NEMS
NATIONAL ENVIRONMENTAL MONITORING STANDARDS

National Environmental Monitoring Standard

Turbidity

Measurement, Processing and Archiving of Turbidity Data

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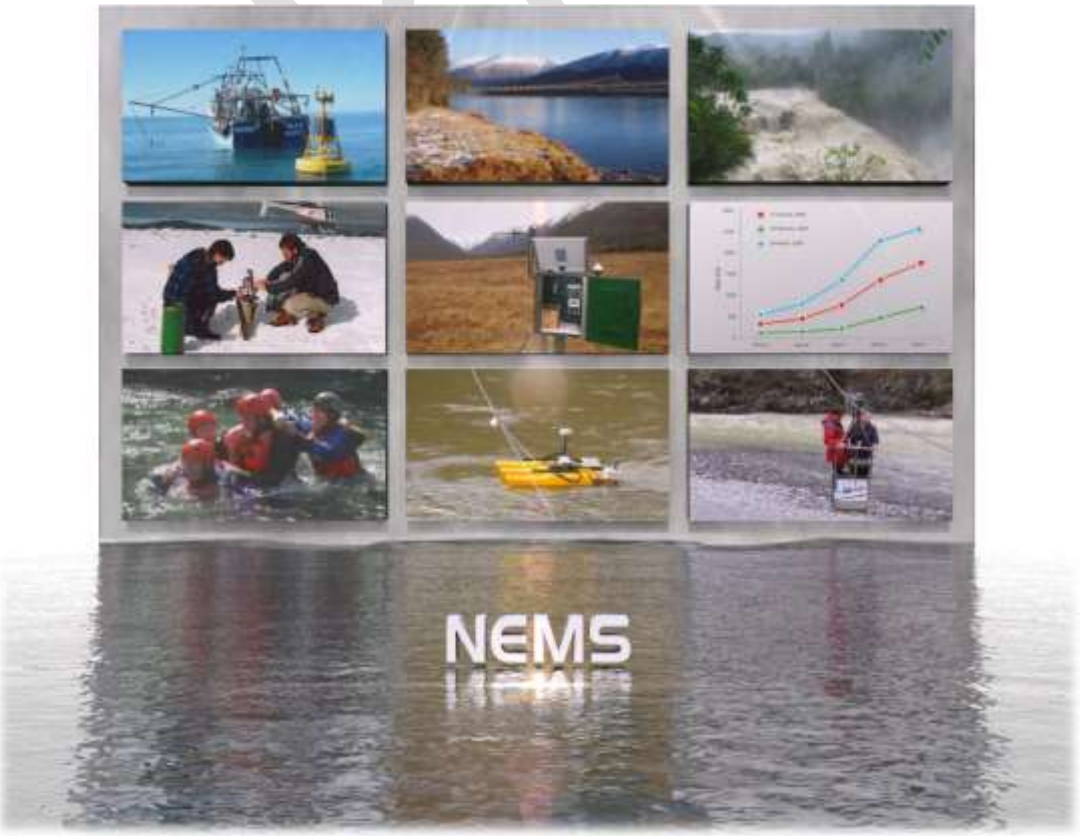

The National Environmental Monitoring Standards

The current suite of National Environmental Monitoring Standards (NEMS) documents, best practice guidelines, glossary and Quality Code Schema can be found at www.lawa.org.nz:

Implementation

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments and the NEMS Codes of Practice shall be complied with.

Limitations

It is assumed that as a minimum the reader of these documents has undertaken industry-based training and has a basic understanding of environmental monitoring techniques. 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.

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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 NEMS initiative has been led and supported by the Local Authority Environmental Monitoring Group (LAEMG), to assist in ensuring the consistency in the application of work practices specific to environmental monitoring and data acquisition throughout New Zealand.

The strategy that led to the development of these Standards was established by Jeff Watson (Chairman) and Rob Christie (Project Manager), and the current steering group comprises Phillip Downes, Martin Doyle, Michael Ede, Glenn Ellery, Nicholas Holwerda, Jon Marks, Charles Pearson, Jochen Schmidt, Alison Stringer, and Raelene Mercer (Project Manager).

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. 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 Brent Watson of Horizons Regional Council, and Murray Hicks of NIWA, with support from Jeff Watson and Michaela Rose of Horizons Regional Council. The input of NEMS members into the development of this document is gratefully acknowledged; in particular, the review undertaken by the NEMS Steering Group.

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- Tasman District Council
- West Coast Regional Council
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Review

The original version of this document was reviewed by the NEMS Steering Group in February 2016, and will be reviewed again approximately every two years. Further details on the review process can be found at www.lawa.org.nz.

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Terms, Definitions and Symbols

Relevant definitions and descriptions of symbols used in this Standard are contained within the NEMS Glossary available at www.lawa.org.nz.

Normative References

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

- NEMS *Glossary*
- NEMS *Quality Code Schema*
- NEMS Best Practice Guideline *Safe Acquisition of Field Data In and Around Fresh Water.*

About this Standard

Introduction

Turbidity is a measure of the optical properties of water that cause light to be scattered and absorbed. Turbid water results from suspended material; for example, sediment, organic matter and dissolved constituents such as organic acids and dyes. Turbidity is often used as an inverse measure of water clarity. It is also a popular surrogate for continuously monitoring suspended sediment concentration because of its dependence on the concentration of sediment particles suspended in the water and because it is relatively simple to measure with in situ instruments (within limits).

The sensor types vary from transmission-type sensors, which capture the attenuation of a light beam along a path between the light source and receiver, and back-scattering sensors, which measure the intensity of light scattered back towards the source.

When calibrating sensors to stock formazin solutions, different sensors can return different results. As a result, turbidity records from different sensors are not necessarily comparable, resulting in a need for standardisation.

The use of different standards between field-deployed instruments and laboratory instruments further complicates the understanding of sensor performance and calibration.

For suspended sediment applications, the range over which sensors operate reliably needs to be considered. High concentrations during floods can be missed because of over-ranging or sensor saturation.

It is important to understand the range of uses to which the data can be put, and ensure that data collected for one purpose can be used as widely as possible in the future. Key to planning, maintaining and recording turbidity is the understanding of and ensuring stationarity of record.

Objective

The objective of this Standard is to ensure that turbidity records and associated calibration and validation data are gathered, processed and archived in a verifiable and consistent manner and is suitable for 'at site' and comparative analysis. This document is made up of two parts: the first part is the Standard and the second part contains supporting information that practitioners are required to implement in order to achieve the Standard.

Scope

The Standard covers all requirements and processes associated with the deployment of continuously recording, in situ turbidity sensors for ambient turbidity monitoring in rivers, streams, lakes and estuaries. This includes:

- site selection
- instrument type
- pre-deployment calibration
- field deployment/installation
- the acquisition of turbidity data
- in situ validation
- data processing, including:
  - data editing
  - replacing missing record, and
  - assigning quality control (QC) codes
- data archiving
- metadata and associated data, and
- quality assurance.

Exclusions

This Standard does not apply to the acquisition and analysis of turbidity for:

- potable water supplies, or
- waste water treatment.

Using Turbidity as a Surrogate

Turbidity is often used as a surrogate for suspended sediment concentration. Procedures for relating turbidity to at-site suspended sediment concentration beside the turbidity sensor and to the cross-section mean suspended sediment concentration are covered in Annex B and C, respectively.

Data fit for purpose

This Standard requires all collected data to be assigned a quality code.

Data that are collected, processed and archived in a verifiable and consistent manner according to this Standard can meet the highest quality code (QC 600).

Data that do not meet QC 600 shall be coded appropriately. This allows monitoring to be carried out that is 'fit for purpose', and these data can be coded as QC 500 (Fair), or QC 400 (Poor). These data are deemed acceptable for specific, often secondary, purposes that only require data of a lesser quality.

Note: Enduring use – It is important to note that data that are coded QC 500 or QC 400 may be restricted in their use for a wide range of (yet unknown) purposes sometime in the future.

The Standard – Turbidity

For data to meet the Standard the following shall be achieved:

Turbidity Measurement Accuracy	Deviation from primary reference	± 3 FNU for values less than 20 FNU, or ± 15 % for values greater than or equal to 20 FNU and less than 750 FNU relative to primary reference. >750 FNU: undefined
Stationarity	Stationarity of record shall be maintained.	

Requirements

As a means of achieving the Standard (QC 600), the following requirements apply:

Units of Measurement		FNU
Resolution		0.1 FNU
Precision		0.1 FNU for values less than 20 FNU 1.0 FNU for values greater than or equal to 20 FNU
Timing of Measurements	Maximum recording interval	Record time-series records of turbidity instantaneously at the logging time, and: • at time intervals ≤ 5 minutes for catchments 25 km² or smaller, or • at time intervals ≤ 15 minutes for catchments larger than 25 km².
	Measurement	A point sample. Any statistical function undertaken on the sensor shall not utilise a sample period greater than the recording interval.
	Resolution	1 second
	Accuracy	± 90 s/month

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Timing of Measurements (con.)	Time zone	Express time as New Zealand Standard Time (NZST). *Note: Do not use New Zealand Daylight Time (NZDT).*
Supplementary Measurements	If sediment loading required…	• Flow • Water samples for analysis of suspended sediment concentration
	Measurement statistics	Any supplementary data stream to be defined in the metadata.
Field Validation Methods	Sensor test	Minimum required pre-deployment test: • zero-point validation.
	Primary reference measurement	• Annual zero-point validation: ± 1 FNU • Monthly validation samples/measurements • Annual validation sample collected during a run-off event in which turbidity range exceeds 100 FNU. *Note: Validation samples are laboratory analysed. Validation measurements are undertaken using a calibrated handheld instrument in the field.*
	Tolerance	• For turbidity values < 20 FNU: ± 3 FNU when averaged over at least 10 consecutive samples. • For turbidity values ≥ 20 FNU: ± 10% when averaged over at least 10 consecutive samples.
Calibration	Frequency	• In situ sensor: Calibration shall occur when validation confirms that the in situ sensor is not conforming to the accuracy of the Standard (QC 600) and/or as per the manufacturer's specifications. • Handheld primary reference meter: As per manufacturer's specifications.
	Method	• Using formazin as per ISO 7027

