ABS is a LISST-ABS (Sequoia Scientific): it uses an acoustic frequency of 8 MHz, senses SSC at a point 5 cm from the transducer at the end of the instrument, and has a reasonably "flat" and strong response for sediment between 32 and 500 microns but is relatively insensitive to clay (finer than 4 microns). The OBS pictured is a HACH Solitax, which is ISO 7027 compliant and has a mechanical lens-wiper. The response of OBS sensors is inversely related to sediment size, so they are most sensitive to suspended clay but relatively insensitive to sand. Graph sourced from Sequoia Scientific, Inc.

8 Office Procedures for the Primary Method

8.1 Calculating SSCQm from gaugings

8.1.1 Preliminary steps

SSC results from individual single-vertical or multi-vertical/composited depth-integrated samples must be converted into discharge-weighted, cross-section averages ($SSC_{Qm,}$ mg/l). This shall be done separately for the sand and mud fractions and their inorganic and organic components.

Before undertaking calculations, analysts shall:

- ascertain the sediment gauging methodology employed (i.e. EDI or EWI)
- check that the laboratory-reported concentration results (c) allow for wash-water added to the sample in the field; if they don't then make this adjustment as

$$c_{adj} = c\ V\ /(V - V_w)$$

where V is the volume of sample analysed and V_w is the volume of wash-water added.

8.1.2 Calculations

8.1.2.1 EDI sampling method

If the EDI sampling method was used and if all samples were composited into one sample for analysis (providing result c), then

$$SSC_{Qm} = c$$

Note: EDI-derived samples should only be composited if their volumes are approximately equal.

If samples from discrete verticals have been analysed separately, then

$$SSC_{Qm} = \sum c_i\ /\ N$$

where c_i is the concentration from the ith vertical and N is the number of samples/verticals.

8.1.2.2 EWI sampling method

If the EWI sampling method was used and all samples have been composited into one sample for analysis (providing result c), then

$$SSC_{Qm} = c$$

If samples from discrete verticals were analysed separately, then

$$SSC_{Qm} = \sum M_i / \sum V_i$$

where M_i is the sample mass from the ith vertical and V_i is the sample volume.

Note: In the EWI case, SSC_{Qm} does not equal the average sample concentration.

8.1.2.3 Irregularly collected samples

If samples were collected without following either the EDI or EWI protocols (e.g. at irregularly spaced verticals that do not represent equal parts of the total discharge), then

$$SSC_{Qm} = \sum c_i Q_i / \sum Q_i$$

where c_i is the concentration of the sample from the ith vertical and Q_i is the sub-section discharge represented by that vertical, with:

- Q_1 being the discharge in the sub-section from the near bank to midway between verticals 1 and 2
- Q_2 being the discharge in the sub-section from midway between verticals 1 and 2 to midway between verticals 2 and 3, and so on until
- Q_n being the discharge in the sub-section from midway between verticals n-1 and n to the far bank.

8.1.3 Bulk concentrations

The bulk SSC_{Qm} shall be determined as the sum of the results for the mud and sand fractions and their respective inorganic and organic components.

8.1.4 Concurrent water discharge

The water discharge at the mid-time of the sediment gauging (i.e. the concurrent water discharge) shall be taken as the discharge derived from gauging immediately prior to the sediment gauging, providing the stage has remained constant between the discharge and sediment gaugings. If there has been a change in stage (equating to a change in discharge exceeding 5%) the derived discharge time-series, incorporating any recent rating change, shall be used.

Note: Any adjustments to the stage-discharge rating based on a discharge gauging performed immediately before the sediment gauging shall be made before extracting the concurrent discharge The concurrent discharge may not equal that measured prior to the sediment gauging if the discharge is changing rapidly.

8.1.5 Quality control checks

Checks on the quality of suspended sediment gauging results shall consider if:

- isokinetic and flow-proportional sampling was achieved, particularly:
    - the average sample volume met the target range

    - the average transit times approximately met the target transit times
- appropriate laboratory methods were used (i.e. for the derived SSC_{Qm} and mass of sediment).

A quality code shall be assigned to each gauging result as detailed in the SSC_{Qm} Value Matrix (see Quality Codes section at the front of this document). In brief, the codes are:

- *QC 600*: Measured data meets all field and laboratory standards
- *QC 500*: Measured field data meet field standards except for required number of sampling verticals and/or non-standard laboratory procedures have been used but a correction has been made using an empirically derived correction relationship
- *QC 400*: Measured data does not meet field standards or laboratory standards
- *QC 200*: Field or laboratory measurements of unknown method or not assigned a quality code.

8.1.6 Archiving

Information to be archived from individual suspended sediment gaugings shall include:

- date, time, and site
- bulk SSC_{Qm}
- proportions of sand and mud and their individual proportions of inorganic and volatile organic sediment
- the concurrent discharge
- method identifiers for field method, including:
    - EDI or EWI
    - sampler, nozzle, and sample container used
    - depth-integration method (two-way, one-way, partial depth, point sampling)
    - number of verticals, and
    - whether or not samples were composited
- method identifiers for laboratory methods
- quality code
- associated data (e.g. discharge measurement, SSC_{index} result from point sample(s) collected concurrently with the sediment gauging, full particle size analysis).

8.2 Processing turbidity or ABS data to provide a surrogate SSCindex record

There are four steps in generating a surrogate SSC_{index} record:

- office validation of the surrogate (turbidity/ABS) record and editing its data (to correct for instrument drift and "noise" due to electronic transients and sensor fouling, and mark gaps due to corrupt sensor performance)
- developing a calibration relationship that relates the surrogate sensor output to the local SSC beside the sensor (i.e. SSC_{index})

- applying the calibration relationship to generate the SSC_{index} record, and
- infilling gaps in the SSC_{index} record.

8.2.1 Office validation and editing of SSC-surrogate record

Field turbidity data collected within the operating range of the turbidity sensor shall generally be validated and edited as detailed in the NEMS *Turbidity Recording*.

The exception is that baseflow turbidity data suspected of being strongly influenced by factors other than the ambient SSC (e.g. dissolved colour, algae), and turbidity data collected in conditions when the sensor is known or suspected to have over-ranged, shall be identified and removed from the record to be used for generating SSC_{index}. The options for securing replacement data are detailed in Section 8.2 of this document.

Similar procedures shall be used for ABS records, although these are less prone to baseflow and over-range issues.

8.2.2 Developing surrogate to SSC_{index} calibration relationships

The SSC-surrogate to SSC_{index} calibration relationship shall be generated as specified in Annex B of the NEMS *Turbidity Recording* (reproduced here as Annex E), with the exception that SSC_{index} may optionally also be related to both the SSC-surrogate and discharge using a multi-variate relationship (e.g. Rasmussen et al., 2009), selecting whichever option provides a more accurate prediction of SSC_{index}.

Calibration shall generally be to the total SSC_{index} (i.e. the total concentration of mud and sand) derived from laboratory results. However, in circumstances where interest may be focussed on the mud or sand components of the suspended load, separate calibrations for sand and/or mud may also be derived.

The at-a-point sample (e.g. auto-sample) SSC_{index} result shall be matched with a running-average value of the surrogate record centred at the time of the calibration sample. The running-average shall be collected over sufficient data points in the surrogate record such that high-frequency "noise" is minimised.

Note: Before extracting time-matched data from the surrogate record, that record shall be checked to ensure that the sampling process has not stirred-up a turbid pulse that has been detected by the sensor. This can result, for example, from the purge cycle of an auto-sampler or bed-scuffing when using a hand-held sampler. If such instances are detected, then uncorrupted sensor data from immediately before sampling shall be used.

Accuracy of the calibration relationship shall be assessed by examining:

- the proportion of total variance explained by the predictive model (r^2), and
- the standard error of the estimate (mg/l).

Note: Scatter in the calibration relationship is determined largely by variation in the particle size of the suspended sediment passing the turbidity sensor. At a particular site, the particle size may vary systematically with discharge (e.g. more sand suspended as turbulence increases) and/or between rising and falling stages and season as sediment delivery from different sources varies. At sites where these variations are observed, multi-variate or conditional (e.g. rising stage / falling stage) calibration relationships may be used providing they improve the above accuracy measures (r2 and standard error of estimate).

Calibration relationships shall be reviewed/re-established:

- annually;
- after major catchment-disturbance events (e.g. large floods, land-cover change) that generate significant changes in sediment supply;
- after any new turbidity instrument is installed (e.g. due to instrument failure); and
- after the monitoring site has been shifted (e.g. because of bank erosion).

8.2.3 Applying the calibration function to the surrogate record

The calibration function(s) relating SSC_{index} to instrument-measured turbidity or ABS over the operating range of the surrogate sensor shall be applied to the edited surrogate record to generate a surrogate-derived SSC_{index} record.

When multiple calibration functions have been developed, e.g. for low and high surrogate ranges, rising and falling stages, or separate seasons, each function shall be applied to the surrogate record in a way consistent with the manner in which the calibration data were separated.

When changing between two calibration functions that do not overlap, a suitable algorithm shall be applied that ensures a smooth transition from one function to the next.

For example, if using separate calibration functions for rising- and falling-stage surrogate values, an algorithm shall be used that progressively shifts the weighting from the rising- to falling-stage surrogate function. The time domain of the transition may be linked to automatically identifiable features on the surrogate hydrograph; for example, points of inflection or fixed periods before and after the peak turbidity.

Note: Gaps in the surrogate record due to unreliable data shall remain as gaps in the SSC_{index} record at this stage.

8.2.4 Filling gaps in the SSC_{index} record

Gaps in the SSC_{index} record shall be infilled as discussed in Sections 8.2.

If infill samples have been collected beside the sensor, their bulk SSC results shall be directly inserted into the surrogate-derived SSC_{index} time series.

When there are no infill samples available, the calibrated SSC_{index} record should be extrapolated over the gap using the equivalent procedure defined for over-range records in the NEMS *Turbidity Recording*.

Appropriate quality codes shall be assigned to the infill data records. Typically, this will be *QC 300* (for synthetic data).

8.3 Calibrating SSCindex to SSCQm

In general, SSC_{index} is unlikely to match SSC_{Qm} because of uneven mixing of the suspended load throughout the cross section. Mixing depends on the:

- turbulence intensity over the cross-section (which varies with discharge and rate of change in discharge), and
- the size grading of the suspended load (which may vary during freshes and floods and over longer timeframes).

There are two steps in converting the surrogate-derived SSC_{index} record to SSC_{Qm}:

- developing a calibration function that relates the SSC_{index} to SSC_{Qm}
- applying the calibration function to generate an SSC_{Qm} time series.

8.3.1 Developing calibration functions for SSC_{index} to SSC_{Qm}

Calibration functions relating SSC_{index} to SSC_{Qm} shall be developed from datasets of SSC_{Qm} results from suspended sediment gauging and the concurrent SSC_{index} point sample results (usually collected by auto-sampler). The suspended sediment gaugings and point samples shall have been collected using the procedures detailed in this Standard.

Procedures for developing such calibration functions are detailed in Annex C of the NEMS *Turbidity Recording* (reproduced in Annex F of this Standard).

Note: As outlined in Section 6.7.3, two SSC_{index} samples are to be taken when carrying out a suspended sediment gauging: one before and one after the gauging. The SSC_{index} to match with the gauged SSC_{Qm} shall be interpolated from the point samples at the mid-time of the SS gauging.

8.3.2 Ensuring sufficient and representative data

Sediment gaugings shall be undertaken during at least four runoff events per year until a relationship between SSC_{index} and SSC_{Qm} emerges. This dataset shall, over time, include measurements across the range between the mean discharge and equal to or exceeding the mean annual flood discharge at the site.

The SSC_{index} to SSC_{Qm} calibration relationship may change if the point-sampling (e.g. auto-sampler) location is shifted or if there is a systematic change in the size mixture of the suspended load (e.g. as detected by a shift in the surrogate sensor calibration). In either case, further gaugings shall be scheduled to check for change and, if need be, to re-establish the SSC_{index} to SSC_{Qm} relationship.

8.3.3 Applying calibrations

The derived calibration function(s) shall be used to convert the surrogate-derived SSC_{index} record to a SSC_{Qm} record.

8.4 Managing suspect SSC laboratory results

When working with SSC data, such as when developing calibration relationships for SSC-surrogate to SSC_{index} or SSC_{index} to SSC_{Qm}, some data points may plot as outliers or be otherwise suspect. Suspect SSC results can stem from several causes:

- corrupt field samples (e.g. excess sand mass collected, sample spillage, etc)
- laboratory calculation/reporting blunders
- inappropriate laboratory analysis procedures (e.g. TSS method used rather than SSC method, or "capping" the reported SSC)
- mis-used laboratory results.

Figure 10-1 illustrates examples of each.

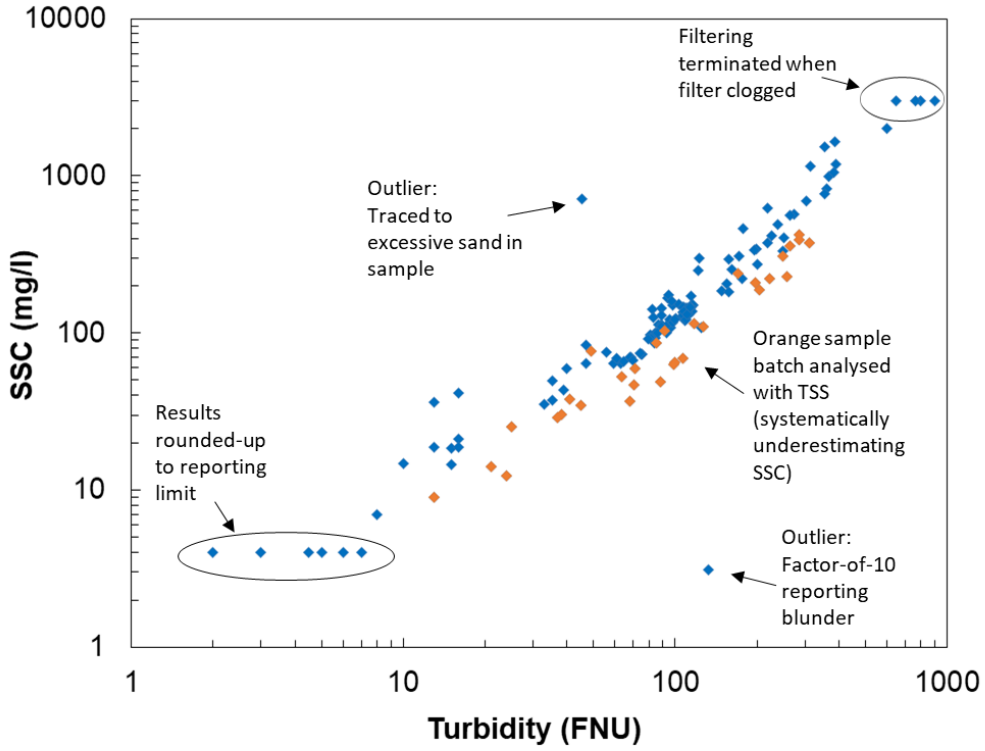


Figure 10-1 A calibration plot, relating SSC to turbidity, illustrating examples of suspect SSC data points. (i) High outlier point traced to unusually high sand mass in sample, suggesting sample corruption by bedform sampling, corroborated by site observations. (ii) Low outlier traced to a laboratory reporting blunder (misplaced decimal point). (iii) One data batch (orange points) plot systematically lower because TSS laboratory method used instead of SSC method. (iv) Six points plotted when SSC at reporting limit (4 mg/l) - such points should not be used in deriving calibration relations, since their actual SSC values are ≤ 4 mg/l (particularly important with log-transformed curve-fitting). (v) Four points were assigned "capped"/ minimum concentrations because filtering was terminated when filter clogged.

8.4.1 Corrupt field samples

Corrupt field samples typically result in unexpectedly high SSC. These can occur when a depth-integrating sampler "scuffs" a sandy bedform, or a bedform builds below an auto-sampler intake. Vigilance in the field should avoid most cases, but field notes of suspect conditions can indicate whether a suspect result may be discarded. A corrupt result can also occur due to sample loss by spillage in transit to the lab. Again, a vigilant lab technician should detect this (e.g. noting signs of spillage or an unusually small water volume).

8.4.2 Reporting/calculation blunders

Outliers, particularly involving very low SSC values, are often due to blunders, such as shifting the decimal point in a result. These can usually be traced by examining laboratory records.

8.4.3 Inappropriate laboratory procedures

Historical/existing SS concentration data may have used the TSS laboratory procedure (APHA, 1995) and so may be biased, possibly underestimating the true SSC. Where this is the case, TSS-derived data shall be regarded as suspect and assigned a downgraded quality code (no higher than QC 400) until either proven otherwise or corrected. Since TSS bias is determined largely by the amount of sand in the sample, which is site-specific, resolving this requires a period of concurrent analysis using both the ASTM (ASTM, 2013) and TSS procedures. A procedure for this analysis is described by Ward (2000).

Another inappropriate laboratory procedure that has sometimes been observed in New Zealand is terminating a filtering analysis when the single filter being used has become clogged, with the residual unfiltered sample being discarded. This provides a "capped"/minimum-value SSC result – which, while usually flagged as such in the laboratory report, is often ignored during subsequent data analysis. Such data points are typically indicated by constant values of SSC (forming horizontal rows of relatively high SSC). Such points should be discarded during data analysis.

Note: The laboratory procedure in this Standard (Section 13.2) requires all of the sample to be analysed, using multiple filters if necessary, when using the ASTM B procedure.

8.4.4 Mis-used laboratory results

An example of mis-used laboratory results is including data at the reporting limit when fitting calibration functions. Often the "<" sign is ignored, and the values are assumed to be at the reporting limit. This can bias function-fitting, particularly when the data have been log-transformed. Such data points are indicated by small, constant values of SSC (forming a horizontal row of low SSC points).

Data at the reporting limit shall not be used when fitting calibration functions or sediment ratings.

