

Continuous Water-Quality Sampling Programs: Operating Procedures



Prepared by
Watershed and Aquifer Science
Science and Information Branch
BC Ministry of Environment

for the
Resources Information Standards Committee

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Abstract

There is an increasing use of continuous water-quality sampling equipment in water-quality studies conducted in British Columbia. The people that collect the data are not necessarily those that use the data and thus there must be standards for collecting and validating the data before it is available for use by others. This manual begins with an overview of the quality assurance, quality control, and quality assessment requirements of a sampling program. Each subsequent chapter describes the recommended procedures for each stage of the sampling program and identifies how the procedures incorporate the quality assurance and quality control requirements. These stages are designing a station, collecting the field and laboratory data during a field visit, and validating the data. A main component of the validation procedure is to determine data grades, which are a measure of the sensor error at the time of a field visit. The derivation and use of the data grades is discussed in detail.

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For further information about the Resources Information Standards Committee, please access the RISC website at <http://srmwww.gov.bc.ca/risc/>.

This edition supersedes "Automated Water-quality Monitoring – Field Manual", by White, 1999.

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A. Introduction

"Water is the best of all things."

C Pindar

Technological advances in water-quality sampling and recording instruments allow for an almost continuous record of the concentrations of water-quality variables in streams and rivers. However, the data collected are only as good as the quality assurance and quality control procedures, and the quality assessment measures incorporated into the sampling program. The purpose of this manual is to describe and explain these requirements for conducting Continuous Water-Quality (CWQ) sampling programs funded by the province of British Columbia. Each major stage of a water-quality sampling program – designing a station, completing the required field and laboratory procedures, and validating the data – represents a chapter in the manual. New terms are explained when they are introduced within the text and are defined in the glossary of terms. The manual begins with an overview of the quality assurance, quality control and quality assessment requirements of continuous water-quality sampling programs.

This manual supersedes White (1999). It covers the same general topics, but there are some important differences and new ideas. Some of these differences include the following:

- An overview of the quality assurance, quality control and quality assessment requirements of a continuous water-quality sampling program.
- The use of data grades based on sensor error with a detailed explanation of the sources of sensor error and the criteria for the data grade.
- A strong emphasis on servicing the equipment, with step-by-step procedures.
- A separate section on validation with Excel programs that complete the calculations.

Continuous electronic monitoring generates large volumes of data. In British Columbia, the Water Inventory Management (WIDM) system is currently used as a repository for hydrometric, snow pillow, manual snow survey, and automated water-quality data, and is available for use by individuals to store, edit, graph, and archive their data. It is an Oracle based application designed to capture continuous time series data from remote and manual sites. Also, it has the capacity to capture written information (meta-data) about the station design and the field observations. Changes are planned to allow direct input of field data onto computer based field forms, and to complete some basic calculations. Information about WIDM and the status of the revisions is available from the WIDM's Applications Manager, BC Ministry of Environment. At the time of writing, the new features of WIDM are not operational. However this manual includes standardized Resources Inventory Standards Committee (RISC) forms that will be incorporated into the computer-based WIDM forms.

New automated water sampling equipment is continually being produced and new software is being developed to analyze automated water-quality data. Therefore this manual does not address specific instruments or software. The objective is to explain the required procedures. In cases where these are instrument-specific, the operator should contact the supplier for details.

B. Quality Assurance, Quality Control, and Quality Assessment Requirements of a Continuous Water-Quality Sampling Program

"Quality is never an accident; it is always the result of high intention, sincere effort, intelligent direction and skillful execution; it represents the wise choice of many alternatives."

William A. Foster

The quality assurance, quality control, and quality assessment requirements for collecting discrete water samples are defined and discussed by Taylor (1987) and Clark (2000a, 2000b). Wagner (2004) provides working definitions for continuous water-quality sampling programs. Details of the sampling vary among the different authors, but the objectives are always the same: to ensure that proper procedures are followed, to measure possible error (bias and variability), and to document the details. The specific requirements for quality assurance, quality control and quality assessment are explained below.

B.1 Quality Assurance

Quality assurance refers to any components of the water sampling program that cannot be measured directly. These are the procedures implemented to *control* all of the components of the sampling program. It means that appropriate equipment must be used, standard procedures must be followed, and any deviations must be recorded and explained.

B.2 Quality Control

Quality control refers to all of the data collected and used to measure bias and variability. Its measures must be defined and then included in the write-up of sampling procedures and subsequent calculations. In a continuous water-quality sampling program, the measures of quality control are the characteristics of the sensors (particularly how accurate they are), the performance of the deployed sensors (or, conversely, the extent of sensor error), and the duration of equipment malfunctions.