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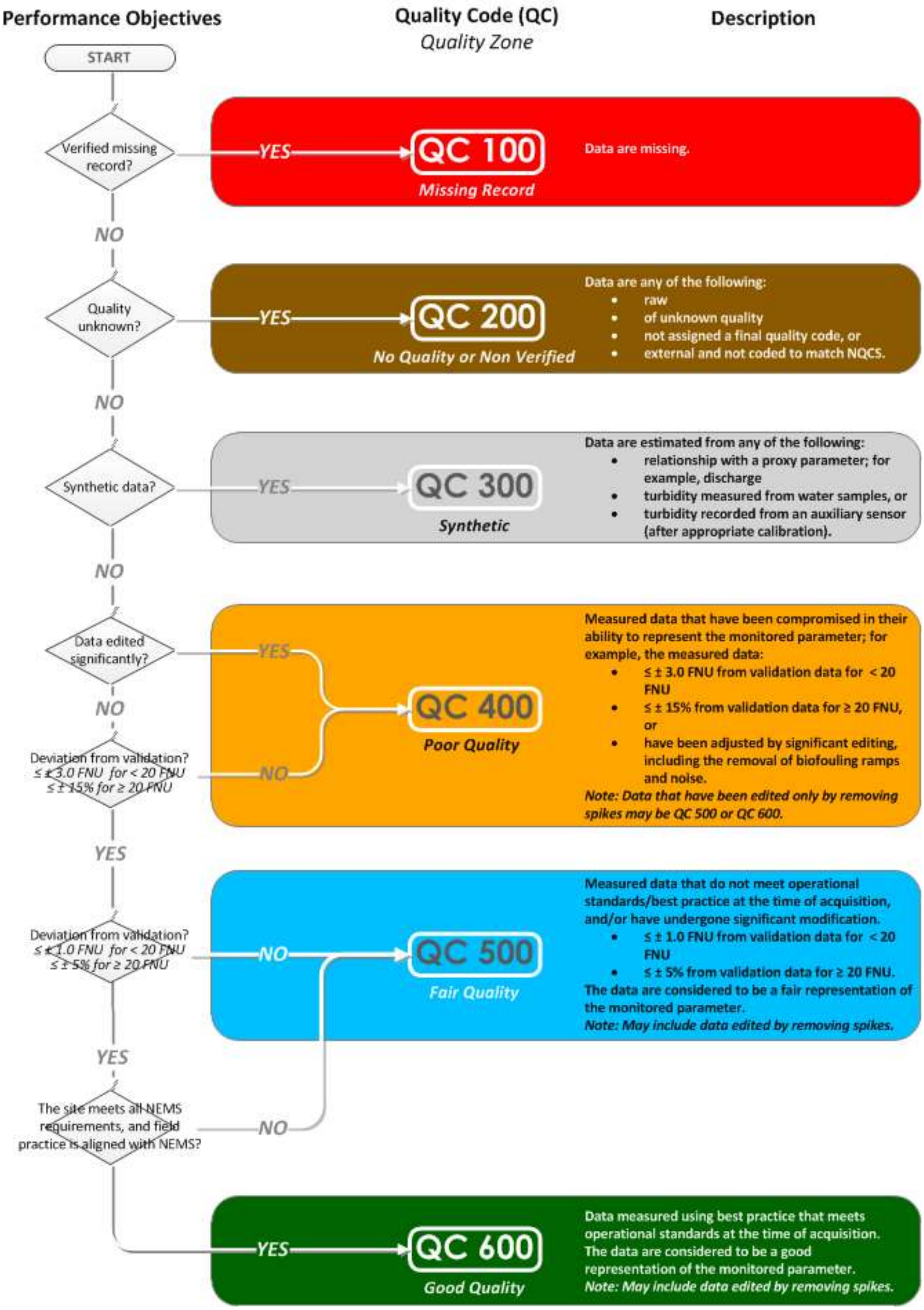
Metadata		Metadata shall be recorded for all measurements.
Quality Assurance		*Quality assurance requirements are under development.*
Processing of Data		All changes shall be documented. All data shall be quality coded as per the Quality Codes flowchart.

The following table summarises best practice and is not required for QC 600:

Validation Methods	Inspection of recording installations	Sufficient to ensure the data collected are free from error and bias, both in turbidity and time.
Archiving	Original and final records	File, archive indefinitely and back up regularly: • raw and processed records • primary reference data • supplementary measurements • validation checks • site inspections • verification results, and metadata.
Auditing		*Quality assurance requirements are under development.*

Quality Codes – Turbidity

All data shall be quality coded in accordance with the National Quality Coding Schema. The schema permits valid comparisons within and across multiple data series. Use the following flowchart to assign quality codes to all turbidity data.



Data are missing.

Data are any of the following:

- raw
- of unknown quality
- not assigned a final quality code, or
- external and not coded to match NQCS.

Data are estimated from any of the following:

- relationship with a proxy parameter; for example, discharge
- turbidity measured from water samples, or
- turbidity recorded from an auxiliary sensor (after appropriate calibration).

Measured data that have been compromised in their ability to represent the monitored parameter; for example, the measured data:

- ≤ ± 3.0 FNU from validation data for < 20 FNU
- ≤ ± 15% from validation data for ≥ 20 FNU, or
- have been adjusted by significant editing, including the removal of biofouling ramps and noise.

Note: Data that have been edited only by removing spikes may be QC 500 or QC 600.

Measured data that do not meet operational standards/best practice at the time of acquisition, and/or have undergone significant modification.

- ≤ ± 1.0 FNU from validation data for < 20 FNU
- ≤ ± 5% from validation data for ≥ 20 FNU.

The data are considered to be a fair representation of the monitored parameter.

Note: May include data edited by removing spikes.

Data measured using best practice that meets operational standards at the time of acquisition. The data are considered to be a good representation of the monitored parameter.

Note: May include data edited by removing spikes.

1 Site Selection and Deployment

In this Section

This section contains information on:

- access considerations
- where to locate turbidity sensors in a river or stream reach
- how to orientate sensors relative to the flow direction, bed, and water surface
- how to protect the sensor, and
- other considerations, for example accessibility.

1.1 Stationarity of Record

Stationarity of record:

- is maintained when variability of the parameter being measured is only caused by the natural processes associated with the parameter, and
- ceases when variability is caused or affected by other processes; for example by moving the station or changing the type of instrument.

Without stationarity, a data record cannot be analysed for changes over time (such as climate or land-use change). While the accuracy of collection procedures may change, it is critical that the methods and instruments used to collect a turbidity record remain without bias over the lifetime of the record. For example, if a back-scatter type turbidity sensor is replaced with another using a different light source and scattering angle, then the signal returned from the field from the new instrument may track lower or higher than the track of the old instrument.

In similar fashion, it is also critical that the same methods and instruments are used to collect and compare turbidity records across multiple sites and/or catchments.

Because the methods of collecting continuous environmental data do change over time, an external reference should always be used against which the continuous data can be checked. In the case of turbidity data, the external reference is stock mixtures of the standard 'sediment' formazin. However, with turbidity it is also necessary to retain the same instrument characteristics.

1.2 Site Selection

Site selection shall consider:

- general location
- accessibility
- channel and bank characteristics, and
- proximity to other sensors and equipment.

1.2.1 General Location

Turbidity records are often used to generate surrogate records of suspended sediment concentrations, which are then combined with flow records to compute sediment loads.

Where practicable, turbidity sensors shall be located at or near flow-recording sites.

1.2.2 Site Access

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

- general access and legal requirements
- instrument servicing
- collecting validation or supplementary calibration samples:
  - by hand, or
  - with auto-samplers.

1.2.2.1 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?
- Can machinery and materials be suitably and safely positioned during construction?
- Is it possible to obtain a long-term access agreement with any landowners whose land must be crossed to access the site?
- What are the environmental effects and resource consent requirements?

1.2.2.2 Instrument Servicing

The turbidity sensor shall be accessible over the majority of the site stage range for:

- servicing, and
- cleaning biofilm from its lens.

1.2.2.3 Collecting Validation or Supplementary Calibration Samples by Hand

If validation or supplementary calibration samples are collected by hand, then access shall permit these to be collected as close as practicable to the turbidity sensor.

Note: It is recognised that in many cases this will be difficult to achieve at high flows. Thus it is preferable to collect validation or supplementary calibration samples using an auto-sampler.

1.2.2.4 Auto-Samplers

If auto-samplers are used to collect validation or supplementary calibration samples, then the auto-sampler shall be located where:

- the auto-sampler is secure from flood damage at high stage, and
- the auto-sampler's intake and the turbidity sensor are, where practicable, within 1 m horizontally and vertically of each other.

1.2.3 Channel and Bank Characteristics

The following characteristics of the channel and banks shall be considered when siting turbidity sensors:

- location in channel
- turbulence characteristics, and
- bank conditions.

1.2.3.1 Location in Channel

Access generally dictates that turbidity sensors are deployed from a stream bank.

1.2.3.2 Turbulence Characteristics

Where practicable, turbidity sensors shall be located where turbulence is sufficient to maximise the mixing of the suspended load over the channel cross-section. For example, turbulent pools immediately downstream from rapids are ideal.

1.2.3.3 Bank Conditions

Bank conditions shall be stable over time. For example, the bankside vegetation does not change over time from grass to progressively larger trees, thereby changing the bankside velocity field.

1.2.4 Sites to Avoid

Sites that exhibit the following features shall be avoided:

- banks that are eroding or are prone to slips
- banks with trees and shrubs that create low-velocity back-waters, or
  Low velocity back-waters can trap sediment.
- sections that have unstable beds.
  For example, pools and beaches where sand, gravel, or mud can build up and bury the sensor.

1.3 Practical Controls

1.3.1 Site Access

Site access shall be secure and safe for the complete period of deployment. A long-term access agreement with any landowners whose land must be crossed to gain access to the site is recommended.

1.3.2 Safety

Hazards (for observers, the public, livestock, and wildlife) related to the location and the measurement activity shall be identified and minimised.

1.3.3 Hazard Review

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

The potential for human activity affecting the measurement, e.g. vandalism, shall be minimised.

1.4 Deploying Sensors

In situ turbidity instruments shall be deployed:

- near to water-level and discharge recording sites
- at a site that permits servicing and validation operations to be carried out on the instrument
- within 1 m horizontally and vertically of the intake point of any co-deployed automatic water sampler, and
- far enough downstream from sources of turbidity that the turbidity from the source is well mixed across the channel by the time it passes the instrument.

1.4.1 Sensor Orientation and Clearances

The manufacturer's specifications shall be followed in regard to:

- how the sensor lens is orientated with respect to the ambient flow direction
- the minimum clearance between the sensor lens and the stream bed, and
- the minimum clearance between the sensor lens and the water surface.

Note: In situations where biofouling is severe and difficult to manage with mechanical or hydraulic devices, and where the purpose of the monitoring is to monitor the suspended sediment load during floods and freshes, it may be pragmatic to position the sensor lens above water level at base flows.

1.4.2 Sensor Protection

As far as practicable, sensors and their cabling shall be protected from damage by vandals, wildlife, flood-scour and debris. Typical protective measures include deployment within steel casings firmly secured to the banks, and buried or ducted cables beyond the banks.

Note: Protection measures should still enable easy access to the sensor lens for cleaning it of biofilm growth and for sensor removal if necessary.

2 Turbidity Instrumentation

In this Section

This section contains information on:

- the purpose of turbidity sensors
- the general and required characteristics of turbidity sensors
- the Standard
- inhibiting biofouling, and
- pre-deployment calibration and validation of turbidity sensors.

2.1 Purpose of Turbidity Sensors

The prime application of in situ turbidity sensors is to provide a:

- continuous record of turbidity, or
- surrogate, continuous record of suspended sediment concentration.