8.5 Assigning quality codes to SSCQm records

Quality codes shall be assigned to the calibrated SSC_{Qm} time-series records using the flowchart provided at the front of this document. These codes reflect the quality of the component steps from the collection of the raw SSC-surrogate data to its transformation to SSC_{Qm}. Thus:

- *QC 600*: Records derived from sensor-measured data acquired using one of the Primary Method options, with all the field and laboratory standards met, calibrated both for SSC-surrogate to SSC_{index} and for SSC_{index} to SSC_{Qm}, and collected from a site with no significant site quality issues.

- *QC 500*: As above but less than ideal calibrations established between surrogate and SSC_{index} or between SSC_{index} and SSC_{Qm}, or the calibrations were derived using SSC_{index} or SSC_{Qm} data most of which is assigned a *QC 500* code, or the site is currently assigned a site quality code < *QC 600*.
- *QC 400*: As above, but time-series SSC_{Qm} records are compromised through either: significant editing or inadequate validation of raw surrogate records; surrogate vs SSC_{index} calibration is poorly established and/or based on *QC 400* rated SSC data; there is no data available on the relation between SSC_{index} and SSC_{Qm}, so that this relation is simply assumed to be 1:1.
- *QC 300*: Time-series records are derived from a non-standard source, such as from: a surrogate instrument other than prescribed in the Primary Method of this NEMS; a sediment rating curve that relates SSC_{Qm} to instantaneous discharge; or hydrological or hydraulic models forced by catchment or channel characteristics and a time-varying record such as rainfall. Typically, *QC 300* data is used to infill gaps or replace unreliable/biased data in the Primary instrument-derived record.
- *QC 200*: Measurements of unknown method, raw data not checked or edited, and/or not assigned a quality code.
- *QC 100*: Missing record that has not been infilled.

Note: Time-series SSC_{Qm} records derived directly from index/at-a-point sampling (such as when an auto-sampler record is used to infill missing/out-of-range surrogate data) shall be assigned to QC 400 – QC 600 as appropriate depending on the quality of the SSC_{index} values and the SSC_{index} vs SSC_{Qm} relation.

8.6 Calculating time-averaged suspended sediment load

8.6.1 Bulk suspended load

The time-averaged load of suspended sediment (Q_s, t/yr), undifferentiated by composition, shall be calculated over the period of interest as:

$$Q_s = k\sum (\Delta t\ (q_n + q_{n+1})(SSC_{Qmn} + SSC_{Qmn+1})/4)/N$$

where q_n is the discharge record at time n, SSC_{Qmn} is the synchronous record of discharge-weighted, cross-section average SSC, q_{n+1} and SSC_{Qmn+1} are the respective records at time $n+1$, Δt is the time interval between records (Δt should range between 5 and 15 minutes, less for smaller catchments), k is a unit conversion factor equal to 10^{-9}, and N (yr) is the duration of the period of interest.

Note:This provides a result for the bulk suspended sediment load (undifferentiated by composition). This will not provide the total stream sediment load (since it excludes the bedload and may underestimate the unmeasured suspended load - see Section 6.4).

8.6.2 Suspended load by constituent

The time-averaged load of suspended sediment by constituent (mud, sand, organic content) may be derived by developing separate calibrations between the measured SSC-surrogate and at-a-point constituent concentration and between at-a-point constituent concentration and cross-section average constituent calibration.

8.6.3 Quality of time-averaged suspended load results

The quality of a time-averaged suspended load result depends on the qualities of the SSC_{Qm} and discharge records that are integrated together (as in equation in 10.6.1 above). A measure of the overall quality of the time-averaged load result may be achieved by first assigning a quality code to the derived load record at each time step, then apportioning the time-averaged load across the QC range (e.g. 90% load based on *QC 600* load records; 10% based on *QC 300* load records).

The QC code of the suspended load derived at each time-step shall be found from the QC codes of the concurrent records of SSC_{Qm} (derived as in Section 10.5) and rated discharge (as defined in the NEMS Rating Curves) using a "lookup" table (**Table 10-1**). In this table, the lesser of the SSC_{Qm} and discharge QC codes are generally used, except for over the *QC 400 – QC 600* range for both SSC_{Qm} and discharge where greater weight is given to the SSC_{Qm} QC code.

Note: Because determining the load at a given time-step involves averaging the SSC_{Qm} and discharge of the current and following records, the QC code associated with the load result shall use the smaller of the QC codes from the current and following records.

		SSC_{Qm} Quality Code					
		100	**200**	**300**	**400**	**500**	**600**
Discharge Quality Code	**100**	100	100	100	100	100	100
	200	100	200	200	200	200	200
	300	100	200	300	300	300	300
	400	100	200	300	400	400	500
	500	100	200	300	400	500	600
	600	100	200	300	400	500	600

Table 10-1 – Assigment of QC codes to derived records of suspended sediment load, using QC codes assigned to concurrent records of SSC_{Qm} and discharge. For example, if the SSC_{Qm} record is *QC 600* and the discarge record is *QC 500*, the derived load is assigned *QC 600*.

9 Flow-Proportional Composite Auto-sampling

9.1 Purpose

The purpose of flow-proportional composite auto-sampling is to provide a direct semi-continuous record of time-averaged SSC and SS load at an index point. By placing multiple samples into each bottle of an auto-sampler (compared with only one sample per bottle), it enables greater temporal detail when auto-sampling though storm events, thus providing more accurate determination of the suspended sediment load while also reducing the number of samples to analyse in the laboratory. It provides an alternative approach (with comparable accuracy) to monitoring SSC using a surrogate such as optical or acoustic backscatter.

9.2 Principles

The flow-proportional composite auto-sampling approach measures the incremental SS load over the period while sub-samples are being added to each auto-sampler bottle. A key requirement is that sampling is triggered when a fixed volume of water has passed the sampling site. This is termed "flow-proportional sampling" since it renders the sampling rate (samples/hour) directly proportional to the water discharge. Each sub-sample represents the SSC in a discharged water volume of which half passes before the sub-sample is collected and half passes immediately after the sub-sample is collected.

In practice, flow-proportional sampling is achieved by programming a stage-sensing data-logger with the site's stage-discharge relation, enabling the logger to calculate instantaneous water discharge and to accumulate water volume discharged on-the-fly. When the target volume (termed "sample trigger volume", V_t) has passed, the logger issues a signal to trigger the auto-sampler and records the time, sub-sample number, bottle number, and the current discharge. For a given discharge, the smaller the target volume the more often samples are collected.

The SS load over the time that a bottle is filled with sub-samples is simply equal to the SSC in the bottle multiplied by the water volume that is discharged over that time.

Note: As with SSC-surrogate sensors, this approach only collects a record of SS load at an index point, and a relationship needs to be established between this point and the cross-section mean SS load.

9.3 Hardware requirements

The site hardware requirements must include:

- An auto-sampler:
  - with at least 24 500ml- or 1000-ml bottles or a single large container at least 20 litres in volume
  - capable of distributing multiple sub-samples into individual bottles, and
  - capable of receiving sampling control from an external signal
- A programmable data logger connected with a stage recorder and programmed with the current stage/discharge rating, updated as necessary
- A telemetry system to relay the auto-sampler status, including battery voltage and bottle use history / bottle availability.

9.4 Parameter setting

The data logger programme should include the following user-definable parameters:

- sample trigger volume (V_t)
- parameters that define the stage/discharge relation
- stage thresholds at which to commence and terminate sampling during the rising and falling stages of runoff events
- number of sub-samples per bottle (N, which is also independently set on the auto-sampler), and
- the sub-sample volume (also set on the auto-sampler).

Typically, to avoid filling bottles with clean water during baseflow periods, the auto-sampler is only activated during runoff events, which is when most sediment transport occurs. This is done most simply by setting a stage threshold at which the auto-sampler begins collecting sub-samples at the beginning of a runoff event and another threshold when sampling ceases on the event recession.

Most of these parameters control the temporal resolution of the sampling and therefore the "endurance" of the sampler (before bottle servicing is required). They need to be determined by trial and error, ideally via desktop simulations using a sample period of flow record from the site. A target should be that the supply of bottles is not quite used up during an event of annual recurrence interval.

Note:
Flow forecasting, if available, may be used via telemetry to adjust the sampling parameters to optimise the use of available bottles.
Beware of seasonal variability in baseflows when setting stage thresholds to start and end flow-proportional sampling. For example, low baseflows often occur during late summer/autumn so only a low stage threshold may be needed to activate sampling during typical runoff events; however, through the winter and spring, when baseflows are higher, the same thresholds may cause almost continuous sampling of predominantly clean water. This can be dealt with by:
Manually adjusting the stage thresholds based on operator awareness of baseflow levels, or
using the data logger to separate stormflow from baseflow (on-the-fly), and activate sampling only during stormflow runoff (using a stormfow/baseflow separation slope parameter).
When activating continous sampling during runoff events using a stage threshold, it is recommended that the first sub-sample of the event goes into a fresh bottle and is triggered immediately when the stage threshold is exceeded.
With some auto-samplers, a bottle-advance cannot be triggered until the active bottle has received its full quota of sub-samples – which means that sub-samples from sequential events will be added to the same bottle if the first event ends before the bottle is full. If this is not desired (e.g. if the sampling purpose includes recording the load of discrete events), then when terminating continous sampling during runoff events using a stage threshold it may be necessary to continue sub-sampling below the threshold stage until the sub-sample quota is met.

9.5 Logging field data

The following data shall be logged at the time that each sub-sample is triggered:

- bottle number
- sub-sample number
- accumulated water volume (V_{ta}), and
- discharge (at the time of sub-sample trigger).

Note: It follows that the data logger shall keep track of the active bottle number and sub-sample number and that these shall be re-set whenever the auto-sampler bottles are replaced.

9.6 Infilling missing record

Missing records can occur when the auto-sampler fills all the bottles in its magazine or during mechanical breakdown. In such cases, the SS load over the period of missing record may be infilled using a sediment rating curve compiled from available data. This rating curve can either relate:

- the time-averaged SSC in individual bottles (containing composite sub-samples) to the discharge averaged over the sample compositing period, or
- event SS load to event hydrological magnitude (e.g. peak discharge or runoff volume).

Note: When applying either type of rating curve to compute sediment loads from a discharge record, the same averaging process shall be applied. For example: a composite sample rating should be applied at a varying time-step that corresponds to the sample trigger volume (thus, the history of trigger volume settings needs to be safely documented). Similarly, an event rating should be applied only to a series of event magnitudes (e.g. peak discharges).

Refer to Event sediment ratings in Section 12.5 for further detail.

9.7 Calculating and filing incremental SS load

The flow-proportional composite auto-sampling approach measures the incremental SS load over the period while sub-samples are being added to each auto-sampler bottle. Each sub-sample represents the SSC in a discharged water volume of which half passes before the sub-sample is collected and half passes immediately after the sub-sample is collected. The incremental load associated with each composite-sampled bottle (L_j, kg) is:

$$L_j = 10^6 \, c_j \, V_j$$

where c_j (mg/l) is the SSC of the composited sample in the jth bottle and V_j (l) is the water volume discharged over the period that the sub-samples were added to the bottle.

In theory, V_j should equal the sample trigger volume (V_t) multiplied by the number of sub-samples (N) placed in the bottle. In practice, because of the finite time-step of the discharge monitoring record, a volume slightly larger than V_t typically passes before the logger triggers a sample (so the actual trigger volume, V_{ta}, is invariably larger than V_t). Thus, the value of V_j should be taken as the accumulated discharge volume between the start time of the first sub-sample that goes into the bottle (t_{sj}) and the end-time of the last sub-sample (t_{ej}) added. For continuous sampling, the end-time of the last sub-sample added into one bottle becomes the start-time of the first sub-sample added to the next bottle (i.e. $t_{ej} = t_{sj+1}$).

t_{sj}, t_{ej}, and V_j are best back-calculated from the discharge record, given the logged sampling times of the first and last sub-samples added to a bottle. t_{sj} shall be taken as the time at which the accumulated volume before the logged time of the first sub-sample equals $V_{ta}/2$. t_{ej} shall be taken as the time at which the accumulated volume after the logged time of the last sub-sample equals $V_{ta}/2$. V_j is then derived by accumulating the discharge volume between t_{sj} and t_{ej}.

The L_j results for the jth bottle shall be filed at time t_{ej} as a load increment record for the period t_{sj} to t_{ej}.

9.8 Calculating time-averaged SS load

Using SS load increment records L_{si} (kg), obtained from flow-proportional composite sampling, the time-averaged load of suspended sediment (Q_s, t/yr), shall be calculated over the period of interest (N, yr) as

$$Q_s = 0.001 \sum L_{si} / N$$

10 Sediment Rating Method

10.1 Preamble

A sediment rating is a relationship between (typically) instantaneous SSC and discharge, compiled from concurrent, irregular measurements of both. The rating is combined with the discharge to estimate the time-averaged suspended sediment load over annual, or longer, time-scales. This approach is not recommended for estimating average loads over shorter periods because of the typically large scatter in the relationship.

By not requiring continuous sampling, the 'sediment rating' approach offers considerable economies of field effort. The key to its successful implementation, though, lies in a well designed and implemented sampling strategy.

A sediment rating dataset can be collated from manual sediment gaugings or from auto-sampling. In the former case, the rating directly relates SSC_{Qm} to discharge. In the latter case (as with other index monitoring), a separate relationship is required to relate SSC_{index} predicted by the rating function to SSC_{Qm}.

Notwithstanding the above-mentioned accuracy issues associated with short-term application, sediment ratings may also be used to infill missing SSC records in the Primary Method, with appropriate data quality codes assigned.
The following focuses on instantaneous ratings; event ratings are covered more briefly in Section 12.5.

10.2 Sediment rating approaches

There are two main approaches to developing and applying instantaneous sediment ratings:

- the statistical approach, and
- the multivariate approach.

10.2.1 Statistical approach

The statistical rating approach acknowledges that there is no unique relation between SSC and discharge (Q), and so aims to model the conditional mean concentration (as a function of discharge) over the time period of interest. The conditional mean relation is estimated by compiling a dataset that samples, without bias, all conditions that cause variability in the Q–SSC relationship. In terms of accuracy of load estimate, it matters little if a statistical rating is integrated with the original discharge record or if the latter is compressed into a flow-duration table, providing that in the flow duration table the flow range is divided into small intervals and the high-flow range is well detailed.

With this approach, it is important that all factors (and associated time-scales) causing variation in the Q–SSC relationship (e.g. controls on sediment supply that vary within, and between, events, between seasons, and due to longer-term trends) are sampled without bias. An example of bias is when a site has systematically higher SSC on rising stages compared with falling stages (e.g. due to an initial 'flush' of readily available sediment from

the channel during the early stages of a runoff event) but samples are only collected on falling stages. A rating derived from this biased dataset will result in an underestimate of the time-averaged SS load. Such bias is common at remote sites where field parties may have difficulty arriving before floods peak.

10.2.2 Multivariate approach

The multivariate approach attempts to explicitly model SSC with an empirically derived multivariate relation, relating SSC not only to water discharge but to other controls or processes affecting the sediment supply, such as season, long-term trend, hysteresis of sediment delivery during storms, and so on. With this approach, time-series information is required on all of the independent variables in order to generate a long-term average sediment load, and multivariate or more sophisticated techniques (e.g. machine-learning, fuzzy logic, neural networks) are used for relation fitting.

A variation on the multivariate approach is to use separate 'conditional' rating functions with discrete parts of the discharge record, for example, for rising and falling stages and/or for different seasons, and/or from one year to the next. An advantage of the conditional rating approach is that it is less subject to bias (because it forces data stratification), but too many conditional ratings become unwieldy to maintain and apply.

10.2.3 Recommended approach

The statistical approach is more commonly used and is recommended in this Standard.

10.3 Sampling strategy for statistical ratings

A properly designed sampling strategy – which directs when samples should be collected – is required to avoid developing a biased rating dataset and to focus sampling on the higher flows that transport most of the SS load in the long term. For example, while regular (e.g. monthly) or random time-interval sampling may be unbiased, it provides a poor rating dataset because the chances of intercepting flood flows are slim. Flow- and load-weighted strategies work better because they produce reasonably uniform densities of data points over the whole flow range.

Auto-samplers, controlled by programmable data-loggers coupled to a stage recorder, permit such sampling strategies to be realised formally. Examples include flow-proportional sampling (see Section 11) and the more sophisticated selection-at-list-time (SALT) method of Thomas (1985). In many situations (e.g. sites difficult to access during floods) the benefit of using an auto-sampler with a formally applied sampling strategy outweighs the disadvantage of having to conduct manual sampling to establish a relation between SSC_{index} and SSC_{Qm}.

When collecting manual gaugings, the sampling strategy requires a written data-collection plan detailing flows to target and continued evaluation of the dataset to refine the sampling plan.

Using either auto-samplers or manual gaugings to compile a rating dataset:

- the dataset should be compiled for at least 5 years (to capture and average-out interannual variability), or longer if the purpose is to detect trends in sediment load

- at least 6 manual gaugings per year (or 6 auto-sampled events) should be collected
- the focus should be on sampling during runoff events, including rising and falling stages
- a "running" rating shall be plotted, with data points identified by year, season, and rising/falling stage, and
- the count of data points should be approximately uniform across different discharge bands when the bands are defined at uniform intervals of the log of discharge.

Note: Where an auto-sampler is installed for the primary purpose of collecting samples to calibrate surrogate records (e.g. turbidity, ABS) to SSCindex, the dataset can also be used to develop a Q–SSCindex rating which can be used to verify the primary, surrogate-based load estimate, and may also be used to fill gaps in the surrogate-derived SSC record.

10.4 Fitting sediment ratings

10.4.1 Principles

The traditional approach to deriving a sediment rating equation has been to plot concurrent measurements of SSC against discharge on log-log graphs. There are several good reasons for this:

- log-log plots accommodate the large ranges of discharge and sediment concentration observed in rivers,
- the data scatter tends to be homoscedastic (i.e. independent of discharge), and
- the underlying relation typically shows a simple power form SSC = aQ^b (where a and b are empirical coefficients), which is linear on a log-log plot.