B.3 Quality Assessment

Quality assessment refers to the system of activities used to ensure that the quality assurance procedures are implemented and that the quality control elements are evaluated. In automated water-quality monitoring programs, quality assessment is the validation process. Secondary components of quality assessment are data approval and data audits. Data approval and data audits are not considered in this document.

The components of quality assessment reflect the stages of the sampling program.

Information is documented on the following components:

- Station location and deployment method
- Important characteristics of the equipment
- Sampling schedule and station maintenance
- Field and laboratory data
- Sampling period data – data anomalies and data gaps

Each of these components of quality assessment is outlined below. To streamline the acquisition of the information, standard RISC forms are used (Appendix 1), Excel programs are included (Appendices 2 and 3), and a summary table to record the results of the assessment (validation) is included (Appendix 4).

B.3.1 Station Location and Deployment Method

Information on the station location is added to *RISC CWQ - 01. Station Design Part 1: Site Description*. Each site is identified by a unique name and number, an Environmental Monitoring System (EMS) number, and a global position (latitude and longitude or UTM). This form also includes a general description of the site, the equipment present, access instructions, and the type of deployment used. Details about the station location and deployment methods are given in Sections C.1 and C.3, respectively.

B.3.2 Sampling Equipment

Information on the sampling equipment at the field sampling site is added to *RISC CWQ - 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters*. Details about the sampling equipment are discussed in Section C.2. The possible combinations of source, sensors, and sensor parameters are explained in Section C.2.1.4. A portable sonde is required for field visits. Specifications of the sensors on the portable sonde are added to *RISC CWQ - 03. Specifications of the Portable Sensors' Parameters*.

B.3.3 Sampling Schedule and Station Maintenance

Information about the site conditions at the beginning and end of each field visit and information on the type of maintenance needed during each field visit are added to the *RISC CWQ - 02. Station Log and Maintenance Form*. The sampling schedule is derived from a series of these forms.

B.3.4 Field and Laboratory Data

The field and laboratory data are the subject of Chapter D. They are collected during the field visit and added to the three parts of *RISC CWQ - 04. Field and Laboratory Data*.

- Part 1: The pre-cleaning, post-cleaning, and re-deployment data.
- Part 2: Sources of standard calibration solutions and calibration data for the **deployed sonde** (C1 & C2).
- Part 3: Sources of standard calibration solutions and calibration data for the **portable sonde**.

The purposes of the field and laboratory procedures are to service the sensors, obtain the information required to determine the data grades, and compare different procedures used in collecting the data. The data grades, which are similar to the data ratings used by Wagner et al. (2006), are based on the accuracies of the sensors at the time of the field visit. A decrease

in accuracy is called sensor error. The sources of sensor error and their measurement are explained in Section D.4.

The required calculations are completed in an Excel program. This is in Appendix 2.

B.3.5 Sampling Period Data – Initial analysis for data gaps and data anomalies

The sampling period data are collected while the operator is absent. If the sensors are in good to excellent working order, based on the data grade, the sampling period data should also be good to excellent. However, before the sampling period data are released, the operator should complete an initial assessment for the following features:

- Unreasonable values
 - Negative values, except for temperature
 - Values that exceed the range of the sensors
 - Truncated values
 - Adjacent values that exceed the accuracy of the sensors
- Abrupt changes
- Prolonged changes
- Data gaps

The Excel program in Appendix 3 flags data points that are unreasonable and gives the number of data gaps. The details are discussed in Chapter E. The numbers (and percentage) of data gaps and the number of flagged data points are tabulated in Appendix 4 as part of the final validation.

C. Station Design

“Where observation is concerned, chance favours only the prepared mind.”

Louis Pasteur

The station design is dictated by the purpose of the study and includes three inter-related parts: the site location, the sampling equipment, and the deployment method. The information on the location, equipment, and deployment method for each station is added to the two parts of *RISC CWQ – 01. Station Design*.

C.1 Site Location

The general location of the site depends on the purpose of the study. The specific location depends on accessibility and safety, protection from vandalism, stream morphology and flow, and proximity to electrical power and telephone service (Wagner et al., 2006; Einarson, Environmental Impact Biologist, pers. comm.).

C.1.1 Accessibility and Safety

All automated water-quality sampling stations must be accessible, safe, and have a minimal chance of being damaged or destroyed by natural forces. The following features should be considered when establishing the location of the sampling site. The information can be obtained from maps, weather records, talking to residents, and a reconnaissance visit.