2.2 Sensor Characteristics

2.2.1 General Characteristics and Standards

Available turbidity sensors vary in terms of the:

- spectrum and beam-width of emitted light
- angle between emitted and detected light beams
- wavelength of detected light
- reference suspension used for calibration, and
- range of turbidity able to measured.

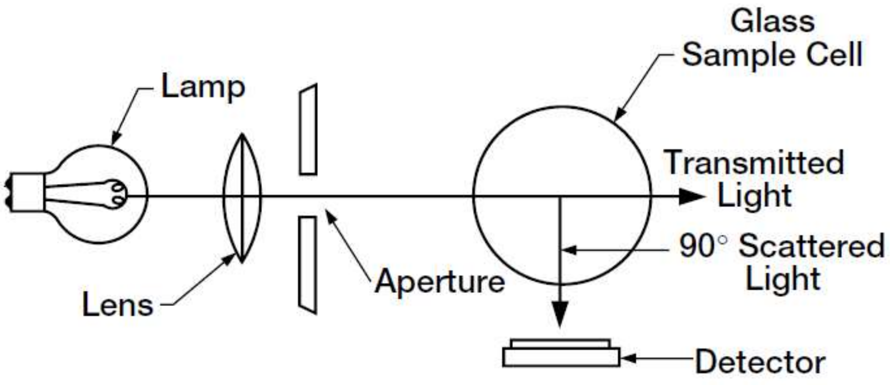


Figure 1 – Schematic of the key components of a turbidity sensor

A sensor that detects light back-scattered at an angle of 90^0 from the transmitted light pathway.

Variation in the first four characteristics can produce different results for the same suspension. Thus a standard set of characteristics is required.

There are two applicable International Standards used for laboratory-based measurement of turbidity. These are:

- ISO 7027:1999 *Water Quality – Determination of Turbidity* (International Organization for Standardization, 1999), and

  Note: The ISO 7027 Standard is protected by copyright. It is therefore necessary that this document be purchased.
- EPA Method 180.1: *Determination of Turbidity by Nephelometry (*EPA, 1993).

Note: The APHA2045 Standard follows the Drinking Water Standard EPA180.1 using broad-spectrum wavelengths and focuses on a relatively low turbidity range (0–40 NTU range). Most field sensors follow the ISO 7027 Standard using monochromatic, near-infrared light and based around wastewater measurements with a higher turbidity range. The near-infrared sensor is also less influenced by sediment colour. Thus, the ISO 7027 Standard has broader field application, notably if the record is to be used as a surrogate for another parameter (particularly suspended sediment concentration), and is the Standard preferred in this document. Results obtained with different standards are not inter-convertible.

2.2.2 Standard for Field Turbidity Sensors

Turbidity sensors deployed in situ for continuous monitoring shall meet the ISO 7027: 1999 *Water Quality – Determination of Turbidity* Standard.

The key features of ISO 7027 are:

- light source: monochromatic infrared beam with a maximum 1.5° convergence angle
- measurement wavelength: 860 nm ± 30 nm
- measurement angle: 90° ± 2.5°
- calibration standard: formazin
- reporting units: Formazin Nephelometric Units (FNU), and
- operational range: 0–4000 FNU.

2.2.2.1 Non-Conforming Instruments

Existing instruments that meet alternative standards, or that do not meet any formal standard, shall be replaced as soon as practicable with an instrument meeting the ISO 7027 Standard. As an interim measure, samples collected from the field for validating the sensor calibration shall have their turbidity measured with a laboratory instrument meeting the ISO 7027 Standard.

2.2.2.2 Reporting in Nephelometric Turbidity Units

Data from existing instruments meeting the EPA 180.1 Standard shall be reported in Nephelometric Turbidity Units (NTU).

2.2.2.3 Reporting in Formazin Backscatter Units

Data from existing instruments meeting neither the ISO 7027 nor EPA 180.1 Standard but using a back-scatter-type detection system and using formazin as the calibration standard shall be reported in Formazin Backscatter Units (FBU).

2.2.2.4 Limited Accuracy

Accuracy may be limited at low turbidity, depending on sensor type, range, and output settings. Such data shall be assigned quality code QC 200.

2.3 Pre-Deployment Validation and Calibration

2.3.1 Purpose

New turbidity sensors that meet the instrumentation standard described above will have been factory-calibrated to formazin. The primary function of the pre-deployment check is to ensure that the factory calibration remains accurate.

If the factory calibration is not accurate, then the instrument shall be recalibrated or returned to the supplier.

The calibration certificate shall be obtained and inspected prior to deployment.

2.3.2 Calibrate to Measure Turbidity

Turbidity sensors shall be calibrated to measure turbidity, irrespective of whether or not the purpose of the monitoring is to:

- collect a record of turbidity, or
- to use turbidity as a surrogate for other variables.
  For example, for suspended sediment concentration.

2.3.2.1 Validation and Calibration Solutions

The calibration/validation solutions used in the laboratory shall be composed of formazin.

WARNING! Formazin may contain carcinogenic compounds. Ingesting formazin can cause serious illness or death.

All staff must be trained in the use of formazin. A health and a safety plan including a MSDS/SDS is required.

Note: Formazin is meeting increasing user-resistance. Non-toxic formazin substitutes are currently under investigation; so far none have emerged as a successor to formazin.

2.3.3 Calibration Procedure

Sensor calibration shall be undertaken as detailed in the instrument reference manual and confirming to the ISO 7027 Standard. In brief, this involves:

- securing fresh stock solutions of formazin that cover the full FNU range of the instrument
- measuring the FNU of these stock solutions accurately with an already-calibrated laboratory instrument that meets the ISO 7027 Standard
- measuring their FNU with the field instrument

2.3.4 Validation Procedure

Sensor validation shall include:

- measuring a clear-water (zero turbidity) sample, and
- checking that the agreement between the laboratory and field instruments is within the tolerance levels. Tolerance Levels for Validation

Generally, the field instrument measurements shall lie within a specified percentage of the laboratory sensor.

2.3.4.1 Mean Difference Between Sensors

The mean difference between the two sensors shall be less than 10% when compared against a minimum of 10 consecutive samples for turbidity values greater or equal to 20 FNU. For turbidity values less than 20 FNU, the agreement shall be to within 3 FNU.

Note: Samples of more than 400 FNU are excluded from the comparison.

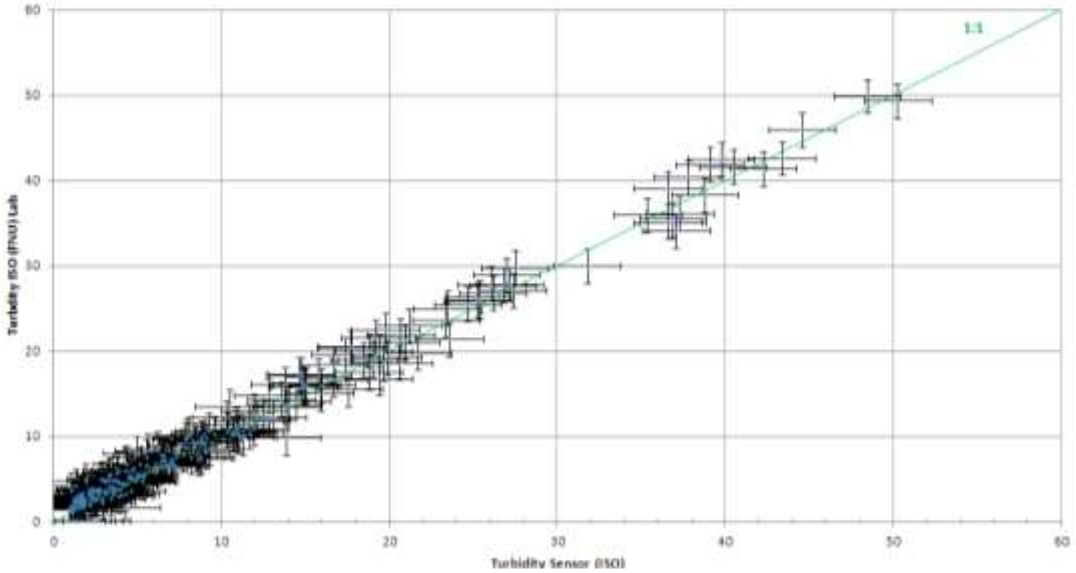


Figure 2 – Cross-comparison of measurements of turbidity made by a field sensor and a laboratory instrument

Both instruments meet the ISO 7027 Standard.
Crosses show uncertainty of individual measurements.

If the factory-calibration fails these validation specifications, then the instrument will require recalibration. This calibration shall follow the procedure detailed in the instrument's reference manual.

3 Data Acquisition

In this Section

This section contains information on the acquisition of turbidity data and associated validation data. It covers:

- time-series data-collection specifications
- monitoring and management of lens fouling
- field procedures for collecting validation data, and
- office procedures for checking the sensor against the field validation measurements and assigning quality codes.

3.1 Data Collection Specifications

Turbidity sensors output a turbidity value measured over a fixed observation period. This period varies between sensor types and may sometimes be adjusted during instrument set-up. The observation period shall be no longer than 300 seconds (5 minutes).

Note: Some sensors require a warm-up period. This is managed either in the on-board control systems or with a programmable data logger.

Time-series records of turbidity shall be recorded as instantaneous values at the logging time, and:

- at time intervals no longer than 5 minutes in catchments 25 km^2 or smaller, or
- at time intervals no longer than 15 minutes in catchments larger than 25 km^2.

It is recommended that all turbidity records be logged at least every 5 minutes irrespective of catchment area.

3.2 Management of Fouling

3.2.1 Biofouling

Unmonitored or unmanaged biofouling may compromise a turbidity record. This effect is most prevalent during summer and where the water has high nutrient concentrations. A management plan shall be devised and implemented to minimise this.

Note: It is recommended that all sites prone to biofouling be equipped with telemetry so that the early signs can be checked in the office on a regular, even daily basis, and appropriate measures taken to clean the sensor before the record deteriorates to the point of losing data.

3.2.2 Chemical Fouling

Chemical films can also accumulate on turbidity sensor lenses, altering the apparent turbidity. Examples include tannin-based compounds sourced from swamps and forested catchments.

3.2.3 Inhibitors

Turbidity sensors deployed in situ for continuous monitoring shall include a mechanism for continuously inhibiting lens fouling.

Mechanisms may consist of a:

- mechanical wiper
- ultra-sonic vibrator
- micro water-jet
- micro bleach-jet, or
- high pressure air jet.

Note: Lens fouling may also be inhibited by specialised, factory-applied polymer coatings.

3.3 Field Validation Measurements

3.3.1 Purpose

Validation measurements involve using an independent instrument to make concurrent measurements of the turbidity of the water passing beside the in situ turbidity sensor.

The purpose of validation measurements is to check that the in situ sensor remains in calibration; thus, validation shall be repeated at regular intervals through the duration of the instrument deployment. The independent instrument shall meet the same standards in terms of instrument characteristics and calibration.

3.3.2 Basic Options

There are two acceptable methods for regular validation monitoring.