Traditionally, such rating equations tended to be eye-fitted, but with the arrival of personal computers and statistical analysis packages, simple linear regression of the log-transformed data became widely used. There are two potential issues with this simple linear regression approach:

- log-transformation bias, and
- curvature in the logSSC vs log$Q$ trend.

When using log-transformed data the linear regression procedure models the trace of the geometric conditional mean SSC, rather than the desired arithmetic conditional mean, thus the predicted SSC tends to be underestimated. Several methods are available to correct for this bias. The recommended correction method is to multiply the coefficient a in the SSC = aQ^b regression equation by Duan's (1983) empirical 'smearing' estimator, which equals the average ratio of observed/predicted SSC in the rating dataset, where the predicted SSC is derived from SSC = aQ^b using the original, uncorrected value of a.

Quite often, the rating data may show a convex, up-curved trend on the log-log plot. In such cases, the simple power law equation SSC = aQ^b, while appearing to fit the overall dataset reasonably well, may give a poor fit to the high discharge end of the data. However, it is these high discharges that transport much of the long-term SS load and so should have a well-fitting rating. When a simple power law equation does not provide a good fit to the high discharge end of the data (e.g. **Figure 12-1**), other, non-linear curve-fitting techniques are required. The recommended approach is to use a scatterplot smoothing approach (e.g. LOWESS or LOESS) that constructs a 'running' linear regression fit to the data in a moving

window (or band) of discharge. With this, when using log-transformed data, the log-bias correction factor may be applied to each window if the data scatter varies across the discharge range (i.e. it is heteroscedastic). If the scatter does not vary appreciably with discharge (i.e. it is homoscedastic), then a global bias correction factor can be derived and applied.

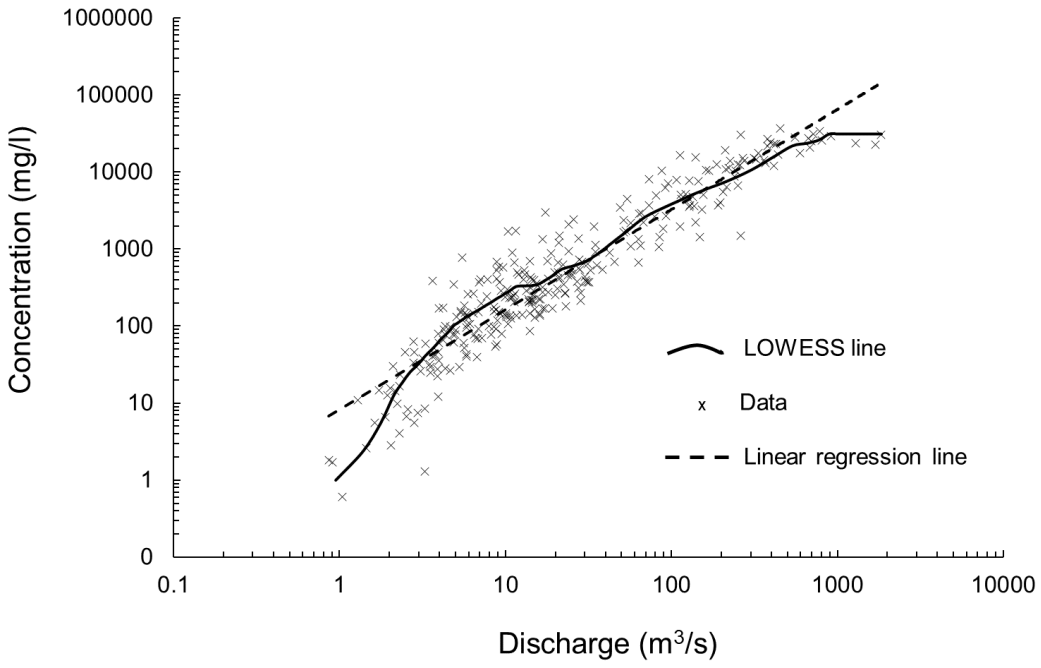


Figure 12-1 – Suspended sediment rating data for the Waipaoa River at Kanakanaia Bridge, with LOWESS and linear regression lines fitted to log-transformed data. Note how the linear regression line projects well above the data points at the high end of the discharge range; indeed, an unrealistic SSC of ~500,000 mg/l is projected for the maximum recorded discharge of ~ 5,200 m^3/s. Using the LOWESS rating the predicted mean annual sediment load is ~11 million t/yr; using the linear regression rating the load is ~24 million t/yr – more than a 100% difference!

10.4.2 Steps for developing and checking a statistical sediment rating

1. Assemble the data and plot on both linear and log-log scales, with the discharge data on the horizontal axis, ensuring that the discharge axis extends at least to the maximum discharge on record.

2. Assess both plots for homoscedasticity, selecting the plot that is most homoscedastic (this will usually be the log-log plot).

3. With the preferred plot type, in the first instance fit a linear regression line (which will be a power-law function of the form $SSC=aQ^b$ on the log-log plot). If the data curve away from the linear trendline, particularly at the high discharge end, abandon the linear regression line and fit a LOWESS (or LOESS) line; otherwise, the linear model may be kept.

4. When fitting a LOWESS/LOESS line, vary the "stiffness" factor (which controls the width of the moving window of discharge) until an optimal fit is obtained (as judged by eye and as confirmed by a maximum r^2 and a minimum standard error). Note: there is little point in over-fitting with too small a stiffness factor if that produces a "crinkly" line.

5. Calculate and apply the bias correction factor. With a LOWESS/LOESS line, use a global bias correction factor (i.e. one factor derived from all the data points) if the scatter about the curve appears reasonably uniform as discharge varies. If not, use a "moving" correction factor.

6. Replot the bias-corrected rating, projecting it out to the maximum known discharge at the site. With a LOWESS/LOESS curve, the projection should be done using the regression coefficients derived for the data point at the highest sampled discharge.

7. Record the rating-fit coefficients, including statistics such as the r^2, standard error, and log bias-correction factor (if appropriate).

8. Check if the SSC predicted at the maximum discharge is sensible (with respect to what is reasonably anticipated for the site, based on data from other nearby sites or other information in the literature, e.g. Hicks et al., 2004). For example, a projected maximum concentration of 250,000 mg/l would be a mudflow and unlikely to occur in most parts of New Zealand. If unbelievable maximum concentrations are predicted, then estimate, from available information, a likely maximum concentration and force the rating to project to that point.

9. Apply the rating to the flow-distribution table for the site to estimate the mean annual SS load, and calculate the percentage of this load carried in discrete discharge bands. Compare the density of data points within each discharge band with the percentage of load carried. Also, calculate how much of the total load is predicted to be transported by discharges higher than currently sampled. Use these results to identify which discharge ranges need to be targeted for further sampling. For example, if only 50% of the estimated load is transported by the sampled range of discharges, then emphasis should be placed on sampling higher discharges.

10. Check for sampling bias in the dataset by:

    a. Identifying points collected on rising and falling stages; if there is a separation, then check if the relative proportions of rising and falling stage data points align with the overall relative durations of rising flows and recessions during runoff events at the site.

    b. Identifying points collected during different seasons; if there is a separation, then check if the relative proportions by season are even.

    c. Construct a time plot of residuals (i.e. the ratio of log rating-predicted/observed SSC versus time). Assess for a statistically significant time trend. If one is observed, check that there is a reasonably uniform number of data points year to year and that these are spread across a range of discharges.

11. If any of these checks indicate sampling bias associated with a factor causing variability in the rating, then further sampling should be directed towards rectifying this bias. For example, if rising and falling stage points plot in different spaces but there are only two rising stage points compared with 50 falling stage points, then the sampling focus should be directed to rising stages.

12. Such sampling recommendations shall be documented on the annual data collection plan for the sediment monitoring site

10.4.3 Rating-fitting software

A rating-fitting software package that streamlines the above steps is recommended. An example is shown in Annex G.

10.4.4 Updating the sediment rating and sampling focus for the coming year

Once at least 12 data points are available, a working sediment rating shall be developed and updated annually, with steps 7-9 from Section 12.4.2 being used to direct the sampling effort in the coming year to mitigate any bias in the dataset.

10.5 Event sediment ratings

10.5.1 Overview

The procedures defined above for rating instantaneous SSC and discharge may be applied (with little variation) to event sediment ratings – which relate event loads to some measure of event hydrological magnitude (e.g. peak discharge). Event ratings are compiled from accurately measured loads from a sample-set of runoff events, typically collected by an auto-sampler with flow-proportional sample scheduling, but a surrogate sensor record calibrated to SSC_{index} may also be used. As detailed in previous sections, SSC_{Qm} will then need to be derived from a calibration with SSC_{index}.

Event ratings may be used to:

- estimate the mean annual sediment load by applying them to a continuous series of event peak discharges
- patch gaps in series of event loads, such as compiled from continuous flow-proportional sampling, or
- predict SS loads from individual runoff events of given return period, for example to design sediment retention ponds in basins undergoing urban development to limit sediment exports.

10.5.2 Developing an event sediment rating

The main difference between deriving an event sediment rating and an instantaneous rating is that for an event rating a selection of different measures of hydrological magnitude should be trialled, such as event:

- peak discharge
- runoff (m^3), and
- quickflow runoff (m^3).

The measure chosen shall be the one providing the best fit with event sediment load (as indicated by the r^2 and standard error statistics and best meeting the data scatter and trend criteria discussed in Section 12.4). **Figure 12-3** shows an example of an event rating using peak discharge.

An event sediment rating may be compiled over as short a time frame as one or two years, provided that an adequate range of event magnitudes is sampled and that the relation remains 'stationary' over the period of application (i.e. the sediment sources and erosion processes in the basin do not change appreciably, such as might occur during a land-use conversion, e.g. forest harvesting or urban development).

See Hicks and Gomez (2016) for further information on developing and using event sediment ratings.

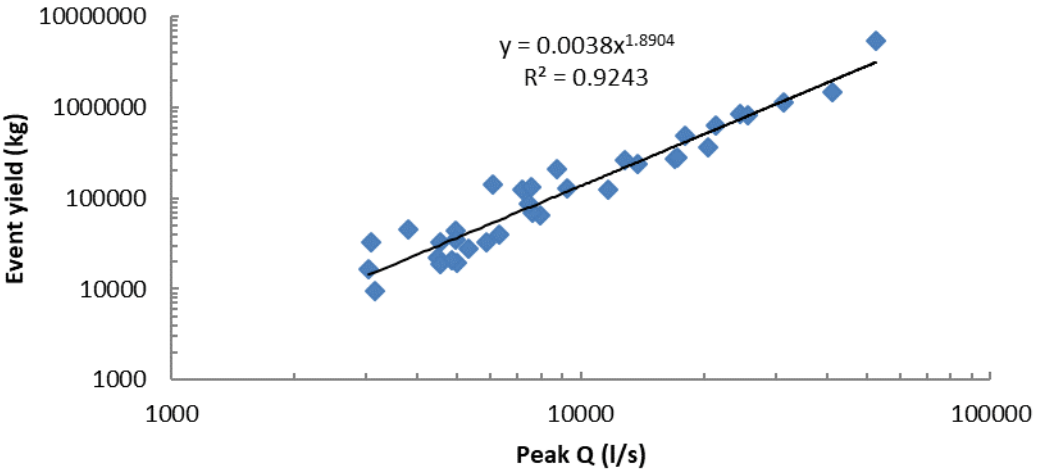


Figure 12-3 – Relation between event sediment load and event peak discharge for Waitomo River at Aranui Caves Bridge. Note even data scatter and linear trend on log-log plot, justifying use of a linear-regression model. The log-bias correction to be applied to the regression coefficient 0.0038, calculated by the Duan (1983) 'smearing' factor, is 1.08.

10.6 Calculating time-averaged SS loads using instantaneous sediment ratings

Time-averaged SS loads may be calculated by combining instantaneous sediment ratings with:

- flow duration tables, or
- discharge time-series records.

10.6.1 Using flow-duration tables

Using flow-duration tables, the time-averaged load of suspended sediment (Q_s, t/yr), shall be calculated over the period of interest as

$$Q_s = k(\sum p_j \, Q_j \, SSC_j)$$

where Q_j is the mid-range value in the jth discharge band (l/s), SSC_j is the matching SSC generated by the rating function (mg/l), p_j is the proportion of time occupied by the jth discharge band, and k is a unit conversion factor equal to 0.03156.

Note: There must be at least 100 discharge bands

- *the discharge bands shall have equal increments of discharge, and*
- *this approach is less suitable for use with conditional ratings (e.g. when different rating functions are used for rising and falling stages, different seasons, etc).*

10.6.2 Using discharge records

Using discharge records, the time-averaged load of suspended sediment (Q_s, t/yr), shall be calculated over the period of interest as:

$$Q_s = k\sum(\Delta t\ (Q_n + Q_{n+1})(c_n + c_{n+1})/4)/N$$

where Q_n is the discharge record at time n (l/s), c_n is the matching SSC generated by the rating function (mg/l), Δt (s) is the time interval between records (Δt will be determined by the discharge record), k is a unit conversion factor equal to 10^{-9}, and N (yr) is duration of the period of interest.

Note: Instantaneous sediment ratings are not recommended for calculating instantaneous or short-term average (e.g. event) loads because of their typically very large estimation error. For the same reason, SSC records generated using sediment ratings should not be archived.

10.7 Calculating time-averaged SS loads using event sediment ratings

Time-averaged SS loads may be calculated by combining event sediment ratings with:

- event-magnitude probability distributions, or
- event-magnitude series records.

10.7.1 Using event-magnitude probability distributions

Taking the example of a rating between event sediment load (Q_{se}) and event peak discharge (Q_p), the time-averaged load of suspended sediment (Q_s, t/yr) over a period of interest can be calculated in five steps:

- extract from the discharge record for the period of interest a peaks-over-threshold series of event peak discharges ($Q_{p(1)}$ ....$Q_{p(i)}$.....$Q_{p(n)}$)
- fit a probability distribution function to the event series
- using the distribution function, calculate the expected number of events per year (p_j) with a peak discharge within discrete discharge bands with mid-value Q_j,
- convert the mid-band peak discharges into event yields (Q_{sej}, t) using the event rating, then
- sum the event loads weighted by their expected occurrence frequency, thus

$$Q_s = \sum p_j Q_{sej}$$

Note: A peaks-over-threshold approach is required to filter-out small perturbations in the discharge record; a recommended threshold is the magnitude of the event with a recurrence interval of two to four weeks.

- *This approach ignores sediment transport during baseflows.*
- *This approach offers some advantage over simply using the event rating with the event magnitude series because the probability distribution function may be extrapolated to events*

larger than sampled in the event series – thus enabling the contribution of larger, rarer events to be added into the estimate of the time-averaged load.

10.7.2 Using event-magnitude series records

Taking the example of a rating between event sediment load (Q_{se}) and event peak discharge (Q_p), the time-averaged load of suspended sediment (Q_s, t/yr) over a period of interest can be calculated in three steps:

1. extract from the discharge record for the period of interest a peaks-over-threshold series of event peak discharges ($Q_{p(1)}$ ….$Q_{p(i)}$……$Q_{p(n)}$)
2. apply the event rating to estimate each event load (Q_{sei}, t), then
3. sum the event loads and divide the total by the duration of the period of interest (N, yr), thus

$$Q_s = \frac{\sum Q_{sei}}{N}$$

Note: A peaks-over-threshold approach is required to filter-out small perturbations in the discharge record; a recommended threshold is the magnitude of the event with a recurrence interval of two to four weeks. This approach ignores sediment transport during baseflows.

11 Laboratory Methods

The laboratory analyses required of suspended sediment samples are to determine their:

- mass SSC (i.e. mass of sediment per unit volume of water sample)
- composition in terms of mineral and volatile organic content, and
- size grading, particularly the proportions of sand and mud (greater and less than 0.063 mm, respectively).

While the mass SSC has always been an essential analysis for determining the bulk suspended sediment load (of all compositions and size fractions), in recent years there has been growing demand for information on the organic content and sand/mud proportions. This stems from the importance of mud and organic material to water quality and environmental effects, since it is the finer, lighter suspended particles that have the greatest impact (per unit particle mass) on water clarity and the habitat quality of deposited sediment.

Accordingly, the analyses required in this Standard for all suspended sediment samples involves:

- a sand/mud split
- analysis of the SSC of the mud and sand splits, and
- analysis of the volatile organic composition of the mud and sand splits.

Full particle-size analyses are not compulsory but may be undertaken, depending on the application of the data.

11.1 Sand/mud splits

Sand/mud splits shall be done on all suspended sediment samples. The procedure is:

- measure the original volume of water sample supplied to the laboratory
- after shaking (to disperse mud flocs), pour the sample through a 0.063-mm aperture, 75-mm diameter test sieve into a clean beaker
- recover the water and mud collected in the beaker and analyse for mud mass following the SSC procedure as below, and
- backwash the sand caught on the sieve into another clean beaker (using a fine brush to dislodge any sediment grains sticking in the mesh) and analyse for sand mass following the SSC procedure below.

11.2 Suspended sediment concentration

11.2.1 Method

Suspended sediment concentration shall be determined for each of the sand and mud splits using a variation of the ASTM SSC Procedure D3977-37 (ASTM, 2013). This procedure (with the partial exception of option C) analyses all the field sample, and offers three options:

- A: evaporation
- B: filtration, or

- C: a hybrid filtration approach involving sample splitting and filtering.

These options cater for different masses of sediment in the sample.

The filtration approach (ASTM Method B) is generally the simplest to use, but large masses of fine sediment can lead to filter paper clogging or sediment spilling off the filter paper. In such cases, use of multiple filters or a larger filter is permitted. Filter discs of 1.5-µm pore size (also referred to as retention rating) are required.

The evaporation method (ASTM Method A) is better suited to high sediment masses but may require significant time (many days) for sediment in the sample to settle before excess clear water can be decanted and the residual water evaporated. The residual water and sediment volume need to be small enough to fit the evaporation dish. Decanting by pouring directly from the sample bottle tends to disturb the sediment settled on the bottom of the bottle, so the recommended approach is to use a "J-tube" (**Figure 13-1**) coupled to a vacuum hose. This facilitates the decanting process while creating minimal disturbance of the sediment layer. With ASTM Method A, the dissolved load (which crystallises-out on evaporation) may become significant with low SSC values, so the method includes estimating the dissolved load concentration with a conductivity meter after decanting and before evaporation to assess if an adjustment for dissolved load is required.