The preferred method is using a calibrated portable turbidity instrument (conforming to ISO 7027) in the field to:

- measure turbidity directly, or
- the turbidity of water samples.

The other method involves transporting water samples to the laboratory where the samples' turbidity is measured with a laboratory instrument (also conforming to ISO 7027).

The laboratory approach:

- removes the need to carry formazin standard stock solutions to the field for calibration of portable instruments
- enables multiple analysis of samples, which ensures greater reliability (repeatability) in the validation result, and
- enables the same sample to be analysed for suspended sediment concentration (SSC).

3.3.2.1 Direct Turbidity Measurements

Direct measurements of turbidity made for validation purposes with the portable instrument shall be:

- made as close as practicable to, and within 1 metre of the in situ turbidity sensor, and
- taken at the time of the data-logger reading.

3.3.2.2 Water Sampling

Water samples collected for validation shall be:

- collected as close as practicable to, and within 1 metre of the in situ turbidity sensor
- collected either by hand into a bottle or a DH48 water sampler, or with an automatic sampler
- at least 100 ml in volume
- taken at the time of the data-logger reading, and
- analysed within 48 hours of sampling.

When collecting water samples, it is necessary to:

- be alert for and avoid turbidity gradients between the sampling location and the in situ sensor.
  Such gradients can develop as a result of incomplete mixing of nearby sources of turbidity, such as a culvert or tributary.
- record the sampling time to the nearest minute, and
  Ensure the time-keeper's watch is cross-checked against the clock on the in situ turbidity sensor.
- clean the lens on the turbidity sensor, and note the time of this action.

Note: Collecting samples and cleaning the sensor lens can stir-up fine sediment, temporarily increasing the turbidity. It is important that the matching turbidity taken from the in situ sensor is recorded several minutes after these activities.

3.3.2.3 Laboratory Analysis

If the water samples are to be analysed for turbidity in the laboratory, they shall be:

- transported as soon as practicable to the laboratory
- stored in a refrigerated, dark space, and
- analysed for turbidity within 48 hours of field collection.

Note: In sunlight and warm temperatures, algae can grow quickly in sample bottles, increasing the turbidity above what it was in the field.

3.3.3 The Independent Turbidity Instrument

The independent turbidity instrument, whether it is field-portable or laboratory-based, shall meet the required ISO 7027 Standard in terms of instrument type and calibration against the formazin standard. For more information, see Section 2: 'Turbidity Instrumentation'.

3.3.4 Laboratory Analysis of Validation Samples

The method of laboratory analysis is described in the ISO 7027 Standard and is not duplicated in this document. Users shall consult this Standard for detailed information on the procedure.

3.3.5 Collection Frequency of Validation Data

Validation samples/measurements shall be collected at least once every month and whenever the sensor is serviced.

Ideally, a validation sample/measurement shall be undertaken before and after any servicing of the sensor; for example, when cleaning the lens of biofouling. If this is not practical, then a sample/measurement shall be collected after the servicing.

Note: Measurements associated with sensor servicing often provide data helpful for editing the sensor record.

In addition, a range of validations shall be obtained at least once per year during a run-off event in which the turbidity range exceeds 100 FNU.

If the purpose of the turbidity monitoring is to provide a surrogate record of suspended sediment concentration, a corresponding set of sediment samples should be collected during this event and analysed for suspended sediment concentration.

Note: Complex catchment responses during run-off events may require targeted sampling to capture multiple turbidity peaks associated with suspended sediment contributions from different tributaries.

3.3.6 Multiple Use of Turbidity Validation Samples

Water samples may also be required to establish calibration relationships between turbidity and suspended sediment concentration. These samples will all require laboratory analysis.

The same sampling considerations and sample treatments as described in subsection 3.3.2: 'Basic Options' apply if these samples are also to be analysed for turbidity and used to validate the in situ turbidity sensor.

Note: Samples collected for other purposes may have additional sampling constraints to those required for turbidity validation.

Note: While the respective Standards for laboratory analysis of turbidity (ISO 7027) and suspended sediment concentration (ASTM D-3977-97, see 'Annex B') strictly require collection of separate duplicate samples for each analysis, in practice the one sample may be used for both analyses providing:

- *the turbidity analysis is undertaken first*
- *the aliquot extracted for turbidity measurement is returned to the original sample prior to analysis for suspended sediment concentration, and*

- *the volume of any wash-water added in the process of returning the aliquot to the original sample is accounted for in the calculation of suspended sediment concentration.*

An example situation is when samples have been collected by auto-sampler during a run-off event in which turbidity and suspended sediment concentration changed rapidly.

3.3.7 Clear-Water, Zero-Point Validation of the In situ Sensor

Once per year, the field sensor shall be removed from its mounting hardware, cleaned thoroughly, and used to measure the turbidity in a black plastic container of clear distilled water (with near-zero turbidity, as measured with a calibrated portable or laboratory instrument).

The comparison shall provide sensor values within ± 1 FNU.

Note: Those performing this test should be familiar with the clear-water sensing range of the particular sensor in use, and ensure that the clear-water container is sufficiently large and the sensor far enough away from the container walls that no back-scattering off the walls is detected.

Note: Most modern sensors should not demonstrate zero offset characteristics due to lens degradation. This is because most utilise sapphire lenses or other methods to prevent degradation due to abrasion by suspended sediment.

3.4 Office Procedures for Validation of Turbidity Measurements

The office procedures involve:

- extracting the turbidity records from the in situ sensor that are concurrent with the validation measurements
- plotting both sets of results as well as their differences on working plots (see Figure 3, page 15)
- deciding if the in situ sensor requires recalibration, and
- assigning quality codes to the time-series data.

3.4.1 Extracting the Concurrent In-Situ Turbidity Value

The concurrent turbidity values that match with the validation sample shall be extracted from the record after the time of the validation sample collection and sensor cleaning, and allowing time also for any fine sediment stirred up by these activities to have settled or drifted away.

Note: The time of the concurrent in situ measurement is best judged by inspection of the in situ turbidity record, whereon any signals due to cleaning and silt stirring can be identified and avoided. It is important not to have too long a time lag if the background turbidity is changing.

3.4.2 Working Plots

A working scatter-plot shall be made that relates the validation turbidity measurements to the concurrent turbidity records from the in situ sensor. This shall include the clear-water zero-point results. This plot shall be extended as data becomes available and shall cover the full range of the in situ sensor.

Two working time-series plots (or run-charts) shall be made and extended as data becomes available:

- one showing the difference between the in situ sensor and the validation measurement less than 20FNU, and
- the other showing the percentage difference relative to the validation measurement equal to or greater than 20 FNU.

Note: The in situ sensor record shall be inspected immediately before and after the time of the validation sample collection. Any difference shall be noted, related to the effect of cleaning the in situ sensor lens, and, as appropriate, used in subsequent data editing. The record immediately after the lens cleaning shall be the one plotted against the validation measurement.

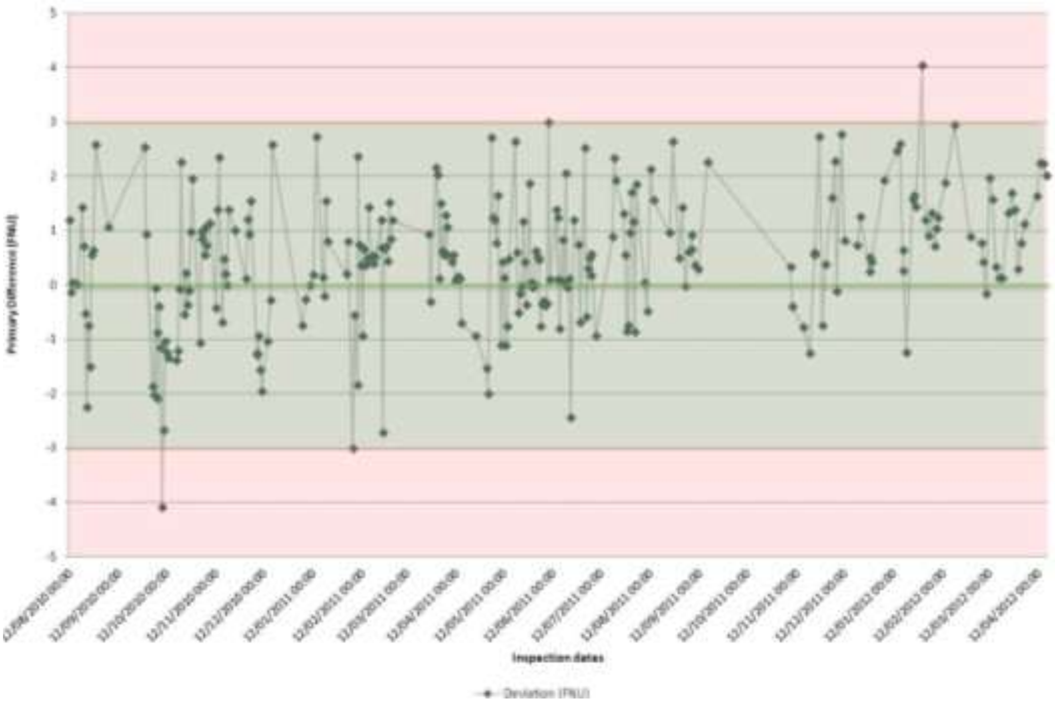


Figure 3 – Time-series (or run-chart) of arithmetic difference between sensor turbidity and validation measurements

Values are shown for which the sensor turbidity is less than 20 FNU.
The acceptable range, within ± 3 FNU, is shaded in green.

3.4.2.1 Evaluating the Deviation

The validation data points shall be evaluated in terms of any systematic (in time) deviation from the 1:1 line.

Separate criteria apply for turbidity measurements less than and greater than or equal to 20 FNU.

The validation shall be considered unacceptable when:

- for turbidity values less than 20 FNU, the deviation exceeds ± 3 FNU for at least three consecutive measurements
- for turbidity values greater than or equal to 20 FNU, the deviation exceeds ± 15% of the validation measurement for at least three consecutive measurements.

Note: It is recommended that sensor validation performance decisions are not based on laboratory-analysed samples with turbidity values exceeding 750 FNU. This is because the dilution procedure required to measure these samples with laboratory instruments reduces the accuracy of the result.

3.4.2.2 Validation Check Failure

If the validation data plot is consistently outside the acceptable ranges, then the data that have been collected and the calculations that have been made, shall be:

- evaluated, and
- the evaluation shall be reviewed.

If the validation check still fails, the field sensor shall be recovered and recalibrated or returned to the manufacturer for repair/recalibration.

3.4.2.3 Assigning Quality Codes

The validation data shall also be used to assign quality codes to the time-series turbidity data.

For a list of codes, see 'Quality Codes – Turbidity ', earlier in this document (page xi). The codes for a particular phase of data collection shall be assigned according to the extent of deviation for the 1:1 line in Figure 2 (page 8).

4 Data Processing and Preservation

In this Section

This section contains information on the office-based processing of turbidity data. It includes:

- editing required to identify and correct corrupt segments of the raw data
- replacing missing record
- assigning quality codes
- archiving turbidity records
- collating metadata, and
- performing quality assurance.