The ASTM Method C involves splitting the sample into mud and sand fractions by wet sieving with a 0.063-mm mesh sieve, then analysing, by filtration, all the sand caught on the sieve and an aliquot of the muddy water passing the sieve that has been separated using a splitting device. The motivation behind this method was largely to reduce the volume of sample returned from the field. Clearly, the wet-sieving component of ASTM Method C is already captured in this Standard by the requirement to do a sand/mud split for all analyses. The only difference in the workflow relates to the way the mud fraction is dealt with.

Figure 13-1 – J-tube (shown inside a glass sample bottle), used for decanting surplus clear water from a settled sample prior to evaporation when using ASTM D3977-37 Method A for SSC analysis. Photo courtesy of Stephen Low, USGS.

11.2.1.1 Variations to the ASTM procedure

Key variations to the ASTM procedure in this Standard are:

- the sample is split into sand and mud fractions prior to concentration analysis
- when filtering (Methods B and C), samples shall be passed through as many filters as are needed to filter the entire sample, and
- the filter diameter may be varied to reduce the number of filters needed per sample.

11.2.2 Excluded methods

Analysis of a sub-sample extracted from the original field sample, as in the Total Suspended Solids (TSS) Procedure (APHA 2540 D; APHA, 1995), is not permitted. The TSS Procedure was developed for analysis of wastewater containing quasi neutrally buoyant particles, and while it may make filtering easier by reducing the sediment mass and it may enable multiple analyses (e.g. dissolved constituent concentration) from the one field sample, the sub-sampling has two key issues:

- by reducing the sample mass and volume, it creates greater uncertainty in the measured values and so in the resultant concentration (= mass/volume), thus raising the level of detection, and
- the sub-sample extraction, even when done after vigorous sample shaking, is known to produce biased/erratic results (inaccurate by up to a factor of 10), with the underestimation of the true concentration increasing with higher proportions of sand in the sample (Gray et al., 2000; Glysson et al., 2001).

When one considers the effort expended to ensure collection of samples that are unbiased in regard to sediment particle size, it is poor practice to compromise this effort with an expedient laboratory procedure.

For these reasons, the TSS Procedure as defined in APHA (1995) should never be used for analysing SSC in samples collected for determining suspended sediment load.

See Ward (2000) for advice on developing site-specific functions to correct historic TSS data to SSC equivalents.

11.2.3 Choosing amongst the ASTM options

11.2.3.1 Sand fraction

Analysis of the sand fraction shall be done using ASTM Methods A or B (with Method B preferred). With sand filtering, the main limitation is with the sample mass collected on filter paper – too much sediment raises the risk of sediment spillage while handling the sediment-laden filter.

A larger diameter filter can safely hold a larger mass of sediment, the permissible mass increasing in proportion to the surface area of the filter. Working limits to avoid spillage are:

- 0.5 g for a 47-mm diameter filter, or
- 3.5 g for a 125-mm diameter filter.

Multiple filters should be used if the sample contains a sand mass exceeding these limits. In practice, analysts should be aware of overloading a filter and should have spare pre-weighed filters available for completing the analysis of a sample.

11.2.3.2 Mud fraction

For the mud fraction, the choice between ASTM Methods A, B, and C relates to the mass of mud to be analysed, which, for filtering, is limited typically by filter clogging during the filtration procedure but may also be limited by the spillage factor. The clogging mass depends on the mud size-mixture and mineralogy and is difficult to foresee; thus, when using Method B or C the recommended procedure is to continue filtering until the filtering rates become impractically slow, then continue processing the sample using multiple filters. The need for multiple filters can be delayed if a larger diameter filter is used. Eventually, for very large sediment masses, Method A is the only pragmatic option.

11.2.3.3 Estimating sediment mass to assist choice of method

Table 13-1 can be used for selecting between methods and planning filter requirements (for Method B) based on the estimated sediment mass in the sample. Sediment mass may be estimated by:

- the thickness of sediment draping the bottom of the sample bottle. The sediment mass (g) ≈ 0.1 × sediment thickness (mm) × base-area of bottle (cm^2) × sediment bulk density, which may be assumed equal to 1.2 g/cm^3 for mud. For example, a 1-mm thick drape of mud at the base of a standard round pint glass bottle (6.5-cm internal diameter) indicates a mass of 0.1 × 1 × 33.2 × 1.2 = 4 g, or
- using an estimate of SSC to estimate sediment mass (sediment mass = SSC × sample volume). SSC can be estimated from either:
    - the discharge associated with the sediment sample using the site sediment rating curve (should one exist), or
    - the turbidity associated with the sample (either recorded from a field sensor or measured in the laboratory prior to concentration analysis), converting turbidity to SSC where a relationship exists for the site (otherwise assuming a 1:1 relationship).

Table 13-1 Sediment mass thresholds (and concentration thresholds assuming several sample volumes) for selecting between methods for SSC analysis.

Method	Estimated sediment mass in sample (g)	Sediment concentration in 1-litre sample (mg/l)	Sediment concentration in 350-ml sample (mg/l)
B-1: Filter using small (47-mm) diameter filter	< 0.5	< 500	< 1430
B-2: Filter using either multiple small filters or one large (125-mm) diameter filter	0.5–3.5	500–3500	1430–10000

B-3: Filter using multiple large diameter filters	> 3.5	> 3500	> 10000
C: Filter using a split mud sample and small diameter filter	> 3.5	> 3500	> 10000
A: Evaporation	> 3.5	> 3500	> 10000

With Method C:

- Splitting shall be done using a cone splitter (see Section 11.1.6)
- The proportion of the sample split from the original may be adjusted to achieve the sample mass target range but shall not be smaller than 300 ml in volume.

With any method, a sample should never be left incompletely analysed or reported as "> *x* mg/l".

11.2.4 Uncertainty for ASTM SSC methods

Uncertainty in SSC analyses stems from two sources:

- precision – relating to the resolution of the apparatus used (e.g. the weighing balance)
- bias – relating to systematic error while undertaking procedures (e.g. weighing, drying, decanting) by different laboratories and operators.

Precision is measured as the standard deviation of multiple tests of a known SSC; bias is the mean deviation of multiple tests from a known SSC; accuracy considers both precision and bias.

Table 13-2 indicates the precision and bias in SSC to be expected using ASTM Methods A, B, and C with 350-ml water samples (from ASTM, 2013). This shows, in general:

- the ASTM methods tend to be negatively biased (i.e. they tend to register less sediment)
- this bias tends to dominate over precision at relatively lower SS mass and SSC (because the loss of a small amount of sediment during the analysis becomes more important when the original amount is small)
- as SSC (and sediment mass) increases, the absolute precision and bias in SSC increase (with an approximate square-root relation), but
- as SSC (and sediment mass) increases, the relative (percentage) precision and bias decrease (with an approximate inverse square-root relation).
- This is important because it means that a single uncertainty value for all SSC analyses should not be assumed.

Figure 13-2, plotting data from **Table 13-2**, may be used to estimate precision and bias associated with ASTM SSC analyses, assuming a sample volume of 350 ml. Expect uncertainties to change in inverse proportion to sample volume (since the critical uncertainty relates mainly to sample mass determination except when the sample volume

becomes too small). **Figure 13-3** shows how ASTM Method B precision changes with SSC and sample volume.

Note: The accuracy of SS laboratory results should be considered when performing calculations of sediment load and/or when calibrating relations between SSC and surrogate measures.
The accuracy of SSC results (stemming from method precision and bias), which varies with SSC, should not be confused with the method detection limit and reporting limit (as defined below).

Table 13-2 Precision and bias in SSC using ASTM Methods A, B, and C with 350-ml water samples (from ASTM, 2013). Precision is indicated by standard deviation of multiple analyses undertaken by different laboratories; bias by average deviation from stock SSC.

Method	Known SSC (mg/l)	Mean SSC (mg/l)	Precision (mg/l)	Precision (%)	Bias (mg/l)	Bias (%)
A	10	9.4	2.5	25.0%	-0.6	-6.0%
	1000	976	36.8	3.7%	-24.0	-2.4%
	100000	100294	532	0.5%	294.0	0.3%
B	10	8	2.6	26.0%	-2.0	-20.0%
	100	91	5.3	5.3%	-9.0	-9.0%
	1000	961	20.4	2.0%	-39.0	-3.9%
C-sand	1	3.4	2.8	280.0%	2.4	240.0%
	9	5	5.9	65.6%	-4.0	-44.4%
	91	107	12.3	13.5%	16.0	17.6%
C-mud	10	8.7	4.3	43.0%	-1.3	-13.0%
	91	79	15.2	16.7%	-12.0	-13.2%
	909	832	87.2	9.6%	-77.0	-8.5%

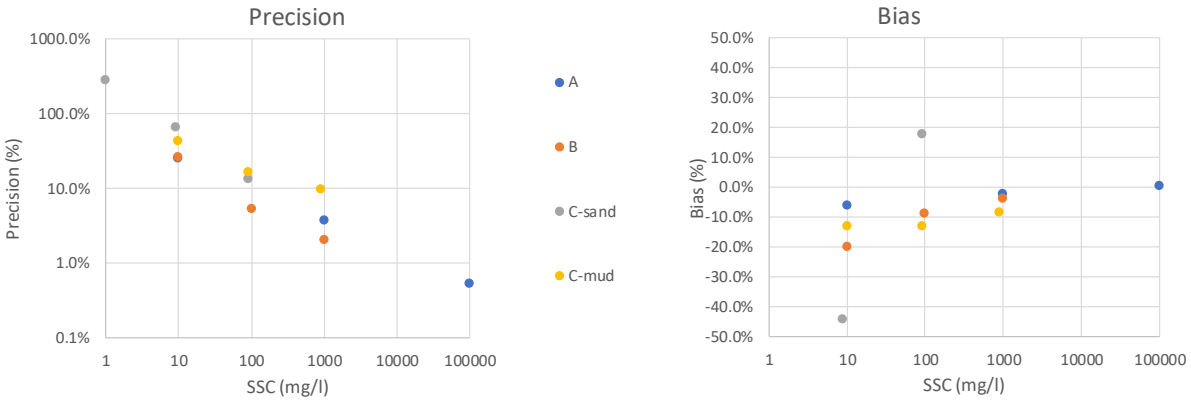


Figure 13-2 Precision and bias of ASTM Methods A, B, and C as reported by ASTM (2013).

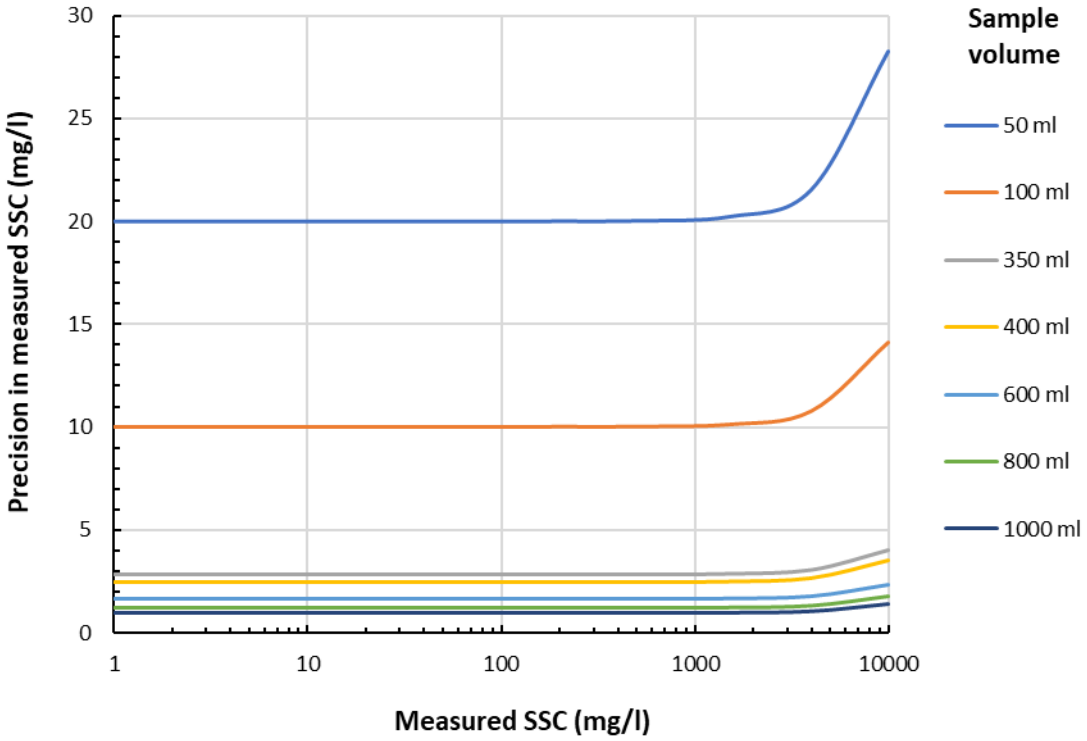


Figure 13-3 Theoretical precision (i.e. range of results from repeat measurements) in total SSC associated with ASTM filter analysis of sand and mud splits in relation to sample volume and SSC. Note how precision quality degrades as sample volume decreases and as SSC increases above about 3500 mg/l.

11.2.5 Method Detection Limit and Reporting Limit for ASTM methods

Each SSC analysis method has its own Method Detection Limit (MDL) and Reporting Limit (RL).

The MDL relates to method sensitivity. As defined conceptually in **Figure 13-4**, the MDL is the minimum quantity of sediment that can be detected whilst being reasonably (99%) certain that the sample actually contains sediment (i.e. that the result is not a 'false positive' which indicates, due to analytical error, an apparent mass of sediment when there is actually no sediment present). The MDL is determined by analysing multiple samples 'spiked' with a small, fixed mass of sediment, and it is assumed that the distribution of the results is the same as that which would be obtained from a set of perfectly blank samples. The RL provides a safety factor that deals with day-to-day variation in method sensitivity. It is set to twice the MDL to minimise the risk that the result from the analysed sample is less than the MDL (i.e. that the result is not a 'false positive'). Raw results that are less than the RL should be reported as "< RL".

The MDL and RL for SSC analysis are controlled by the measurement of sediment mass, rather than sample volume (which should always be large enough to render its measurement error minor); thus, MDL and RL shall be defined in terms of sediment mass, not SSC. This means that the RLs on SSC will vary as sample volume changes.

This Standard adopts USGS protocols for MDLs and RLs associated with the ASTM methods. Past USGS procedures had a reporting limit of 0.5 mg/l (thus reporting raw results less than this value as "< 0.5"), but the USGS are currently reviewing MDL and RL values associated with SSC determination and will likely set these in relation to sediment mass.

As an interim measure, this Standard shall require (based on the ASTM, 2013, study data) a reporting limit of 1 mg of sediment mass. Note that a 1-mg mass in a 250-ml water sample (which is the minimum sample volume permissible) equates to an SSC of 4 mg/l.

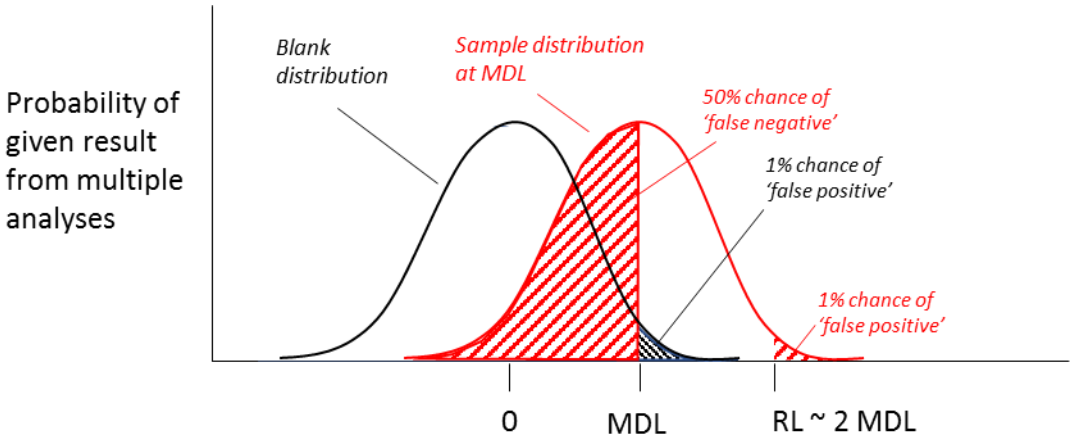


Figure 13-4 Method Detection Limit (MDL) and Reporting Limit (RL) definitions. Analysis of blank samples provides a distribution of results (coloured black) centred about zero. The MDL is where there is only a 1% chance of a false positive value being detected. Analysis of a sample with actual value at the MDL (coloured red) has a 50% chance of the result being less than the MDL (i.e. a false negative). The RL is set so that there is only a 1% chance of a false exceedance of the MDL. This is approximated by RL = 2 × MDL.

11.3 Organic content

Organic suspended sediment concentration shall be determined for both the sand and mud splits using the APHA 2540 E procedure (APHA, 1995).

APHA 2540 E involves a continuation of the ASTM SSC Procedure whereby the dried sediment residue (on filter paper or evaporation crucible) left at the end of the SSC procedure is ignited at 550°C to combust any volatile organic compounds. The proportional loss in sample mass after combustion provides the volatile organic content.

Note: Organic fragments coarser than 2 mm shall be removed from the sample before analysis, at the same time as the sand/mud split is conducted. This shall be done using a 2-mm mesh sieve.

11.4 Reporting concentration results

SSC results reported shall include:

- sample volume (V, ml)
- sand sample mass (M_s, mg)
- mud sample mass (M_m, mg)
- sand concentration (c_s, mg/l)
- mud concentration (c_m, mg/l)
- sand organic concentration (c_{os}, mg/l), and

- mud organic concentration (c_{om}, mg/l).