4.1 Data Editing

Editing is required to correct data that are corrupt.

The first step is to identify suspect data and the probable cause. The correction procedure depends on the cause of the problem, its duration, and when it occurs during a high flow or turbidity event.

Corrected data shall be inserted into the record at the same time interval at which the raw data were collected.

4.1.1 Recognising and Managing Corrupt Turbidity Data

Corrupted turbidity data can be caused by any of the following:

- electronic transients
- macro-fouling
- biofouling
- chemical fouling
- sensor burial
- sensor exposure
- over-ranging, and/or
- chemical fouling.

4.1.1.1 Electronic Transients

Unexpectedly high, solitary data values (commonly termed 'spikes') can occur due to electronic transients or floating debris passing within range of the sensor's light source. They are easily recognised, and can be isolated within a record using numerical filtering.

Spikes shall be removed from the record either by manual editing or by use of a numerical filter. The removed value may be replaced with one interpolated between adjacent data values.

4.1.1.2 Macro-Fouling

Macro-fouling occurs when solid objects are caught within or otherwise invade the sensor's detection volume. Examples include leaves or branches snagged on the sensor or its housing, loitering fish, or progressively growing in-stream vegetation (often termed 'macrophytes'). The effects are manifest in the record as continual or erratic spikiness usually within a phase of generally low turbidity.

Macro-fouling during base-flow conditions shall be removed from the record either by manual editing or by use of a minimum-value-type numerical filter. This low-pass filter can be applied as 3-hour (QC 500), 6-hour (QC 400) or 12-hour (QC 300) time steps. The removed values may be replaced with values interpolated linearly between adjacent retained data values. The remaining data may require correction or adjustment to the post-maintenance data and/or to validation data.

Macro-fouling during high-flow events shall be edited in the same way, providing that the outline of a sensibly-shaped turbidity hydrograph appears from the minimum value filtering. If it does not, then the macro-fouled data shall be discarded.

If persistent macro-fouling is detected, the sensor and its environs shall be inspected and any in-stream or bankside vegetation or other clutter from the sensor's field of view shall be removed.

Note: Bankside vegetation shall be maintained in a state as near to constant as possible.

4.1.1.3 Biofouling

Biofouling occurs when an algal film grows on the sensor lens. This tends to progressively increase the backscatter signal. The effect is often compounded by fine sediment settling in the algae.

A typical manifestation is to see the record begin to:

- ramp up above the expected base-flow turbidity levels, and
- get progressively more erratic or noisy.

Such signs should disappear when the sensor lens is cleaned.

Data during base flows showing evidence of biofouling shall be cleaned in the following ways:

- Fit a decay curve through the span of suspect data (providing it is below 20 FNU).
- Significantly affected data shall have a median filter (spanning an hour of record) applied before the application of the decay function.
- The removed values may be replaced with values interpolated linearly between corrected values (QC 400).
- Data shall be filed to the nearest whole FNU.

Data collected during the recession periods of high-flow events shall be edited in the same way providing the:

- outline of a sensibly shaped turbidity hydrograph appears after the use of a minimum-value-type numerical filter, and

This low-pass filter can be applied as 3- (QC 500), 6- (QC 400) or 12-hour (QC 300) time steps.

- the batch of suspect data terminates at a time when the sensor lens is known to have been cleaned fully.

If either condition is not met, then the fouled data shall be discarded.

Partially biofouled data collected during the rising stages of high-flow events shall be examined for an underlying turbidity hydrograph. The data shall be discarded if this is not apparent.

Note: Biofouling should disappear when the lens is cleaned.
Partial lens cleaning may occur naturally during floods because of the drag from high velocities, increased turbulence and abrasion by suspended sediment.

4.1.1.4 Chemical Fouling

Fouling can also occur when a chemical film accumulates on the sensor lens; for example, from tannins in the water.

Chemical fouling should disappear when the lens is cleaned.

Chemically fouled data shall be edited similarly to biofouled data.

4.1.1.5 Sensor Burial

Sometimes, sediment deposition during floods lifts the streambed into the turbidity sensor's field of view – or may even bury the sensor. This is manifest in the record as persistent, exceptionally high or over-range turbidity readings.

If sensor burial is suspected (e.g. on telemetered record):

- the site shall be inspected as soon as possible, and the sedimentation cleared or the sensor raised
- the affected data shall be removed from the record, and
- the removed data may only be replaced with data from another source or synthetic data (QC = 300).

Note: If sensor burial occurs on a regular basis, the sensor shall be shifted to a location less prone to sediment accumulation.

4.1.1.6 Sensor Exposure

Sensors may sometimes become exposed at low water levels. The manifestation of exposure varies with the sensor type (e.g. a zero value may be returned).

The person processing the data shall be alert to this possibility by:

- being familiar with the signal returned by the sensor when it is not submerged, and
- knowing the level of the sensor relative to the datum of the nearby water-level gauge.

Note: Sometimes, turbidity sensors may be deployed purposely above the base-flow water level so that they are only immersed during high-flow events. This practice is sometimes *followed to mitigate severe biofouling at sites where the focus of data collection is on high-flow events; for example, for monitoring suspended sediment load.*

4.1.1.7 Over-Ranging

Over-ranging occurs when the sensor encounters a turbidity reading greater than it is designed and calibrated for. The value returned varies according to the type of instrument, for some instruments, an error code is returned.

Over-ranging may be difficult to detect in the record of some instruments, since turbidity values read beyond the instrument range may actually show as lower turbidity values (this occurs because of excessive absorption of the emitted light pulse). This behaviour can be manifest during high-flow events as a dip in the turbidity record under the true turbidity peak as shown in Figure 4 (page 28).

When processing data it is necessary to be:

- familiar with how the turbidity sensor responds outside its calibrated range, and
- alert for false readings around the top end of the instrument's range.

Over-range data must be replaced with data from another source or with synthetic data (QC = 300).

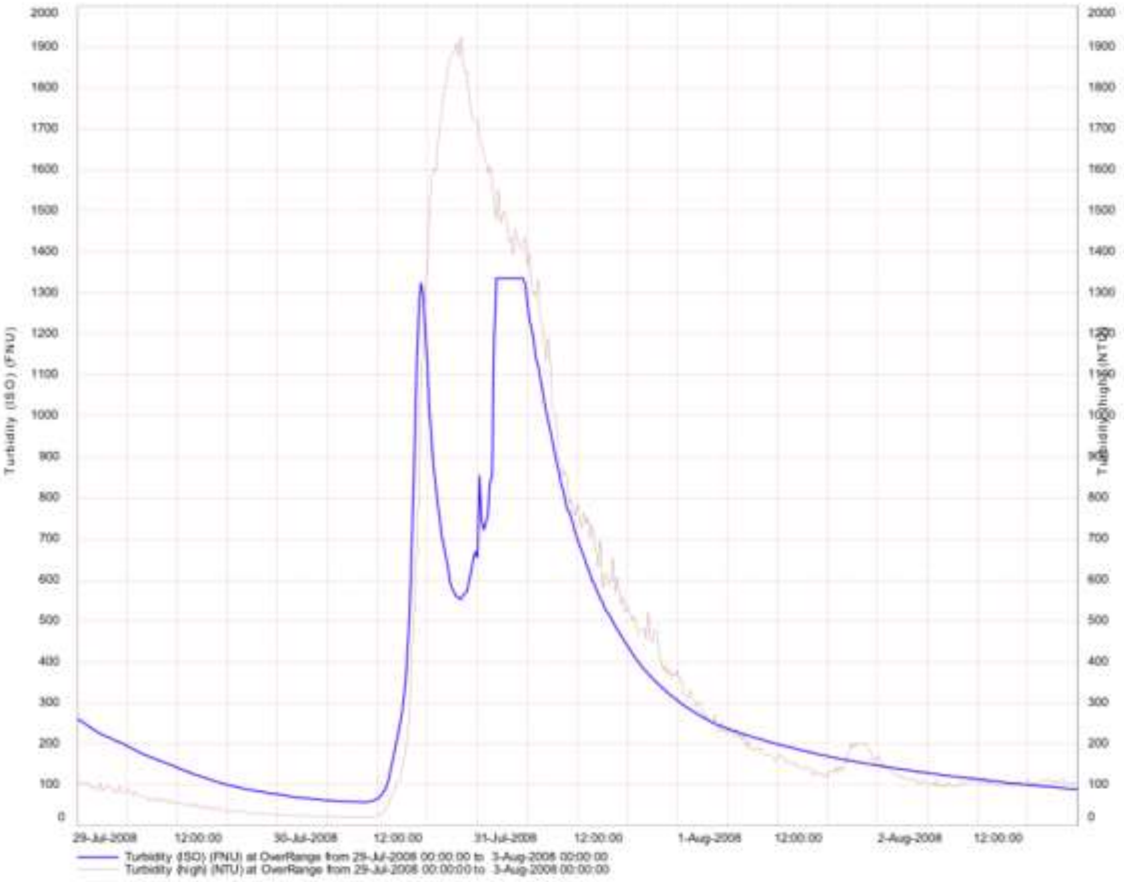


Figure 4 –Characteristic turbidity dip owing to over-ranging on a sensor with a maximum range of 1300 FNU (blue line)

The true turbidity peak is recorded by a higher range sensor (brown line).

4.2 Replacing Discarded Record

Segments of turbidity record discarded during editing shall be replaced, if practicable, with data from one of several potential sources. These are, in order of preference:

- turbidity records from a backup or supplementary sensor at the same location
- turbidity values measured in the laboratory from water samples collected at the same location, or
- synthetic turbidity records generated from a rating relationship between turbidity and discharge.

Replacement data shall be:

- inserted into the record at the same time interval at which the raw data were collected
- assigned the appropriate quality code, and
- accompanied by a processing comment that shall be filed with the data to provide information on the synthetic record or supplementary source.

4.2.1 Backup Turbidity Records

Records from a backup turbidity sensor at the same location shall be used by preference.

The backup sensor may be in situ or it may be connected into a water circuit that is continuously pumped from and returned to the river or stream.

By preference, the backup sensor should meet the ISO 7027 instrumentation standard.

If this is not the case, then to optimise compatibility between the backup record and the primary record:

- recent overlapping periods of data from both sensors shall be used to compile a relationship between the backup and primary sensor over as wide a range of turbidity as practicable
- an appropriate function shall be fitted to this relationship, and
- this function shall be used to transform the backup data to values compatible with the primary sensor.

Note: Locally weighted scatter-plot smoothing techniques, which fit a continuously varying function over the turbidity range, are the preferred method of fitting such correction functions. While simple regression techniques may be used to derive the correction function, care should be exercised to ensure that a single function is appropriate over the full range of data (e.g. it does not produce negative turbidity values).

Note: A suspended sediment sensor may also be used to provide a backup record. These sensors usually also measure light transmission or scattering but their output is calibrated directly to suspended sediment concentration. When used to provide a replacement turbidity record, these data shall be treated the same way as data derived from turbidity sensors that do not meet the ISO 7027 Standard.

4.2.2 Water Sample Turbidity Data

Water samples may be collected from the turbidity-monitoring site during the period of discarded turbidity data providing:

- the samples are handled and analysed
  For more information, see Section 3: 'Data Acquisition'.
- the sampled time-series record has adequate temporal resolution to capture the expected form of the turbidity hydrograph, and
- turbidity peaks are well resolved.

Water samples collected under the provisions listed above may be:

- analysed for turbidity in the laboratory, and
- used to replace the discarded record.

For example, water samples collected from the turbidity-monitoring site as validation measurements or supplementary calibration samples may have been collected by auto-sampler over a high-flow event.

4.2.3 Synthetic Data Generated from Rating Relationships

If auxiliary turbidity measurements of adequate temporal resolution are not available, then the discarded data shall be replaced with synthetic data.

Synthetic turbidity data are generated from the discharge record using a 'rating' relationship between measured turbidity and discharge at the measurement site.

4.2.3.1 Characteristics of Turbidity-Discharge Relationships

Relationships between turbidity and discharge typically show substantial variability over time and from site to site. This variability stems largely from the dependence of turbidity on the concentration and characteristics (mainly grain size) of suspended material, which can vary (at a given discharge):

- within high-flow events
- between events
- seasonally
- over multi-year periods, because of legacy effects of large, catchment-disturbing events (e.g. rainstorms, earthquakes), and
- from catchment to catchment

Within-event variability can be:

- relatively simple, or
  For example, higher values at a given discharge on rising stages compared to on recessions, which produces a 'loop' rating over the event.
- complex.
  For example, when the contributions of suspended material from tributaries upstream arrive at different times, which produces a complexly looping rating over an event.

4.2.3.2 Developing Turbidity-Discharge Rating Functions

The person processing the data shall be familiar with typical patterns of variability in the turbidity-discharge relationships at each site before selecting an appropriate form for the rating function.

The rating form may be one or more of the following:

- a simple function that is stationary in time
- a function that varies according to the slope and curvature of the discharge hydrograph
- a function that captures event-based loop ratings
- a function that varies seasonally, and/or
- a function that has a time trend.

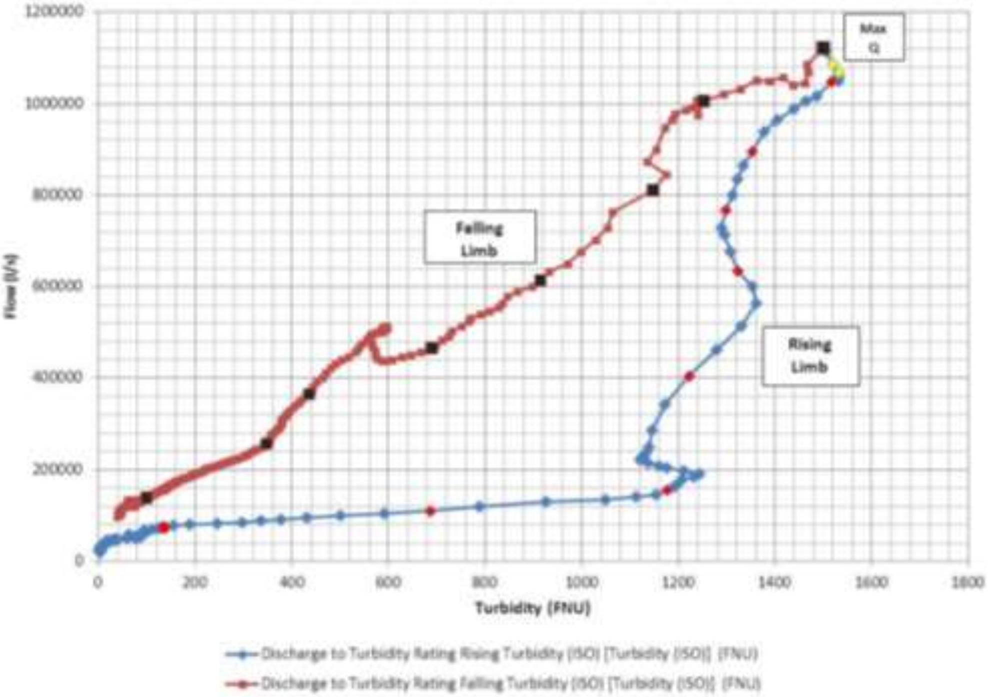


Figure 5 – Example of a relatively simple within-event loop rating between turbidity and discharge

Turbidity values measured at a given discharge on the rising limb of a hydrograph are larger than the turbidity values on the falling limb at the same discharge.

4.2.3.3 Loop Rating Characteristics

Turbidity and discharge data series shall contain sufficient detail to capture loop-rating characteristics. An example loop-rating is shown in Figure 1Figure 5.

4.2.3.4 Locally Weighted Scatter-plot Smoothing Techniques

Locally weighted scatter-plot smoothing techniques, which fit a continuously varying function over the turbidity range, are the preferred method of fitting such correction functions. While simple regression techniques may be used to derive the correction function, care should be exercised to ensure that a single function is appropriate over the full range of data; for example, it does not produce negative turbidity values.

4.2.3.5 Rating Functions

When used to create synthetic data, rating functions may need to be extrapolated beyond the range of discharge for which they were derived. The person processing the data shall:

- be aware of the calibrated range of the rating function, and
- check the sensibility of any synthetic data derived from rating extrapolation.

4.2.3.6 Turbidity-Discharge Rating

The turbidity-discharge rating shall be developed using reliable segments of the turbidity and discharge records.

4.2.3.7 Case of Data Missing Due to Sensor Over-Ranging

When turbidity data have been discarded only across the peak of an event because the turbidity sensor has over-ranged, generate synthetic turbidity data.

4.2.3.8 Generating Synthetic Turbidity Data by Rating Relationship

Follow these steps to generate synthetic turbidity data for an event.

1. **Plot edited turbidity versus discharge**

   Note: Use data points linked in time sequence. For example, see Figure 6 (page 26).

2. **Look for a loop truncated at the maximum turbidity range.**

3. **Extend the two truncated ends.**

   Note: Extend along their tangents until they intersect the peak discharge on the hydrograph.

4. **Calculate the turbidity at the peak discharge.**

   Note: Do this by weighting the turbidity values for the extrapolated rising and falling limbs at the peak discharge by the relative durations of lost record on the rising and falling limbs.

5. **Generate a rising limb rating function.**

   Generate this as the line between the last recorded turbidity-discharge point on the rising limb and the peak discharge point.

6. **Generate a falling limb rating function**

   Generate this as the line between the peak discharge point and the first turbidity-discharge point in the resumed falling limb record.

7. **Generate the synthetic turbidity data.**

   Use the rating functions to generate the synthetic turbidity data from the discharge record.

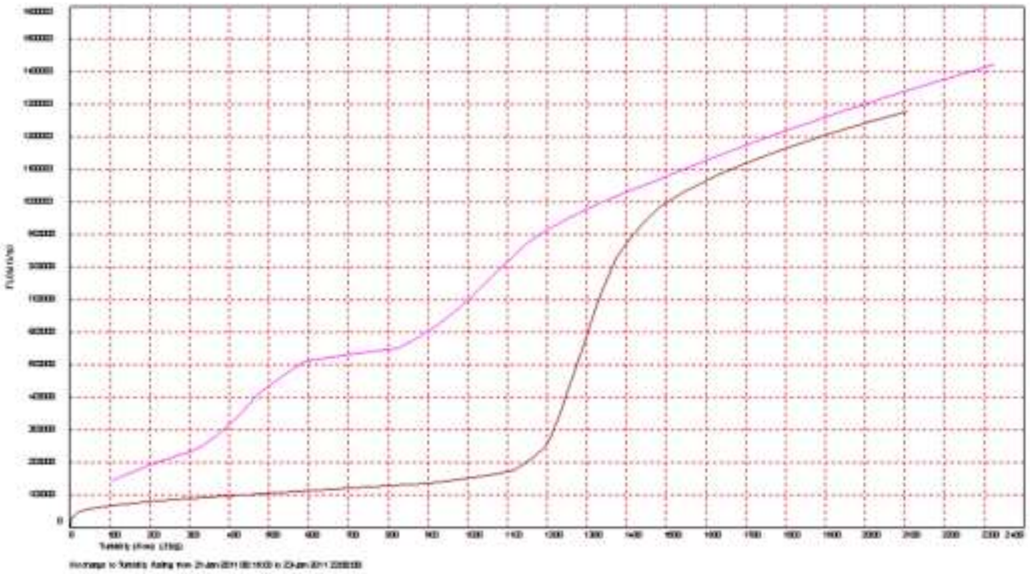


Figure 6 – Approach to use when generating synthetic turbidity data to replace data lost by sensor over-ranging

The brown curve is for rising limb of hydrograph. The pink curve is for falling limb.

4.2.4 Synthetic Data is Unavailable

It may not be possible to generate synthetic turbidity data because:

- the water discharge (or other surrogate measurement) record is missing, or
- the available turbidity record is either too short or covers too small a range in turbidity to provide a satisfactory rating relationship.

In the former case, the turbidity record shall remain as missing data and be assigned quality code QC 100.

In the latter case, if practicable, the data replacement shall be delayed until adequate rating relations become available. Until the data become available, the turbidity record shall remain as missing data and shall be assigned quality code QC 100.

4.3 Assigning Quality Codes

Before editing, all turbidity time-series records shall be assigned a quality code consistent with the results of field validation measurements. For more information, see 'Quality Codes – Turbidity ' (page xi). These may be degraded during the editing process:

Data Editing	Reference	Constraint	Maximum Quality Code
Electronic Transients	4.2.1.1. p.24	Data segments have been retained but spikes shall be removed from the record, replaced with one interpolated adjacent data value.	600
Macro-Fouling	4.2.1.2.	Data segments have been retained but have been filtered or otherwise adjusted to correct for	400

	p.24	macro-fouling	
Biofouling	4.2.1.3. p.25	Data segments have been retained but have been filtered or otherwise adjusted to correct for biofouling	400
Chemical Fouling	4.2.1.4. p.26	Data segments have been retained but have been filtered or otherwise adjusted to correct for chemical fouling	400
Sensor Burial	4.2.1.5. p.26	Data segments have been removed and replaced with data from another source or synthetic data	300
Sensor Exposure	4.2.1.6. p.26	Data segments have been removed and replaced with data from another source or synthetic data	300
Over-Ranging	4.2.1.7. p.26	Data segments have been removed and replaced with data from another source or synthetic data	300
Backup Turbidity Records	4.3.1. p.28	Data segments filled from backup or supplementary sensor at the same location: Sensor meets IS0 7027 Sensor does not meet ISO 7027	 500 200
Water Sample Turbidity Data	4.3.2. p.29	Turbidity values measured in the lab from water samples collected at location at temporal resolution to capture form of turbidity hydrograph	300
Synthetic Data Generated from Rating Relationships	4.3.3. p.29	All edited data segments that have had data replaced with synthetic data Data segments that have been discarded and for which replacement with synthetic data is pending	300 100
Synthetic Data is Unavailable	4.3.4. p.32	Data segments that have been discarded and will not or cannot be replaced with synthetic data	100

4.4 Preservation of Record

Turbidity records shall be archived at even time intervals that match the raw logging interval from the field.