When multiple filters have been used for a single field sample, the sand and mud masses reported shall be the masses totalled over all filters.

Results less than the RLs (defined in **Table 13-3**) shall be recorded as "Less than *x*", where *x* is the method RL.

Results greater than or equal to the RLs shall be reported to the nearest integer value.

Table 13-3 Reporting limits for results from SSC and associated analyses. Results less than the reporting limits shall be reported as "less than *x*", where *x* is the reporting limit.

Result	Units	Reporting Limit (RL) (*x*)
Sample volume, V	ml	1
Sand mass, M_s	mg	1
Mud mass, M_m	mg	1
Sand concentration, c_s	mg/l	$1/(V/1000)$ rounded-up to nearest integer
Mud concentration, c_m	mg/l	$1/(V/1000)$ rounded-up to nearest integer
Total concentration, c_T	mg/l	$1/(V/1000)$ rounded-up to nearest integer
Sand organic content, c_{os}	mg/l	As for c_s
Mud organic content, c_{om}	mg/l	As for c_m

Note:

- *RLs should not be confused with accuracy. Reporting limits indicate minimum levels of detection. Accuracy relates to precision and bias above the level of detection. Accuracy depends on sediment mass and concentration and increases above the RL.*
- *Reported results shall not be rounded in regard to accuracy. Accuracy should only be considered when the data are analysed. For example, a measured SSC of 969.4 ± 20 mg/l in a 1000 ml sample shall be reported as 969 mg/l, not 960 mg/l.*
- *Results identified as less than the RL shall be utilised with caution, depending on the application of the data. Avoid using results rounded-up to the RL when developing calibration relations with log-transformed data, since this is likely to produce a biased relation. For example, SSC data reported as "< 1 mg/l" should not be plotted on a log-log plot as 1.*

11.5 Particle size

Laboratory analysis of suspended sediment samples for particle size grading is covered in Section 14.

11.6 Other laboratory procedures

Other procedures for analysing suspended sediment samples include analysis of settled sediment volume concentration. Settled sediment volume concentration provides the bulk volume of sediment that settles from a sample (i.e. the combined volume of sediment grains and the void spaces between the grains). It may be used as a measure of potential deposited sediment thickness for ecological assessments but is not part of any of the Primary Method pathways. The settled sediment volume concentration can be measured with an Imhoff Cone.

The Imhoff Cone procedure is:

- disperse the sample by vigorous shaking
- pour into Imhoff Cone
- record total volume of sample from cone-side scale
- allow sediment to settle
- record volume of settled sediment, then
- determine the settled sediment volume concentration from the ratio of settled sediment volume to total sample volume.

Note:

- *The Imhoff Cone does not measure sediment particle volume. The latter requires knowledge of the void ratio in the deposited sediment, which will depend on the particle size mixture.*
- *The Imhoff Cone procedure shall not be used for estimating mass concentration.*

12 Particle Size Analysis

12.1 Overview

Data derived from suspended sediment particle size analyses have many potential uses. There is a broad choice of particle size analysis methods and, apart from the simple mud/sand split required in this Standard for all suspended sediment samples, no single standard method is prescribed for deriving more detailed size gradings. Instead, when these are required, the method should be chosen to suit the application. The following summarises the broad options and factors to consider.

12.2 Purpose

Particle size information of the suspended sediment load is useful for many purposes, including:

- relating SSCs to optical water quality variables such as visual clarity
- understanding how this relationship varies within runoff events
- explaining variability in calibration relationships between SSC and surrogate measures
- helping identify sediment sources
- measuring deliveries of sand and mud to coasts
- estimating particle fall speed and, therefore, sediment settling rate in receiving water bodies (reservoirs, lakes, estuaries), e.g. as input to numerical models predicting sedimentation rates
- estimating sediment contaminant loads, where contaminants (e.g. heavy metals) are preferentially associated with certain particle size fractions
- assessing the degree of bias in suspended sediment concentration induced by non-standard laboratory analyses (e.g. error in the TSS laboratory procedure increases as the sand proportion of the suspended sediment sample increases).

Applications generally require information on either sediment grain dimensions (mm) or fall speed. Fall speed depends on grain dimensions, but also grain shape and mineral density.

12.3 Variables measured

Particle size analysis methods typically either measure:

- grain dimensions, or
- fall speed.

The two measures may be inter-converted by formula, making assumptions regarding grain shape and mineral density. For example, fall speed-based analyses normally report results as the equivalent diameter of quartz spheres.

To avoid approximations inherent in such conversions, the choice of analysis method should reflect the intended application of the results (**Table 14-1**).

Table 14-1 Methods of particle size analysis matched to applications of particle size data. There is a wide choice of commercially available instruments. Examples provided imply no recommendation.

Application	Method type	Example	Comment
Fall speed for use in sediment transport calculations or numerical modelling	Fall speed measuring instruments Manually operated settling devices	Rapid sediment analyser, Sedigraph Pipette, burette, bottom-withdrawal tube, hydrometer (all mainly for mud)	Typically return results as equivalent quartz-sphere diameters, which may be converted to fall speed
Relating particle geometric properties (shape, axis size, perimeter) to in-stream optical properties (e.g. visual clarity)	Image-analysis	Malvern Morphologi	Analyse shape characteristics of discrete particle outlines Lab and in situ applications
Bulk size by particle volume-based distributions for general application	Laser diffraction instruments	Sequoia LISST series Malvern Mastersizer	Lab and in situ devices available; LISST devices also measure volumetric concentration
Size by particle count-based distributions for general application	Particle counters, Laser obscuration time instruments	Coulter Counter	Measure chords across particles while laser beam traverses particles
Bulk diameter by mass-based distributions of sand grades for general application	Manual sieving (wet or dry)	Endicotts sieves	

12.4 Method options

Grain dimensions may be measured directly by:

- sieving – usually done wet, and limited to sand grades
- grain image analysis – numerical image-analysis techniques are used with narrow depth-of-field images to map and analyse grain boundaries
- laser diffraction, or

- laser-beam obscuration timing – relates grain dimensions to the time a moving laser-beam is obscured by a grain crossing the beam.

Fall speed-based measurement devices monitor the:

- time-evolving SSC at a point in a settling tube (either by withdrawing a discrete sample, e.g. visual accumulation tube or pipette methods, or by measuring the SSC with light or X-ray diffraction), or
- mass accumulation at the bottom of a settling tube (bottom withdrawal tube, rapid sediment analyser) or at the bottom of a series of tubes of progressively increasing diameter while a sample is pumped through the tubes (elutriation method).

12.5 In situ vs laboratory measurements

In situ measurement of particle sizes avoids degradation of particle characteristics between the river and laboratory (e.g. particle flocs may break-up or build in the sample bottle). However, there are few methods and instruments suitable for in situ deployment in streams and rivers (e.g. LISST-SL, Czuba et al., 2015), and until recently these have remained in the research domain by virtue of cost and/or limited conditions of application. Thus, for routine monitoring, particle size analyses are usually undertaken in the laboratory using samples extracted from the field. The choice of laboratory instrument shall reflect the application, the results required, and any unavoidable constraints on sample size.

12.6 Field sampling requirements for laboratory analysis of particle size

Suspended sediment samples collected for laboratory analysis of particle size shall be representative of the cross-section-averaged load, thus:

- they shall have been collected using the samplers and procedures as detailed in Section 6
- samples collected from multiple verticals and composited for analysis shall be done so on a flow-proportional basis (i.e. using the EWI method with a constant transit rate or the EDI method with equal sample volumes)
- the composite sample shall contain an adequate sediment mass for the analysis procedure, and
- if the sample contains too much sediment mass for the analysis procedure, then the sample may be spilt for analysis using an approved splitting device.

Sample-splitting devices approved by the USGS for this purpose (and approved for this Standard) include (Capel and Larsen, 1996):

- Cone splitter – an inverted cone that splits the sample into sub-samples in a radial pattern – approved for samples with sediment concentrations up to 10,000 mg/l including all mud and sand grades (while not formally certified for splitting samples with concentrations exceeding 10,000 mg/l, the cone splitter nonetheless provides a reasonable result up to concentrations of 100,000 mg/l)
- Churn splitter – the sample is agitated in a small drum and sub-samples are extracted during agitation through a spigot – approved only for concentrations less than 1,000 mg/l and sediment finer than 250 μm (fine sand and mud).

Note: The Jones-Ott splitter or FISP US72A splitter (essentially the same device) approved to split the muddy filtrate passing a 63-µm sieve in the ASTM Method C for SSC analysis shall not be used for splitting for particle size analysis. This is because these splitters do not split suspended sand uniformly.

Thus, for this Standard, when sample-splitting for obtaining sub-samples for particle size analysis, the cone splitter shall generally be used, except if the SSC is less than 1,000 mg/l and the sediment is finer than 250 µm.

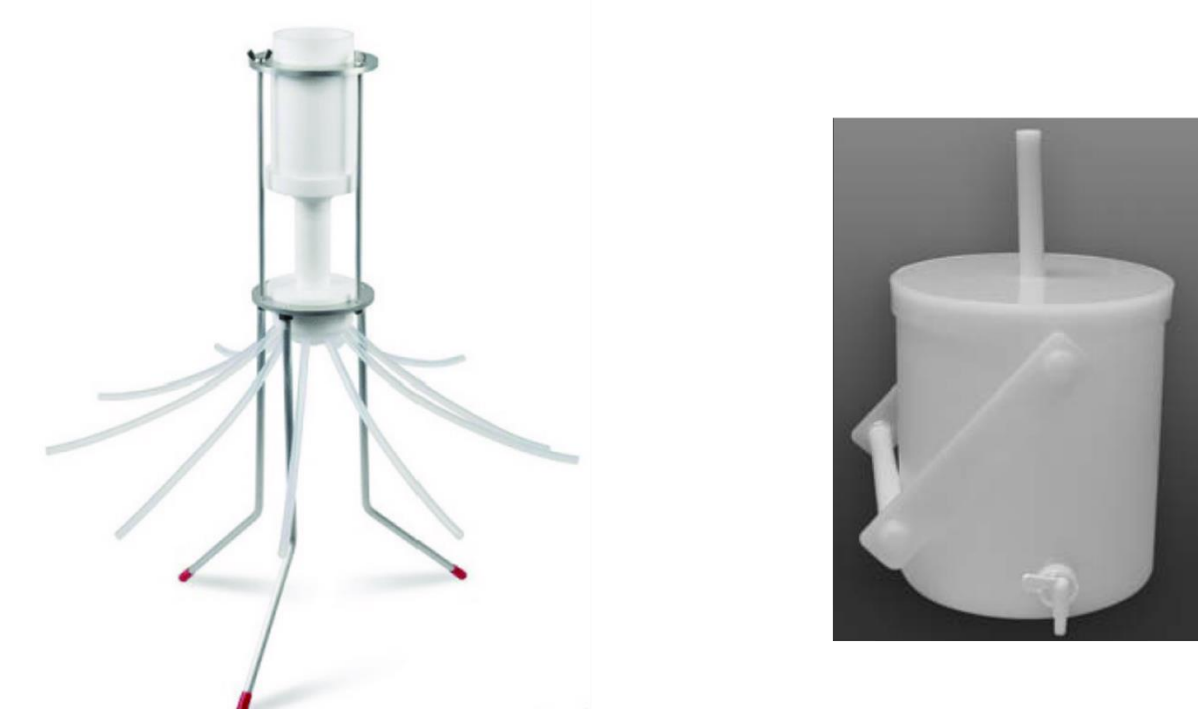


Figure 14-1 Sample splitters for reducing sediment mass for particle size analysis. Left: cone splitter (the original sample drains into multiple outlet pipes). Right: churn splitter (a sub-sample is drawn off via the spigot while the piston agitates and mixes the original sample).

12.7 Sample mass requirements for particle size analysis

The optimal range of sediment mass for particle size analysis varies substantially among the different method options, the choice of which is influenced by the application of particle size data (**Table 14-1**). Thus, before collecting field samples for particle size analysis, the following shall be identified:

- the application of the data
- the analysis approach and instrument to be used, and
- the sample mass limits of the chosen instrument/method.

12.8 Converting particle or volume-based data to mass-based size distributions

Raw measurements of particle size may be presented as tables of frequency or cumulative frequency per size / fall speed fraction by particle mass, volume, area, or count – depending on the method/instrument used.

Results based on particle count, area, or volume should be converted to equivalent results by mass to align with SSC or load measurements (which are mass based). This requires assumptions around particle shape and mineral density. It is typically assumed that mineral density is independent of grain size, but this may not be the case.

13 Deposited Fluvial Sediments

Deposited fluvial sediment may be of broad interest to river managers. For example:

- ongoing build-up of bed-material (coarse sediment) in a channel (i.e. sand in a sand-bed channel, gravel in a gravel-bed channel, etc) can compromise flood conveyance, so is of concern to river engineers
- Ongoing or transitory build-up of fine sediment (sand and mud) on and in gravelly-cobbly streambed substrate can degrade physical habitat for benthic biota and spawning fish, so is of interest to stream ecologists.

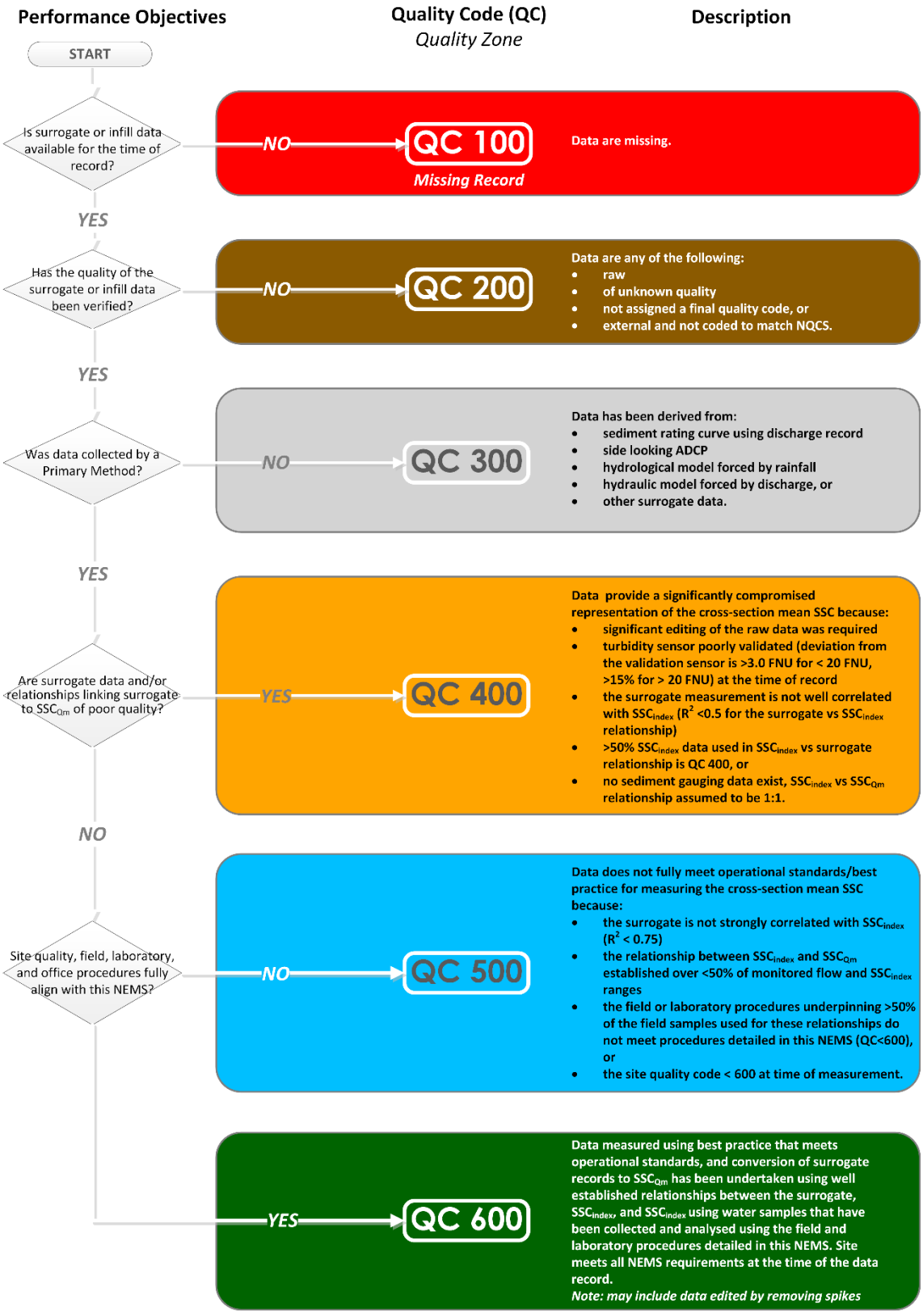
Deposited fine sediment is most likely to accumulate from the suspended load on the recessions of floods and freshes, preferentially settling in low velocity zones such as along channel margins. It is more likely in streams draining catchments with elevated fine sediment delivery.

Procedures for monitoring coarse sediment (bed-material) deposition (and erosion) are provided in river engineering guidelines (e.g. NIWA, 2010) not yet captured in a NEMS.

Procedures for monitoring fine sediment deposition are provided by Clapcott et al. (2011) but have not yet been included in a NEMS.

14 Quality Codes

All derived SSC_{Qm} time-series records shall be quality coded in accordance with the flowchart below.



Separate QC codes shall be assigned to:

- SSC values from samples collected at index points (SSC_{index})
- discharge-weighted cross-section average SCC (SSC_{Qm}) values derived from suspended sediment gaugings
- the suspended sediment monitoring site.

The QC codes for the site, and the QC codes for SSC_{index} and SSC_{Qm} values used in the relationships that convert SSC-surrogate records to SSC_{Qm} records, are considered in the time-series record flowchart when distinguishing between *QC 400*, *QC 500*, and *QC 600*.

Site, SSC_{index} value, and SSC_{Qm} value quality codes shall be assigned using the following matrices. Completed examples of these matrices are included in Annex H.