Every turbidity record shall be archived with a synchronous quality code.

4.4.1 Metadata and Associated Data

4.4.1.1 Turbidity Sensor Metadata

Metadata for the in situ turbidity sensor shall be filed as electronic ‘comments’ with the data archive.

The metadata shall include the:

- the sensor model, manufacturer and serial number
- the instrumentation standard; for example, ISO 7027
- the sensor range, as deployed
- characteristics of the on-board anti-fouling mechanism
- the date, laboratory, and identification number of the sensor calibration against formazin standards

  Note: All calibration information shall be updated with each re-calibration.
- the date and time of deployment
- the data-logging interval and a statement that instantaneous data are being logged
- any additional statistics of turbidity that may also be logged

  For example, 1-minute average.
- the method employed for collecting validation data, and
- the date and time of any relocating of the sensor and the reason for any relocation.

4.4.2 Site Information

4.4.2.1 During Site Setup

The following information shall be collected from the deployment site at set-up:

- photographs of the deployed instrument, showing detail and bankside context, and
- the level of the sensor relative to the local staff gauge datum.

4.4.2.2 During Validation

At times of validation measurements/sampling, the following information shall be collected:

- observations of changes in the composition of the bed material of the channel (with estimated percentages of boulders, gravel, sand, mud and bedrock), and
- observations of the level of the bed under the sensor.

4.4.2.3 Annually

At least once per year, photographs of the deployment site shall be collected.

Note: The purpose of the photos is to capture, for example, changes and growth in bankside vegetation.

4.4.2.4 Archiving

Site information shall be:

- archived in hard copy, and
- archived electronically.

The monitoring authority shall retain the archives.

The archiving procedures, policies and systems of the archiving body shall consider:

- future data-format changes

- off-site duplication of records, and
- disaster recovery.

4.4.3 Running Validation and Calibration Charts

Copies shall be kept of all running plots and control charts used to:

- validate the turbidity sensor's calibration
- develop relationships between the primary turbidity sensor and any non-standard sensor used for back-up purposes
- develop relationships between turbidity and water discharge, and
- develop relationships between turbidity and suspended sediment concentration.

4.5 Quality Assurance

The information on quality assurance below is considered to be best practice. All agencies should implement a standard methodology for data audit and review.

Note: This is to ensure standardisation of data sets that enable meaningful analyses and comparison of turbidity and suspended sediment concentration within regions, across regions and nationally.

4.5.1 Audit Cycle

Quality assurance procedures shall include an audit of the data:

- at a frequency appropriate to the organisation's and users' needs, and
- as defined by the organisation's quality management system documentation or documented procedures.

This work shall be undertaken by a suitably trained and experienced practitioner.

Unaudited data that is released for use shall be identified as unaudited.

Audit reports may cover more than one turbidity record or parameter.

4.5.2 Minimum Audit Report Requirements

As a minimum, analyses and information required for an audit report for turbidity sites shall cover:

- site deployment metadata details including catchment (if applicable) and site details
- comments and quality coding attached to the records
- missing or over-ranged data
- data summary statistics, and
- data plots.

4.5.2.1 Catchment and Site Details

The following shall be included in the audit report:

- a site details summary, and
- a location map, with locations of in situ turbidity sensors identified.

The site details summary shall:

- identify the river and catchment
- identify associated water-level and discharge sites
- identify associated auxiliary sensors, and
- for each turbidity record, identify:
  - the period of record covered
  - the site name and number
  - the map reference
  - the turbidity sensor type, and
  - the turbidity sensor range (in FNU)
  - the date of most recent calibration against formazin standard solutions.

4.5.2.2 Comments and Quality Coding

The following shall be included in the audit report for each turbidity record:

- a copy of the filed comments for the record total record period
- an analysis of the quality codes filed with the data, which shall include:
  - a pie graph or table showing the time-proportion of the record by quality code, and
  - if site discharge data is available, a bar graph or table showing the proportion of record by discharge band and quality code.

4.5.2.3 Missing or Over-Ranged Data

The following shall be included in the audit report for each turbidity record:

- a list of periods of missing record (QC 100)
- comments as to whether these periods included freshes and floods, and
- a list of all occasions when the raw turbidity equalled or exceeded the calibrated range of the sensor.

4.5.2.4 Data Summary Statistics

Tables of monthly mean, minimum, and maximum turbidity shall be included in the audit report for each turbidity record.

4.5.2.5 Data Plots

The following shall be included in the audit report for each turbidity record:

- time-series run-plots showing the deviation of recorded turbidity from validation measurements of turbidity for the total record period, and
- if discharge records are available for the station, a scatter-plot of recorded turbidity versus discharge for the review period.

Note: Turbidity and discharge may both be plotted to a logarithmic scale.

4.5.3 Other Requirements

4.5.3.1 Outputs

Recommended report outputs include:

- a hard copy report,
- an electronic report, or
- at a minimum, an electronic document that only identifies which record periods have passed audit.

4.5.3.2 Audit Certification

The completed audit shall contain the name and signature of the auditor and the date that the audit was completed.

Annex A – List of Referenced Documents

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Annex B – At-Site Turbidity to At-Site Suspended Sediment Concentration

Preamble for Annex B and Annex C

In rivers and streams, a typical purpose of turbidity monitoring is to provide a surrogate record of suspended sediment concentration (SSC).

This is often combined with a discharge record to determine the suspended sediment load, which is then integrated over a span of record to give the suspended sediment yield.

The conversion of turbidity to suspended sediment load is a two-step process:

- converting the at-site turbidity at the sensor location to at-site suspended sediment concentration, and
- converting the at-site SSC to the discharge-weighted, cross-section mean suspended sediment concentration.

The second step is necessary because suspended sediment is usually not perfectly mixed over the cross-section. The degree of mixing depends on the intensity of turbulence across the section (which typically varies with discharge) and the size grading of the suspended sediment load. Mixing is greatest for clay and silt sediment grades but may be poor for suspended sand.

For both steps it is necessary to develop empirical calibration functions by collecting water samples and analysing them for suspended sediment concentration.

In This Annex

This annex outlines procedures for converting turbidity records to suspended sediment concentration records at the point location of the turbidity sensor. In particular, it covers:

- collecting calibration water samples
- laboratory procedures for analysing SSC
- developing calibration functions between turbidity and SSC
- applying calibration functions, and
- documenting calibration functions.

Collecting Calibration Water Samples

Where to Sample

Water samples collected for the purpose of relating turbidity to suspended sediment concentration shall be collected as close as practicable to the lens of the turbidity sensor, ideally within 1 m of the sensor.

How to Sample

By preference, water samples shall be collected using an automatic pumping sampler (auto-sampler) that has its water inlet nozzle fixed in location beside the turbidity sensor. Auto-samples shall:

- be collected on a one-sample, one-bottle basis
- be at least 300 ml in volume
- have their time of sampling recorded on a data logger (preferably the same logger that records the turbidity record), and
- be preceded by a purge cycle.

Alternatively, a sample may be manually collected using either a handheld bottle or a specialised handheld sampling device; for example, a DH-48 suspended sediment sampler held stationary beside the sensor. For more information, refer to Hicks and Fenwick (1994).

Note: An auto-sampler is preferred because:

- *its location is fixed*
- *it employs an identical sampling procedure for all samples*
- *it can be scheduled to sample through all conditions, night and day, and*
- *it can sample safely during floods.*

Note: Commonly available auto-samplers are limited to a 6-m lift between the intake 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, providing mains power is available at the site.

When and How Often to Sample

Samples for suspended sediment concentration calibration shall be collected:

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

Scheduling Auto-Samples

When using an auto-sampler to collect calibration samples during freshes and floods:

- only one auto-sample shall be collected into each sample bottle
- samples shall ideally be collected for as long as the stage (water level) exceeds a threshold level, and
    - by preference, samples shall be scheduled on a flow-proportional basis, or
    - samples may be collected at fixed time intervals.

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*
- *helps ensure that samples are collected around flood peaks.*

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

Note: Most auto-samplers have 24 to 28 bottles available. Site-specific simulations are helpful for optimising auto-sampling thresholds.

Data Collection Plan

A data collection plan shall be developed annually that identifies the range of turbidity over which sampling for the coming year should focus. This shall be based on information derived from the calibration data collected to date.

Analysing Suspended Sediment Concentration

Water samples shall be analysed in the laboratory for suspended sediment concentration using the ASTM Designation: D-3977-97 standard procedure (ASTM, 1997).

This procedure may employ one of the following methods:

- filtration method or
- evaporation method.

Whichever method is used, the analysis shall be undertaken on the whole of the water sample.

Note: Sometimes, SSC analyses have been undertaken on sub-samples drawn from the original sampling container. Procedures that do this include the Total Suspended Solids method (EPA, 1999) and shall be avoided because they can deliver erratic, biased results. This stems from differential settling of different size fractions of the suspended load within the sample bottle during the sub-sampling process. For details, refer to Guo (2006).

Note: Sometimes, it may be desirable to derive separate concentrations of the sand and mud fractions of the suspended load. In this case a variant of the filtration approach is used that involves wet-sieving the sample prior to filtration. This procedure is described in ASTM D-3977 Test Method C—Wet-sieving-filtration *(ASTM, 1997).*

Associated Observations

Any unusual features of the water samples shall be noted; for example, unusually high sand or organic content, unexpectedly small water volume, or evidence of leakage such as a loose cap.

Reporting Units

SSC results shall be reported as mg/l.

Note: Sometimes, SSC analyses, such as from the evaporation method, are reported as parts per million (ppm) by weight. These are equivalent to mg/l up to concentrations of approximately 12,000 mg/l. This extends beyond the typical range of turbidity sensors. The equation for converting ppm to mg/l is given below.

Converting Units

The conversion factor, C, for converting ppm to mg/l is:

$$C = (\rho_s \times \rho_w \times 1{,}000{,}000)/(\rho_s \times 1{,}000{,}000 - [(\rho_s - \rho_w) \times ppm])$$

where:

ρ_s = density of sediment, in g/cm^3 (ρ_s typically assumed to be 2.65 g/cm^3)

ρ_w = density of water, in g/cm^3 (ρ_w typically assumed to be 1.00 g/cm^3)

`ppm` = sediment concentration, in parts per million.

Developing Calibration Functions Between Turbidity and Suspended Sediment Concentration

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.