14.1 Site Quality Matrix

When quality coding sediment data, assess your site against the following matrix. The site assessment shall be reviewed after significant runoff events. **Criteria**	**3 Points**	**1 Point**	**0 Points**
Sampler intake or sensor location	Affected by bedforms		Not affected by bedforms
	☐		☐
Bank stability	Unstable slumping banks upstream		Stable banks or engineering controls
	☐		☐
Incomplete mixing from nearby upstream sediment inputs (e.g. tributaries, bank erosion)	Sediment inputs occur within two morphological units (e.g. meanders, riffle/pool sequences) upstream of monitoring site	Sediment inputs occur beyond two morphological units but within 200 m upstream of monitoring site	None
	☐	☐	☐
Ability to do SS gaugings at high discharges, considering site access and physical ability	Not achievable during any flood	Achievable up to mean annual flood	Achievable above mean annual flood
	☐	☐	☐
Metadata recorded	Not recorded		Recorded
	☐		☐
Sum			
Total score			
Site QC assessment *QC 600 = 0–3* *QC 500 = 4–9* *QC 400 = >9*			

14.2 SSCindex Value Quality Matrix

Criteria	**12 Points**	**3 Points**	**1 Point**	**0 Points**
Sampling	Location of sample collection point varies and/or is not within 1 m of surrogate sensor	Location of sample collection point between 0.1 m and 1 m of surrogate sensor	Manual samples collected within 0.1 m of surrogate sensor	Auto-sampler used with intake co-located within 0.1 m of surrogate sensor
	☐	☐	☐	☐
Laboratory analysis of SSC	Non-standard laboratory procedures used, and no correction applied, and/or results truncated or inappropriately rounded-up	Non-standard laboratory procedures applied but result corrected based on site-specific empirical relation	Standard laboratory procedures applied but were pressing limits of practical ranges of methods	Standard laboratory procedures applied and properly reported
	☐	☐	☐	☐
Sum				
Total data quality score				
Overall QC assessment *QC 600 = < 3* *QC 500 = 3-11* *QC 400 = > 11*				

14.3 SSCQm Value Quality Matrix

Criteria	**12 Points**	**3 Points**	**1 Point**	**0 Points**
Sampling	NEMS-compliant samplers and procedures not used	NEMS-compliant isokinetic samplers used but with less than the specified number of verticals	NEMS-compliant isokinetic samplers used but deployed outside recommended operating ranges	NEMS-compliant isokinetic samplers and procedures used correctly
	☐	☐	☐	☐
Laboratory analysis of SSC samples	Non-standard laboratory procedures used, and no correction applied, and/or results truncated or inappropriately rounded-up	Non-standard laboratory procedures applied but result corrected based on site-specific empirical relation	Standard laboratory procedures applied but were pressing limits of practical ranges of methods	Standard laboratory procedures applied and properly reported
	☐	☐	☐	☐
Sum				
Total data quality score				
Overall QC assessment *QC 600 = < 3* *QC 500 = 3-11* *QC 400 = > 11*				

Annex A – List of Referenced Documents

Agrawal YC, Pottsmith HC. 1994. Laser diffraction particle sizing in STRESS. *Continental Shelf Research* 14(10): 1101-1121. http://dx.doi.org/10.1016/0278-4343(94)90030-2

Anderson CW. 2005. Turbidity. In: *U.S. Geological Survey Techniques of Water-Resources Investigations*, book 9, chap. A6., sec. 6.7, from http://pubs.water.usgs.gov/twri9A6/. USGS

APHA. 1995. *Standard methods for the examination of water and wastewater (19th ed.)*. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, D.C., variously paged.

ASTM. 2013. Standard test methods for determining sediment concentration in water samples: D 3977-97, vol. 11.02. American Society for Testing and Materials Water (II), 395-400.

Capel PD, Larsen SJ. 1996. Evaluation of selected information on splitting devices for water samplers. US Geological Survey Water-Resources Investigations Report 95-4141.

Clapcott JE, Young RG, Harding JS, Matthaei CD, Quinn JM, Death RG. 2011. Sediment Assessment Methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Nelson, New Zealand, Cawthron Institute.

Colby BR. 1964. Discharge of sands and mean-velocity relationships in sand-bed streams. US Geological Survey Professional Paper 462-A, 47 p.

Colby BR, Hembree BH. 1955. Computations of total sediment discharge, Niobrara River near Cody, Nebraska. US Geological Survey Water Supply Paper 1357, 187 p.

Czuba JA, Straub TD, Curran CA, Landers MN, Domanski MM. 2015. Comparison of fluvial suspended sediment concentrations and particle-size distributions measured with in-stream laser diffraction and in physical samples. Water Resources Research 51: 320–340. doi:10.1002/2014WR015697.

Diplas P, Kuhnle R, Gray J, Glysson D, Edwards, T. 2008. Sediment transport measurements. In: M Garcia (ed.) Sedimentation engineering: processes, measurements, modeling, and practice. ASCE.

Duan N. 1983. Smearing estimate: a nonparametric retransformation method. Journal of the American Statistical Association 78: 605-610.

Edwards TK, Glysson GD. 1988. Field methods for measurement of fluvial sediment. US Geological Survey Open File Report 86-531, 18 p.

Edwards TK, Glysson GD. 1999. Field methods for measurement of fluvial sediment. In: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Chapter C2. https://pubs.usgs.gov/twri/twri3-c2/

Federal Interagency Sedimentation Project (FISP). 2013. Best Practices for FISP bag sampler intake efficiency tests and operational velocities. FISP_Tech_Memo_2013.01. https://water.usgs.gov/fisp/docs/FISP_Tech_Memo_2013.01.pdf

Felix D, Albayrak I, Abgottspon A, Boes RM. 2016. Real-time measurements of suspended sediment concentration and particle size using five techniques. IOP Conference Series:

Earth and Environmental Science 49 122006. doi:10.1088/1755-1315/49/12/122006.

Glysson GD, Gray JR, Schwarz GE. 2001. A comparison of load estimates using total suspended solids and suspended-sediment concentration data. Proceedings of the 2001 ASCE Water World Congress, Orlando, FL, May 20-24, 10 p. (http://water.usgs.gov/osw/pubs/TSS_Orlando.pdf).

Gray JR, Gartner JW. 2009. Technological advances in suspended-sediment surrogate monitoring. Water Resources Research 45(4): W00D29. 10.1029/2008WR007063

Gray JR, Glysson GD, Edwards, TE. 2008. Suspended-sediment samplers and sampling methods. In: M Garcia (ed.) Sedimentation Engineering – Processes, Measurements, Modeling, and Practice. American Society of Civil Engineers Manual 110, Chapter 5.3, p. 318-337. (http://water.usgs.gov/osw/techniques/Diplas_Kuhnle_others.pdf).

Gray JR, Glysson GD, Turcios LM, Schwarz GE. 2000. Comparability of suspended-sediment concentration and total suspended solids data. US Geological Water-Resources Investigations Report 00-4191, Reston, Virginia.

Gray JR, Landers MN. 2014. Measuring suspended sediment. In: Ahuja S. (ed.) Comprehensive Water Quality and Purification. United States of America, Elsevier, vol. 1, p. 157-204. http://water.usgs.gov/osw/techniques/sediment/gray_landers_elsevier_chapter_12_10_17_2013.pdf.

Gray JR, Landers MN. 2015. History of the Federal Interagency Sedimentation Project, Part V. Proceedings of the 3rd Joint Federal Interagency Conference (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), April 19 – 23, 2015, Reno, Nevada, P. 264-275. http://acwi.gov/sos/pubs/3rdJFIC/Contents/2C-Gray.pdf and http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf.

Gray JR, O'Halloran D. 2015. Maximizing the reliability and cost-effectiveness of your suspended-sediment data. Proceedings of the 3rd Joint Federal Interagency Conference (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), April 19 – 23, 2015, Reno, Nevada., p. 433-446 (http://acwi.gov/sos/pubs/3rdJFIC/Contents/3C-Gray.pdf.

Guy HP, Norman VW. 1970. Field methods for measurement of fluvial sediment. U.S. Geological Survey Techniques for Water Resources Investigations, Book 3, Chapter C2, 59 p.

Haun S, Rüther N, Baranya S, Guerrero M. 2015. Comparison of real time suspended sediment transport measurements in river environment by LISST instruments in stationary and moving operation mode. Flow Measurement and Instrumentation 41: 10-17. http://dx.doi.org/10.1016/j.flowmeasinst.2014.10.009

Hicks DM, Fenwick JK. 1994. Suspended Sediment Manual. NIWA Science and Technology Series No 6, NIWA Christchurch, 84 p.

Hicks DM, Gomez B. 2016. Sediment transport. In: GM Kondolf and H Piegay (eds) Tools in fluvial geomorphology. 2nd edition. Wiley Blackwell, Chichester, UK.

Hicks M, Quinn J, Trustrum N. 2004. Sediment load and organic matter. In: JS Harding, MP Mosley, CP Pearson, and BK Sorrell (eds). Freshwaters of New Zealand. New Zealand Hydrological Society and New Zealand Limnological Society, Wellington, 764p.

Holmquist-Johnson CL, Raff D. 2006. Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) Program for Computing Total Sediment Load. Federal Interagency Sedimentation Conference in Reno, NV., April 2-6, 2006. Federal Interagency Sedimentation Project. p. 8.

Landers MN, Straub TD, Wood MS, Domanski MM. 2016. Sediment acoustic index method for computing continuous suspended-sediment concentrations. In: U.S. Geological Survey Techniques and Methods, book 3, chap. C5, 63 p., http://dx.doi.org/10.3133/tm3C5.

Mikkelsen O, Pejrup M. 2001. The use of a LISST-100 laser particle sizer for in-situ estimates of floc size, density and settling velocity. Geo-Marine Letters 20(4): 187-195.

NIWA. 2010. River managers guide v.11.2010. An e-book compilation of river management advice, practices and examples contributed by New Zealand river managers. Available on request from NIWA, Christchurch.

Oudyn FW, Lyons DJ, Pringle MJ. 2012. Appropriate maximum holding times for analysis of total suspended solids concentration in water samples taken from open-channel waterways. Water Science and Technology 66(6): 1310-1316. DOI: 10.2166/wst.2012.316

Rasmussen PP, Gray JR, Glysson GD, Ziegler AC. 2009. Guidelines and procedures for computing time-series suspended sediment concentrations and loads from in-stream turbidity sensor and streamflow data. In: US Geological Survey Techniques and Methods book 3, Chapter C4, 53 pp. https://pubs.usgs.gov/tm/tm3c4/pdf/TM3C4.pdf

Thomas RB. 1985. Estimating total suspended sediment yield with probability sampling. Water Resources Research 21: 1381-1388.

Topping DJ, Wright SA. 2016. Long-term continuous acoustical suspended-sediment measurements in rivers – theory, application, bias, and error. US Geological Survey Professional paper 1823.

United States Geological Survey (USGS). 1993. Policy and technical guidance for conversion of sediment concentration from parts per million (ppm) to milligrams per

liter (mg/L). U.S. Geological Survey, Office of Surface Water Technical Memorandum 93.21.

Vanoni A. 1975. Sedimentation Engineering. American Society of Civil Engineers, 745 p.

Ward JR. 2000. Collection and use of Total Suspended Solids data. US Geological Survey Office of Water Quality Technical Memorandum No. 2001.03. https://water.usgs.gov/admin/memo/SW/sw01.03.html.

Wood MS. 2014. Estimating suspended sediment in rivers using acoustic Doppler meters. U.S. Geological Survey Fact Sheet 2014-3038, 4 p., http://dx.doi.org/10.3133/fs20143038.

Annex B – Other SSC measurement technologies

B-1 Laser diffraction

Field-deployable, laser-diffraction instruments have been used in several investigations in marine and estuarine environments since the 1990s (e.g. Agrawal and Pottsmith, 1994; Mikkelsen and Pejrup, 2001). More recently, these instruments have provided high temporal and spatial resolution measurements of volumetric suspended sediment concentration and volumetric particle-size distribution in fluvial environments (e.g. Haun et al., 2015). FISP-sponsored research found excellent correlations between calibrated volumetric suspended sediment concentration and traditional mass suspended sediment concentration (FISP, 2013).

The Laser In-Situ Scattering and Tranmissometry (LISST) series of instruments developed by Sequoia Scientific, Inc. for field use are the first such instruments to be commercially available. A fixed-location, laser-diffraction instrument provides real-time, high temporal resolution data, while a user-deployed instrument in a weighted bomb like a point-sampler (e.g. LISST SL-2) can provide at-a-point data in real time when suspended by a cable.

Limitations and advantages of laser diffraction instruments are listed in **Table B-1**. A key advantage is the ability of devices such as the LISST to measure the temporal variability of suspended sediment by grain size at-a-point (e.g. Czuba et al., 2015). A disadvantage is that they do not measure mass-based SSC directly, so it must be calibrated from manually collected samples using an "effective" sediment density.

Table B-1: Advantages and limitations of laser diffraction instruments.

Advantages	Disadvantages
Able to resolve particle concentration and particle size	Mineral composition (especially mica) can influence the results through particle shape
Can be deployed at-a-point or suspended by cable, so offer potential to substitute for manual sample collection and laboratory analysis	Affected by particle colour (via refractive index)
	Returns only particle volume, so requires an empirical calibration for particle density to convert to mass concentration
	Errors in particle size distribution results occur when operating in river systems with strong thermal or density fluctuations

B-2 Pressure differential systems

Estimation of suspended sediment concentrations from fluid density computed from pressure measurements shows promise for monitoring highly sediment-laden stream flows. This technique relies on simultaneous measurements from two exceptionally sensitive pressure transducers arrayed at different fixed elevations in a water column (Gray and Gartner, 2009). When corrected for water temperature, the density data are easily converted to sediment concentration. **Table B-2** lists the advantages and disadvantages of the pressure differential technique. A disadvantage is that it cannot measure sediment concentrations less than about 10 g/L with adequate resolution. Also, temporal changes in temperature gradient, turbulence, and sediment concentration can all affect the measurements. See also Felix et al. (2016).

Table B-2: Advantages and limitations of pressure differential technology (from Gray and Gartner, 2009).

Advantages	Disadvantages
Inference of sediment concentration in a single vertical (note that this technique may not provide SSC data representative of mean cross-sectional values)	Assumes that the concentration in the vertical profile above the lower pressure sensor is constant to the surface
Biological fouling and signal drift are not problems	Incapable of measurements in low sediment concentrations, so only suited to high sediment loading
Higher accuracy with increasing sediment concentration	Incapable of measurements when the top orifice is not submerged or the bottom orifice is buried in sediment
Relatively simple and straightforward technology	

B-3 Other types under development/evaluation

Other surrogate technologies for estimating suspended sediment concentration, such as focused beam reflection, digital optical, vibrating tube, the nuclear technique and the impact sampler, remain under development or their robustness requires further evaulation (Gray and Gartner, 2009).

Annex C – Isokinetic samplers developed by FISP and their characteristics2

Sampler type	Weight (kg)	Suspension type	Type of container	Intake nozzle size (mm)	Maximum depth (m)	Recommended velocity range (m/s)	Nozzle distance from streambed (cm)	Sampler container size (litres)	Suitable for Water Quality?
US DH-2	13	Handline	Quart** bottle/flexible bag	7.9	4	0.6–1.8	9	1	Yes
				6.4	6.1				
				4.8	10.5				
US DH-48	1.6	Rod	Pint** glass bottle	6.4	2.7	0.5–2.7	9	0.47	No
US D-49	28	Reel and cable	Pint glass bottle	3.2*	4.6	0.5–2	10	0.47	No
				4.8					
				6.4					
US D-49A	19	Reel and cable	Pint glass bottle	3.2*	4.6	0.5–2	10	0.47	No
				4.8					
				6.4					
US DH-59	10.9	Handline or reel and cable	Pint glass bottle	3.2*	4.6	0.5–1.5	11	0.47	No
				4.8					
				6.4					

[2] Sourced from Gray and Landers (2014).

Sampler type	Weight (kg)	Suspension type	Type of container	Intake nozzle size (mm)	Maximum depth (m)	Recommended velocity range (m/s)	Nozzle distance from streambed (cm)	Sampler container size (litres)	Suitable for Water Quality?
US D-74	28	Reel and cable	Round or square, pint or quart glass bottle	3.2* 4.8 6.4	4.6	0.5–2	10	0.47 or 0.95	No
US D-74AL	19	Reel and cable	Round or square, pint or quart glass bottle	3.2* 4.8 6.4	4.6	0.5–1.8	10	0.47 or 0.95	No
US DH-75P	0.7	Rod	Pint plastic bottle	4.8	4.6	0.5–2	8	0.47	Yes
US DH-75Q	0.7	Rod	Quart plastic bottle	4.8	4.6	0.5–2	11	0.95	Yes
US DH-76	11.3	Handline or reel and cable	Quart plastic bottle	3.2* 4.8 6.4	4.6	0.5–2	8	0.95	No
US D-77	34	Reel and cable	Round plastic bottle/flexible bag	7.9	5.2	0.3–2.1	18	3	Yes
US DH-81	0.23	Rod	Litre plastic bottle	4.8 6.4 7.9	2.7	0.6–1.9 0.6–2.3 0.6–2.1	10	1.0	Yes
US DH-95	13.1			4.8	4.6	0.6–1.9	12	1.0	Yes

Sampler type	Weight (kg)	Suspension type	Type of container	Intake nozzle size (mm)	Maximum depth (m)	Recommended velocity range (m/s)	Nozzle distance from streambed (cm)	Sampler container size (litres)	Suitable for Water Quality?
		Handline or reel and cable	Litre plastic bottle	6.4		0.5–2.1			
				7.9		0.6–2.3			
US D-95	29	Reel and cable	Litre plastic bottle	4.8	4.6	0.5–1.9	12	1.0	Yes
				6.4		0.5–2			
				7.9		0.5–2			
US D-96	60	Reel and cable	Flexible plastic bag	4.8	34	0.9–3.8	10	3.0	Yes
				6.4	18				
				7.9	12				
US D-96-A1	37.2	Reel and cable	Flexible plastic bag	4.8	34	0.9–1.8	10	3.0	Yes
				6.4	18				
				7.9	12				
US D-99	124.7	Reel and cable	Flexible plastic bag	4.8	67	1.22–4.6	24	3.0 or 6.0	Yes
				6.4	37	0.9–4.6			
				7.9	24	0.9–4.6			
US P-61-A1	47.6	Reel and cable	Quart glass bottle	4.8	37	0.5–3.0	11	0.95	No
			Pint glass bottle		55			0.47	
US P-6	45	Reel and cable	Quart glass bottle	4.8	37	0.5–4.0	11	0.95	No

Sampler type	Weight (kg)	Suspension type	Type of container	Intake nozzle size (mm)	Maximum depth (m)	Recommended velocity range (m/s)	Nozzle distance from streambed (cm)	Sampler container size (litres)	Suitable for Water Quality?
US P-63	90.7	Reel and cable	Quart glass bottle	4.8	37	0.5–4.6	15	0.95	No
			Pint glass bottle		55	0.5–3.0		0.47	
US P-72	18.6	Reel and cable	Quart glass bottle	4.8	16	0.5–1.6	11	0.95	No
			Pint glass bottle		22			0.47	

* 3.2-mm nozzles are no longer recommended by the USGS because of issues with sand trapping efficiency and susceptibility to damage that alters their efficiency. ** Quart and pint refer to the U.S. quart and pint measures.

Annex D – Description of FISP Suspended Sediment Samplers

Sampler nomenclature

Suspended sediment samplers developed by the FISP are designated by the following codes:

- US: United States standard sampler
- D: depth integrating
- P: point integrating
- H: hand-held by rod or line
- Year: last two digits of the year in which the sampler was developed
- W: weighted bottle (non-isokinetic).

Isokinetic depth-integrating samplers3

US DH-2

The US DH-2 is a handline suspended sediment sampler capable of collecting a one-litre sample to a maximum depth of 10.5 m (using a 4.8-mm internal diameter nozzle). It also can be used for water quality sampling. The sampler works in stream velocities ranging from 0.6 to 1.8 m/s.

The DH-2 has a collapsible bag, which eliminates the depth limitation due to the size of the sample container.

US DH-48

The US DH-48 was one of the first samplers designed by the FISP. The US DH-48 is a lightweight hand-held depth-integrating sampler used for the collection of suspended sediment samples in wadeable streams. This instrument is calibrated with an intake nozzle of 6.3-mm diameter. The un-sampled zone using the US DH-48 is 9 cm. The sampler can be used in velocities that range from 0.5 to 2.7 m/s.

A standard 12.7-mm diameter wading rod is threaded into the top of the sampler body for suspending the sampler. To sample to depths greater than can be waded, wading rod extensions in 0.3- and 0.9-m lengths can be added to the sampler. With the extensions, the sampler can be deployed from a low bridge or boat.

US D-49 and US D-49A

The US D-49 and US D-49A are older versions of the D-74 sampler and were used for depth-integrated sediment sampling when streams cannot be waded, but are shallower

[3] Sourced from FISP (2013) and Gray and Landers (2014).

than about 4.6 m. These samplers are no longer manufactured by the FISP but remain widely used around the world and in New Zealand.

The head of the sampler is drilled and tapped to receive a 6.3-, 4.8-, or 3.2-mm intake nozzle which points into the current for collecting the sample. The US D-49 sampler, weighing 28 kg with a cast bronze streamlined body, is heavier than the D-49A model which is cast from aluminium (19 kg). A round or square pint[4]-bottle sample container is enclosed for both samplers. The US D-49 is suitable for depth integration of streams with velocities less than 2 m/s.

US DH-59

The US DH-59 is a medium-weight hand-line suspended sediment sampler. This sampler is designed for the use in shallow but un-wadeable streams with velocities ranging from 0.5 to 1.5 m/s. It can be used in stream depths up to 4.6 m. Sediment can be collected to within 11 cm of the stream bed. Intake nozzles of 3.2, 4.8, and 6.3 -mm diameter are calibrated for use with these samplers and may be interchanged as necessary when variable flow conditions are encountered.

US D-74

The US D-74 is a 28-kg, cable-suspended sediment sampler. The sampler is a more recent version of the D-49 sampler. The D-74 will accommodate either round or squared pint or quart bottles. Unlike the D-49, the D-74 is hinged at the bottom and swings downward to open.

The D-74 sampler is lowered and raised from a bridge crane or cableway by means of a standard hanger bar and reel and cable suspension system. The sampler can be used in stream depths up to 4.6 m and in stream velocities ranging from 0.5 to 2 m/s. Distance between nozzle intake and streambed is 10 cm. Intake nozzles of 3.2-, 4.8-, and 6.3-mm internal diameters are available.

US D-74AL

The US D-74AL sampler, with aluminium casting, is a lighter version (19 kg) of the D-74.

US DH-75

The US DH-75 series are lightweight, freeze-resistant samplers for collection of samples where a wading-rod suspension system is required. They were designed for use in sub-freezing winter conditions and use under ice cover. The open sheet-metal body of this sampler provides easier removal of the sampler container when ice forms over the sampler as it leaves the stream. Their low mass also defrosts more rapidly than the similar light-weight hand-held samplers such as the US DH-48.

Two versions of the sampler, the DH-75P and DH-75Q, accept plastic containers of pint and quart type, respectively. The sampler only works with the 4.8-mm nozzle. The DH-75Q sampler is a modification of the DH-75P allowing it to tilt to a vertical position to permit use through a 15 cm ice hole to obtain the suspended sediment samples. The

[4] The pint and quart bottles used in FISP samplers refer to the U.S. customary volume measures.

sampler weighs 0.4 kg excluding the sample container. The instrument can sample to 8 cm and 11 cm of the stream bed using pint and quart containers, respectively.

US DH-76

The US DH-76 is a more recent version of the DH-59 sampler, designed to take a quart glass bottle sample container for additional sample volume. The tail assembly extends below the body of the casting to ensure sampler alignment parallel to the flow direction with the intake nozzle. It uses 3.2-, 4.8-, and 6.3-mm internal diameter nozzles.

These medium-weight handline samplers (i.e. DH-76 and DH-59) are the most commonly used for sediment sampling during normal flow in small and, perhaps, intermediate-sized streams because they are small, light, durable, and adaptable.

US D-77

The US D-77 sampler can be used in most streams with low to moderate velocities from 0.3 to 2.1 m/s and at depths to about 5.2 m. A 7.9-mm nozzle is used. The distance between the nozzle and the sampler bottom is 18 cm.

The design of this sampler is different from the D-74 and its predecessors (D-49); it is constructed without a head assembly to cover the mouth of the container. Instead, a cap, nozzle, and air-exhaust assembly, which are made from autoclavable plastic, are screwed onto the mouth of the sample container at the front of the sampler.

The sample bottle is made of autoclavable plastic to make it possible to collect a depth-integrated sample for water quality (bacteriological) analyses. The large three-litre bottle makes collection of a large volume of water easier and faster than with any other available depth-integrating sampler. A flexible plastic sample bag may also be used.

US DH-81

The US DH-81 is a sediment and water quality sampler fabricated using parts from other FISP samplers, including the DH-81A adaptor and the cap and nozzle of the D-77 sampler. It may be deployed on a wading rod.
The US DH-81 sampler will collect samples at an acceptable inflow efficiency in stream velocities ranging from 0.6 to 1.9 m/s with a 4.8-mm nozzle, 0.6 to 2.3 m/s with a 6.3-mm nozzle, and 0.6 to 2.1 m/s with a 7.9-mm nozzle. The sampler will collect samples to a maximum depth of 2.7 m using a 1-litre bottle.

US DH-95

The DH-95 is a handline or cable and reel sampler capable of collecting non-contaminated samples for trace-element analysis. The sampler weighs approximately 13.1 kg. The DH-95 sampler collects water-sediment samples at acceptable inflow efficiencies and remains stable in stream velocities ranging from 0.5 to 2.3 m/s. The sampler can be used in stream depths up to 4.6 m. The distance between the centreline of the nozzle and the streambed is 12 cm. Three nozzles are available (4.8, 6.3, and 7.9 mm). The recommended sample volume to be collected with the US DH-95 sampler is 800 ml.

US D-95

The US D-95 is used to collect water samples using a cable and reel deployment. Depending on the nozzle diameters used, the sampler operates properly in flow velocities exceeding 0.5 m/s but no greater than 2.0 m/s. The sampler should be used in water less than 4.6 m deep. It uses 4.8-, 6.3-, and 7.9-mm internal diameter nozzles, and weighs 29 kg. The recommended sample volume to be collected with the US D-95 sampler is 800 ml. Its unsampled zone is 12 cm.

US D-96

The US D-96 is a collapsible-bag sampler capable of collecting a 3-litre sample and can also be used for water quality sampling. Weighing 60 kg, it will collect acceptable isokinetic samples in velocities exceeding 0.9 m/s but no greater than 3.8 m/s. It can be used in water with a maximum depth of 12 m with a 7.9-mm internal diameter nozzle, 18 m with a 6.3-mm internal diameter nozzle, and 34 m with a 4.8-mm internal diameter nozzle. Its unsampled zone is 10 cm. Water temperature must be at or greater than 4°C; however, the sampler performs sub-isokinetically at temperatures less than about 10°C at velocities less than about 1.1 m/s.

US D-96-A1

The US D-96-A1 is a lighter (37.2 kg) version of the D-96 sampler with similar dimension, design and casting materials (i.e. fabricated from aluminium and bronze castings with a high-density polyethylene tail). The main difference is that the D-96-A1 sampler works to a maximum velocity of 1.8 m/s (compared with 3.8 m/s for the D-96). The US D-96-A1 sampler is theoretically capable of sampling to depths similar to the D-96 sampler using different nozzles. However, in streams with high velocities, the obtainable sampling depths will likely be less than theoretical depth due to the large drift angle created by the sampler in high stream velocities.

US D-99

The US D-99 is the heaviest (124.7 kg) depth-integrated suspended sediment/water quality sampler, with a collapsible bag capable of collecting a 6-litre sample. The sampler will collect samples in stream velocities ranging from 0.9 to 4.6 m/s. However, extreme care should be practiced when deploying the sampler at stream velocities above 3 m/s. The sampler works properly to a maximum depth of 24 m with a 7.9-mm internal diameter nozzle, 37 m with a 6.3-mm internal diameter nozzle, and 67 m with a 4.8-mm internal diameter nozzle. The distance of the nozzle from the riverbed is 24 cm. Similar to the D-96 series sampler, water temperature must be at or greater than 4°C.

14.3.1 Isokinetic point-integrating samplers

US P-61-A1

The US P-61-A1, weighing 48 kg, is a point-integrating suspended sediment sampler with an electrically operated valve for starting and stopping the collection of a sample. The sampler can be used for depth integration as well as point integration to the maximum

recommended depth for different container types. The sampler uses a 4.8-mm internal diameter nozzle and can be used in stream velocities ranging from 0.5 to 3 m/s. The maximum sampling depth is about 37 m using the quart container and 55 m with the pint container.

US P-6

The latest in the P-series of point-integrating samplers, the US P-6 is very similar to the P-61 but has somewhat better capabilities. It weighs 45 kg, uses a 4.8-mm internal diameter nozzle, uses only a quart-sized sample bottle, and can be used in stream velocities ranging from 0.5 to 4 m/s at depths up to 49 m.

US P-63

The US P-63 differs from the P-61 mainly in size and weight. The P-63 is a 91-kg point-integrating sampler and is better adapted to high velocities. The maximum sampling depth is the same as for the P-61, about 55 m with a pint sample container and about 37 m with a quart container. The sampler uses a 4.8-mm internal diameter nozzle and can be used in stream velocities ranging from 0.5 to 4.6 m/s.

US P-72

The US P-72 is a light version of the P-61, weighing 19 kg. The sampler uses a 4.8-mm internal diameter nozzle and its recommended velocity range is 0.5–1.6 m/s. It can be used to a depth of 22 m with a pint container and 16 m with a quart container. These maximum depths are less than one-half of the maximum usable depths for the P-61 with the same container sizes.

14.3.2 Non-isokinetic samplers (for use in very slow, shallow conditions)

US WBH-96

The US WBH-96 weighted-bottle sampler is a stainless-steel housing that is used to secure an open-mouthed (nozzle-less) 1-litre bottle for sampling in streams with a velocity too low or depth too shallow for isokinetic samplers. The metal housing has holes drilled near the top for a rope line that is used to secure the bottle and deploy the sampler.

Annex E – Developing calibration functions between turbidity and suspended sediment concentration

This is part of Annex B from the NEMS *Turbidity Recording*.

Preamble

The relationship between turbidity and suspended sediment concentration (SSC) is strongly influenced by the suspended sediment size grading. For a given suspended sediment concentration, the finer the sediment size, the higher the turbidity. For sand/silt/clay mixtures, the turbidity signal is dominated by the clay and silt concentrations, and the sand may barely affect turbidity value.

The suspended sediment size grading typically varies at a site during a fresh or flood. The sand concentration is often in-phase with the water discharge, but the silt and clay concentrations depend more on the travel time of water from the sediment source locations and may lag or lead the peak discharge. Thus, the turbidity versus suspended sediment concentration relationship may show a hysteresis loop (or several hysteresis loops for multiple sources) throughout a high-discharge event.

Longer-term shifts or drift in the suspended sediment grading (and so the turbidity-SSC relationship) can also occur:

- because of seasonal effects on sediment supplies
- after a large, catchment-disturbance event (e.g. a large rainstorm or earthquake), and
- catchment land-use change.

It is, therefore, important to be familiar with the characteristic responses shown by a given site in order to:

- design a suitable conversion function, and
- quantify the magnitude and the time scale of the error inherent in the calibration function.

Key Tasks

The key tasks are to:

- assemble the turbidity and SSC data
- plot the data
- examine the plots for:
    - time trends
    - hysteresis loops during events
    - systematic differences between events
    - outliers, and

    - linear or non-linear trends
- fit appropriate functions, and
- calculate error statistics.

Assemble Data

Turbidity data that is concurrent with the sampling times of suspended sediment concentration results shall be extracted from the edited turbidity records.

The quality code of the turbidity data and the discharge shall also be noted.

Care shall be taken that the turbidity value is not taken from any momentary pulse in turbidity associated with manual sampling or the purge cycle of an auto-sampler.

Plot Data

The SSC and turbidity data pairs shall be plotted on a scatter-plot, with turbidity on the horizontal axis, refer to Figure 7 (page 49). Consideration should be taken of event trends and isolation of unique events by indicating data points from individual events on the plot where applicable.

SSC and discharge data pairs shall also be plotted on a scatter-plot, with discharge on the horizontal axis, refer to Figure 8 (page 49). Consideration should be taken of event trends and isolation of unique events by indicating data points from individual events on the plot where applicable.

If there are existing calibration functions, a time-series plot shall be made of the residuals of the new data.

Note: Residuals are the difference between the measured SSC and the SSC predicted by the current calibration function.

If there is existing data, the new data shall be over-plotted.

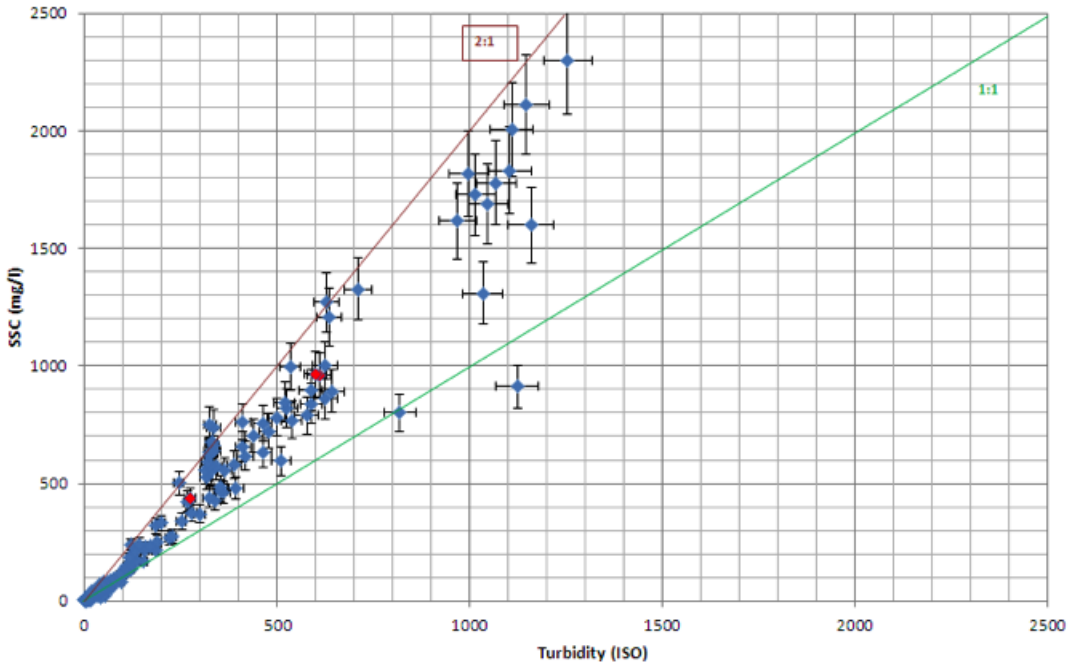


Figure 1 Example plot of turbidity versus suspended sediment concentration (SSC). Crosses show uncertainties. Note how scatter and uncertainty increase as turbidity values and suspended sediment concentrations increase.