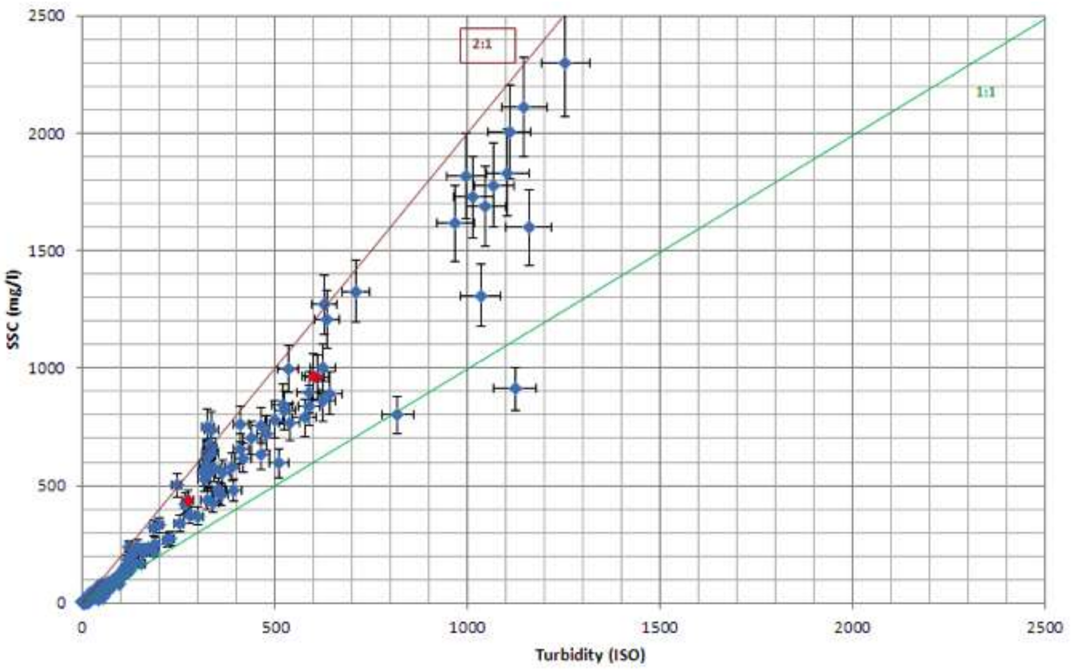

Figure 7 – Example plot of turbidity versus suspended sediment concentration (SSC)

Crosses show uncertainties.

Note how scatter and uncertainty increase as turbidity values and suspended sediment concentrations increase.

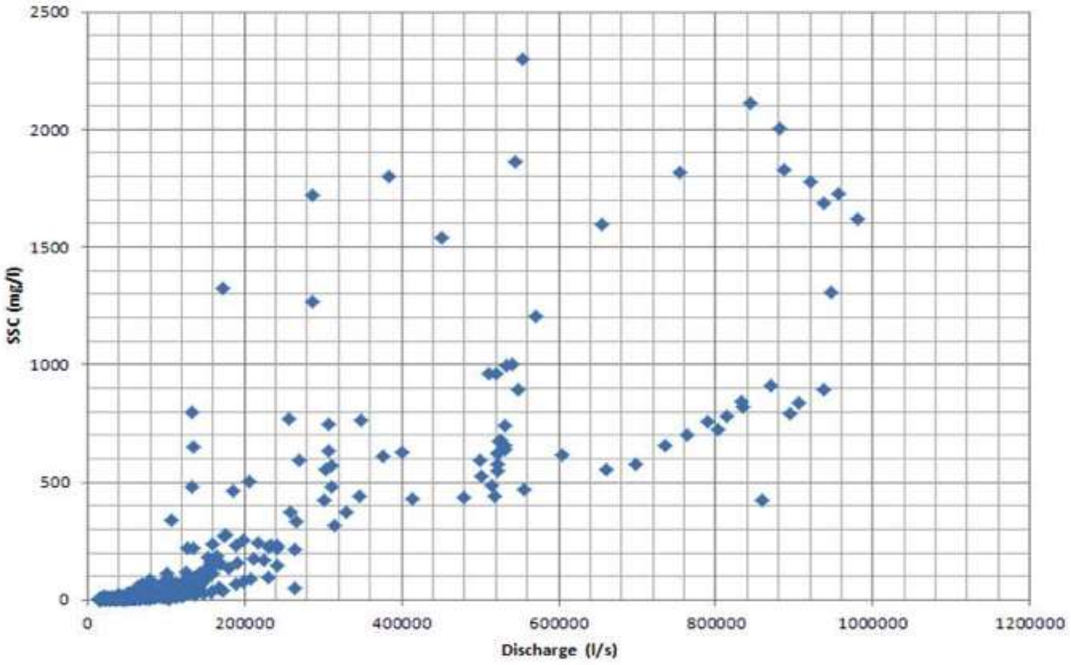

Figure 8 – Example plot of discharge versus suspended sediment concentration (SSC)

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 (r^2), 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.

Applying Calibration Functions

The turbidity-SSC calibration functions shall be used to convert turbidity records to SSC records.

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

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

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

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 (r^2, 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 are 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 C – At-Site Suspended Sediment Concentration (SSC) to Cross-Section Mean SSC Conversion

In this Annex

This annex covers converting at-site suspended sediment concentration (SSC) to cross-section mean SSC. In particular, it covers:

- measuring the cross-section mean SSC
- laboratory procedures for analysing SSC
- developing a calibration function relating at-site and cross-section mean SSC
- applying the calibration function, and
- documenting the calibration function.

Measuring Cross-Section Mean Suspended Sediment Concentration

What to Measure

The objective is to measure the discharge-weighted cross-section mean SSC. This is equivalent to the sum of the suspended sediment load over the cross-section divided by the water discharge.

Accordingly, the following need to be determined concurrently:

- water discharge, and
- suspended sediment load.

Note: In practice, the cross-sectional sediment load is derived by multiplying the discharge-weighted cross-section mean SSC by the cross-section discharge.

How to Measure the Suspended Sediment Load

The suspended sediment load passing the cross-section shall be measured using the suspended sediment gauging procedures detailed in the NIWA *Suspended sediment manual* (Hicks & Fenwick, 1994).

In brief, this requires:

- use of depth-integrating or point-integrating suspended sediment samplers
- sampling at multiple verticals over the cross-section
- combining the results with sub-sectional water discharges to calculate sub-sectional sediment loads, and
- totalling the sediment loads by sub-section.

How to Measure the Discharge

The discharge past the cross-section shall either be:

- gauged using a current-meter or acoustic Doppler velocity profiler
  Refer to NEMS 'Open Channel Flow Measurement – Measurement, Processing and Archiving of Open Channel Flow Data'.
- determined at higher flows from three or four partial section ratings that in sum describe the total sectional discharge, or
- derived from a water level measurement and the current stage–discharge rating function, providing the current rating is known to be accurate to within a standard error of ± 5%.

Note: The method involving partial section ratings requires more effort to establish, but once established, it speeds up the sediment gauging considerably.

Where to Locate the Measurement Cross-Section

The measurement section shall be located:

- near the turbidity monitoring station, and
- at a site that facilitates deployment of the suspended sediment sampling and discharge measurement equipment during both normal and flood flow conditions; for example, a bridge or cableway.

Note: The measurement section shall not be located upstream from the turbidity sensor where a source of suspended sediment enters the river between the section and the sensor.

Concurrent At-Site Water Sampling

At-site water samples shall be collected from beside the turbidity sensor either:

- manually (e.g. using a dip-bottle), or
- (preferable) using an auto-sampler.

Samples shall be collected at least at the beginning and end of each suspended sediment gauging.

Note: If using an auto-sampler:

- *more samples are recommended if the SSC appears to be changing over the duration of the suspended sediment gauging*
- *auto-samples shall be triggered manually, and*
- *only one sample shall be collected per sample bottle.*

Particle Size Data

Replicate depth-integrated water samples collected during the suspended sediment gaugings may be analysed for particle size grading. Particle size grading provides information regarding the likely extent of mixing over the cross-section.

Sampling requirements and analysis procedures for suspended sediment size grading remain to be updated and written into a Standard. In the interim, it is recommended that the procedures in Hicks and Fenwick (1994) be followed.

When and How Often to Measure the Cross-Section Mean SSC

Discharge-weighted cross-section mean suspended sediment concentration (SSC) measurements shall be collected:

- over as wide a range of SSC as possible
- over as wide a range of discharge as possible
- during at least one fresh or flood per year, including on rising and falling stages of the same event, and
- more frequently during the first year that the turbidity sensor is installed, in order to quickly:
  - identify typical characteristics of suspended sediment mixing at the site, and
  - establish an at-site versus cross-section mean SSC calibration function.

Data Collection Plan

A data collection plan shall be developed annually to identify the range of discharge and SSC over which sampling for the coming year should focus. This shall be based on an appreciation of the calibration data collected to date.

Laboratory Procedures for Analysing SSC

Water samples shall be analysed for SSC using the ASTM Designation: D-3977-97 standard procedure (ASTM, 1997, as detailed in Annex B). This procedure may employ the:

- filtration method or
- evaporation method.

Whichever method is used, the analysis shall be undertaken on the whole of the water sample collected.

Note: Sometimes, SSC analyses have been undertaken on sub-samples drawn from the original sampling container. Procedures that do this include the Total Suspended Solids method (EPA, 1999) and shall not be followed because they can deliver erratic, biased results. This stems from differential settling of different size fractions of the suspended load within the sample bottle during the sub-sampling process. For details, refer to Guo (2006).

Associated Observations

Any unusual features of the suspended load in the river shall be noted; for example, unusually high sand quantities in sample bottles, visibly contrasting water colour, local sediment sources.

Reporting Units

Discharge-weighted cross-section mean SSC results shall be reported as mg/l.

Developing a Calibration Function

This topic outlines how to develop a calibration function relating at-site and cross-section mean suspended sediment concentration (SSC).

Preamble

The relationship between the bankside, at-site SSC and the discharge-weighted cross-section mean SSC 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 cross-section mean SSC to at-site SSC (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 at-site and cross-section mean SSC 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 the cross-section mean SSC and the at-site SSC shall be assembled.

The at-site SSC 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:

- cross-section mean SSC versus at-site SSC
- the mixing ratio, and
  That is, cross-section mean SSC divided by at-site SSC versus discharge.
- 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, or
  For example, if a data-entry error was made for the suspended sediment concentration value.
- 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 cross-section mean SSC to at-site SSC if the former explains more variance in the measured cross-section mean SSC.

Calculate Error Statistics

The following statistics shall be calculated for the preferred calibration relationship:

- the regression coefficient (r^2), 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 at-site SSC derived from turbidity records to cross-section mean SSC either prior to or in the process of integrating suspended sediment yields.

Documenting Calibration Functions

Documents shall be compiled that list:

- the at-site SSC to cross-section mean SSC 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.

Archiving Derived Suspended Sediment Concentration

It is recommended that turbidity-derived SSC records adjusted to cross-section mean SSC records are not archived. This is to avoid confusion over:

- the extent to which a SSC record has been adjusted, and
- which at-site to cross-section mean calibration function has been used.

Instead, it is recommended that when calculating suspended sediment loads the adjustment to cross-section mean SSC is performed 'on the fly' (that is, as an intermediate step within the load-calculation procedure).


NEMS