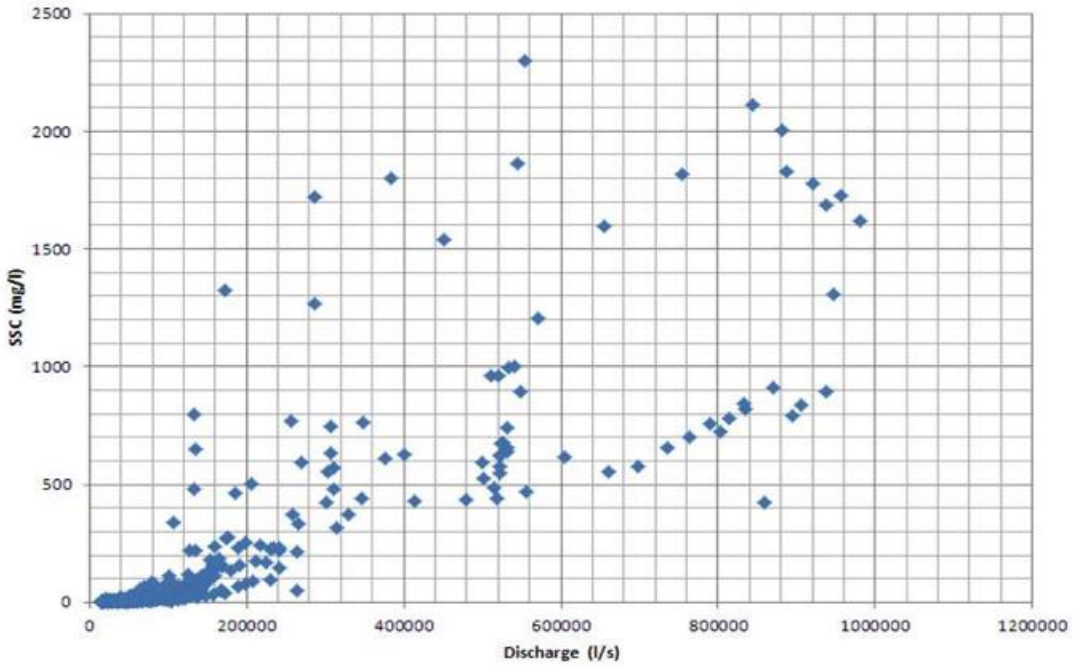


Figure 2 Example plot of discharge versus suspended sediment concentration (SSC). Note wide scatter associated with loop ratings during discrete events.

Examine Residuals for a Time Trend in Suspended Sediment Concentration on a Run-Plot

If there are existing data and an existing calibration function, then checks shall be made for a time-shift in the turbidity-SSC relationship by inspecting both the turbidity-SSC scatter-plot and residuals plot for a systematic shift in the new batch of data.

If a shift is visible, and a trend line fitted to the new data batch lies outside the confidence interval defined by the standard error of the regression for the existing calibration function, then a new calibration function shall be established.

Check for Consistent Hysteresis Behaviour and Different Rising/Falling Stage Behaviour

All event data on the turbidity-SSC scatter-plot shall be examined for hysteresis loops. If a consistent difference emerges for rising- and falling-stage data, then the rising- and falling-stage data shall be split into separate data sets and separate functions shall be fitted to each data set.

Check for Systematic Differences between Events

The data from separate events shall be examined on both the turbidity-SSC and residuals time-series plots for differences that are systematic between events but appear random over many events.

Note: The time scale of systematic differences, whether within events or over several events, determines how error in the calibration functions affects the error in the time-integrated sediment load.

Remove Outliers

The data on the turbidity-SSC scatter-plot, residuals plot and the run-plot shall be examined for outliers. Data producing residuals greater than 30% of the estimated SSC shall be suspected as outliers. For outliers, both the SSC and turbidity values shall be checked. If a clear explanation for the outlying point appears, the outlier may either be corrected (e.g. if a data-entry error was made for the SSC value) or removed (e.g. the water sample had an unusually high sand content or a loose bottle cap; the turbidity value was collected during an auto-sampler purge cycle; or the turbidity value was based on synthetic data of dubious quality).

Notes shall be kept of removed outliers by annotating plots, either electronically or on hard copies.

Check for Linear or Non-linear Behaviour

The turbidity-SSC scatter-plots shall be examined for evidence of linearity or otherwise. A linear relationship is appropriate where:

- the data points plotted are along a straight line

- a scatter-plot of the residuals and turbidity shows no trend for the residuals to increase, decrease, or curve as turbidity increases
- a scatter-plot of the residuals and turbidity shows no trend for the scatter in the residuals to increase as turbidity increases, and
- the residuals appear to be normally distributed.

If one or more of the above conditions fail, then it is likely that an improved calibration function will be found by transforming the turbidity and SSC data; for example, as logarithms.

Fit Functions

Calibration functions shall be fitted to the data (whether in their original values or as logarithms) using linear regression methods.

If the data have been transformed to logarithms, the re-transformed regression function shall be corrected for logarithmic bias using the method of Duan (1983).

With either untransformed or log-transformed data, the reliability of the calibration function shall be checked at low values of turbidity. If the function does not follow the trend of the low-range data, a separate function shall be fitted to the low-turbidity range.

This function shall intersect the function developed for the higher-range data.
If the data have been split into rising and falling stage subsets, then separate functions shall be fitted to each subset.

Calculate Error Statistics

The following statistics shall be calculated for each calibration relationship:

- the regression coefficient (r2), and
- the standard error of the estimate.

Note: When using untransformed data, the standard error of the estimate is an additive error (i.e. + or -) on the predicted SSC. When using log-transformed data, the standard error of the estimate becomes a factorial (i.e. × or ÷) error on the predicted SSC.

Where data quantity and range permit, standard errors of the estimate shall also be calculated separately for each turbidity quality code.

Note: The standard error of the estimate in the turbidity-SSC calibration, when combined with an appreciation of the time-span of systematic variation in the residuals, helps determine the error in the time-integrated suspended sediment load.

Documenting Calibration Functions

If the software used to apply the calibration functions does not file these functions as ratings, then documents shall be compiled that list:

- the turbidity-SSC calibration functions

- the conditions that they relate to (for example, all flows, rising and falling stages, low and high turbidity ranges)
- the time periods to which they apply
- the range of turbidity data over which they were calibrated, and
- accuracy statistics (r2, standard error of the estimate) for:
    - the overall data set, and
    - if possible, also by quality code for the turbidity data.

Archiving Derived Suspended Sediment Concentration

The SSC records generated by applying the turbidity-SSC calibration functions may be archived, providing that:

- the quality codes of the underpinning turbidity records are included for each derived suspended sediment concentration record, and
- the above documentation of the calibration functions is also filed.

Note: Organisations may prefer to not archive the derived SSC but to generate this as required; for example, when suspended sediment yields are to be calculated.

Annex F – Developing calibration functions between SSCindex and SSCQm

This section is reproduced from Annex C of the NEMS Turbidity Recording, and while the method description is unchanged, the terminology has been changed to reflect the use of the abbreviations 'SSC_{index}' and 'SSC_{Qm}' in this document.

Preamble

The relationship between the bankside, at-site SSC (SSC_{index}) and the discharge-weighted cross-section mean SSC (SSC_{Qm}) depends on the:

- turbulence intensity over the cross-section (which varies with discharge and rate of change in discharge), and
- size grading of the suspended load (which may vary during freshes and floods and over longer time frames).

Longer-term shifts in the suspended sediment grading can occur:

- owing to seasonal effects on sediment supplies
- after a large, catchment-disturbance event (e.g. a large rainstorm or earthquake); and
- catchment land-use change.

It is important to establish whether these factors cause variations in the ratio of SSC_{Qm} to SSC_{index} (known as the mixing ratio) that are:

- random
- systematic with discharge or SSC, or
- changing with time.

It is important to be familiar with the characteristic mixing ratios shown by a given site in order to:

- design a suitable conversion function, and
- quantify the magnitude and the time scale of the error inherent in the conversion function.

Key Tasks

The key tasks are to:

- assemble the concurrent pairs of SSC_{index} and SSC_{Qm} data
- plot the data
- examine the plots for
    - trends with discharge, and
    - time trends
- fit appropriate functions, and

- calculate error statistics.

Assemble Data

Concurrent measurements of SSC_{Qm} and SSC_{index} shall be assembled.

The SSC_{index} at the mid-time of cross-section suspended sediment gaugings shall be interpolated from the results of the at-site samples collected before and after sediment gauging.

Discharge shall be interpolated from the discharge record at the mid-times of the suspended sediment gaugings.

Plot Data

Scatter-plots shall be made of:

- SSCQm versus SSCindex
- the mixing ratio (i.e. SSCQm divided by SSCindex) versus discharge, and
- the residuals of regression functions fitted to both of the above plots versus time.

Such plots shall be added to as data are accumulated.

Remove Outliers

The data on all plots shall be examined for outliers. The reliability of outlier data points shall be checked. If a clear explanation for the outlying point appears, the outlier may either be:

- corrected (for example, if a data-entry error was made for the suspended sediment concentration value), or
- removed as appropriate.

Notes shall be kept of removed outliers by annotating plots, either electronically or on hard copies.

Fit Functions

Functions shall be fitted to the data (whether in their original values or as logarithms) using regression methods.

Note: It may be appropriate to transform the data to logarithms to optimise the linear regression approach. If this is done, then the re-transformed regression function shall be corrected for logarithmic bias using the method of Duan (1983).

A function relating mixing ratio to discharge shall be preferred over a function relating SSC_{Qm} to SSC_{index} if the former explains more variance in the measured SSC_{Qm}.

Calculate Error Statistics

The following statistics shall be calculated for the preferred calibration relationship:

- the regression coefficient (r2), and
- the standard error of the estimate.

Note: When using untransformed data, the standard error of the estimate is an additive error (i.e. + or -) on the predicted SSC. When using log-transformed data, the standard error of the estimate becomes a factorial (i.e. × or ÷) error on the predicted SSC.

Examine Data for a Time Trend Residuals

As data are accumulated and the calibration relationship is refined, checks shall be made for a time-shift in the relationship by inspecting time-series plots of the residuals from the preferred relationship.

If a shift is detected visually, and a trend line fitted to the new data batch lies outside the confidence interval defined by the standard error of the regression for the existing calibration function, then a new calibration function shall be established.

Applying Calibration Functions

The preferred calibration function shall be used to convert SSC_{index} derived from turbidity records to SSC_{Qm} either prior to or in the process of integrating suspended sediment yields.

Documenting Calibration Functions

Documents shall be compiled that list:

- the SSCindex to SSCQm calibration function and any revisions
- the time periods to which they apply
- the range of SSC and discharge data over which they were calibrated, and
- accuracy statistics (r^2 and standard error of the estimate) for the overall data set.

Annex G – Example desktop for fitting sediment rating curve

This Annex shows an example of how the steps and checks in fitting a sediment rating curve listed in Section 12.4.2 can be undertaken using a rating-fitting software package.

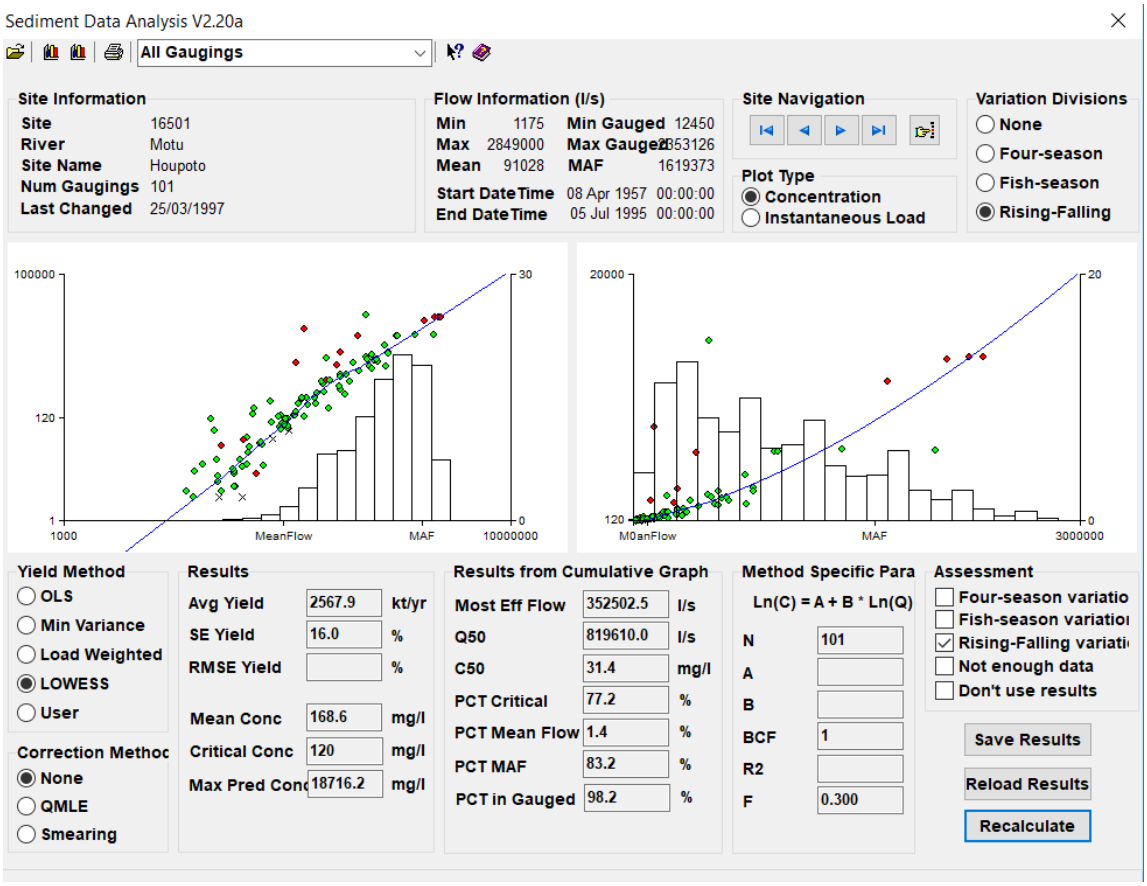


Figure G-1: Example of steps and checks when fitting a sediment rating curve, illustrated for the Motu River at Houpoto dataset with the desktop displayed by the rating-fitting software SEDRATE. Data plots on log (left graph) and linear (right graph) scales show more uniform data scatter with log transformation. On log scales, the trend is reasonably linear so either a least-squares or LOWESS fit could be chosen (LOWESS is selected in this case). The maximum predicted SSC is 18,712 mg/l, which is reasonable for the Motu region. Sample density aligns reasonably with the load distribution (bar graphs); 98.2% of the estimated load (2,567,900 t/yr) is transported at discharges within the sampled range. Thus, the discharge-targeting sampling strategy is reasonable. Rising stage points tend to plot higher than falling stage points, thus it is important to keep the rising stage point count in proportion to the duration of rising stages. Alternatively, if there is a strong separation of rising and falling stage points, separate rising-stage and falling-stage rating curves could be fitted.

Annex H – Quality matrix examples

This Annex provides examples of completed Site quality and SSC_{index} and SSC_{Qm} value quality matrices.

Site Quality Matrix

Criteria	**3 Points**	**1 Point**	**0 Points**
Sampler intake or sensor location	Affected by bedforms		Not affected by bedforms
	☐		☑
Bank stability	Unstable slumping banks upstream		Stable banks or engineering controls
	☐		☑
Incomplete mixing from nearby upstream sediment inputs (e.g. tributaries, bank erosion)	Sediment inputs occur within two morphological units (e.g. meanders, riffle/pool sequences) upstream of monitoring site ☐	Sediment inputs occur beyond two morphological units but within 200 m upstream of monitoring site ☐	None ☑
Ability to do SS gaugings at high discharges, considering site access, and physical ability	Not achievable during any flood ☐	Achievable up to mean annual flood ☑	Achievable above mean annual flood ☐
Meta data recorded	Not recorded ☑		Recorded ☐
Catchment stationarity	Catchment land-cover and sediment sources changing significantly		Catchment land-cover and sediment sources not changing significantly
	☐		☑
Sum	3	1	0
Total score	4		
Site QC assessment *QC 600 = 0–3* *QC 500 = 4–9* *QC 400 = >9*	*QC 500* Comment: The site quality code has been downgraded because metadata has not been recorded. This could be upgraded to QC 600 once metadata was recorded.		

SSC_{index} Value Matrix

Criteria	12 Points	3 Points	1 Point	0 Points
Sampling	Location of sample collection point varies and/or is not within 1 m of surrogate sensor ☐	Location of sample collection point between 0.1 m and 1 m of surrogate sensor ☐	Manual samples collected beside surrogate sensor ☐	Auto-sampler used with intake co-located within 0.1 m of surrogate sensor ☑
Laboratory analysis of SSC	Non-standard laboratory procedures used, and no correction applied, and/or results truncated or inappropriately rounded-up ☐	Non-standard laboratory procedures applied but result corrected based on site-specific empirical relation ☐	Standard laboratory procedures applied but were pressing limits of practical ranges of methods ☑	Standard laboratory procedures applied and properly reported ☐
Sum	0	0	1	0
Total data quality score	1			
Overall QC assessment	*QC 600*			
QC 600 =<3	Comment: The point/index-sampled SSC data value has no significant issues with regard to sampling location or laboratory analysis.			
QC 500= 3-11				
QC 400 = >11				

SSC_{Qm} Value Matrix

Criteria	12 Points	3 Points	1 Point	0 Points
Sampling	NEMS-compliant samplers and procedures not used ☐	NEMS-compliant isokinetic samplers used but with less than the specified number of verticals ☐	NEMS-compliant isokinetic samplers used but deployed outside recommended operating ranges ☐	NEMS-compliant isokinetic samplers and procedures used correctly ☑
Laboratory analysis of SSC samples	Non-standard laboratory procedures used, and no correction applied, and/or results truncated or inappropriately rounded-up ☐	Non-standard laboratory procedures applied but result corrected based on site-specific empirical relation ☐	Standard laboratory procedures applied but were pressing limits of practical ranges of methods ☐	Standard laboratory procedures applied and properly reported ☑
Sum *Total data quality score* *Overall QC assessment* *QC 600 =<3* *QC 500= 3-11* *QC 400 = >11*	0	0	0	0
	0 *QC 600* Comment: The gauged discharge-weighted cross-section averaged SSC data value has no significant issues with regard to field sampling procedures or laboratory analyses.			


GLEN
NAPIER
NEMS