- The stations should be located near a road for easy access to the station.
- The station should have shallow sloping banks to ensure safe access to the stream.
- The potential for snow pack and ice to limit access and to damage the equipment should be determined.
- The presence of large trees and the potential for windfalls that could damage the station should be assessed.

C.1.2 Protection from Vandalism

Protection from vandalism is important to ensure that a valid and useful data record is obtained, and because the sampling equipment is expensive. The protection required depends on the arrangement of the equipment, but in general there are three components to keep secure: the sonde, the accessory equipment (data logger, batteries, & additional power sources), and the cables. In all cases, the sonde is protected in a deployment tube. The design of deployment tubes is the topic of Section C.3. There are several options that can be used to protect the components.

- In a self-contained system (Figure C-1), the data logger and batteries are contained within the sonde, and the sonde is locked in a deployment tube. The deployment tube is anchored to a bridge or other permanent structure and the cable is protected in a casing.
- Systems in which the sonde is physically separated from the accessory equipment present several options for protective structures. The accessory equipment can be protected in a walk-in shed (Figure C-2) or a locked box (Figure C-3). The sonde is then connected to the accessory equipment via a cable that is contained in casing (Figure C-4), and may be buried.

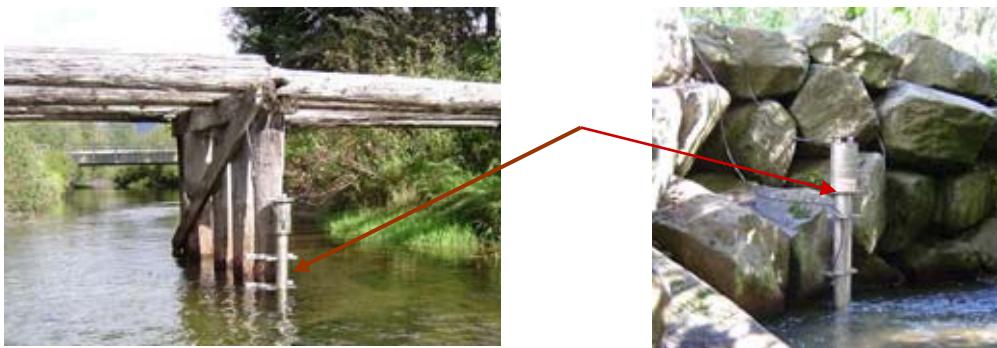


Figure C-1. A self-contained sonde provides its own protection and can be attached to a bridge or rock wall. Photos: Rod Shead



Figure C-2. A walk-in enclosure is one way to protect the equipment. Photo: Judith Burke



Figure C-3. A sturdy box that contains an external data logger and battery can be used to protect the equipment. Photo: Linda Gregory

C.1.3 Stream Morphology and Seasonal Flow Patterns

The gradient and shape of the channel and the seasonal flow patterns of the stream affect the velocity, bedload transport, flooding potential, damage due to moving debris, turbulence, and cross-sectional variability. Stream characteristics that minimize these effects and ensure the continued presence of water are identified below.

- There must be a pool of water removed from riffle areas, in which the sensor can be deployed, e.g. Figure C-4. This is important because of the specific characteristics of pools (see Glossary).
 - Pools are areas that are deeper than other areas and have a concave bottom that will help ensure that the sensors are underwater during low flow.
 - Pools are the areas that have the lowest velocity and a surface water gradient, near zero. Therefore, during high flow periods the deployment tube and sensors will be least susceptible to debris and bedload movement.
 - Pools are less turbulent and are areas of fewer bubbles, which obviates the effect of bubbles on optic measurements.



Figure C-4 Deployment tube in Beaver Creek. Note the cable in the casing and the location of the deployment tube on the downstream side of the stump where there is some pooling of water. The vertical tube is a pressure transducer used to measure water level. Photo: Julia Beatty

- A straight stretch of stream above and below the sampling location is required to minimize the cross-sectional variability. The distance upstream and downstream that is straight will depend on the size of the stream. In small streams it may be as little as 10 m and in large streams it may be 100 m. ***The variation in the water chemistry across the stream at the sampling site should be determined before the station is established.***
- There must be no tributaries in the general vicinity of the sampling site that could affect uniform flow and increase cross-sectional variability.
- There must be one stream channel along which all of the flow passes.

- There must be minimal signs of erosion and deposition in the stream at the sampling site.
- Stable banks are required to accommodate periods of high water. There must be no signs of high-water debris damage at the level of the sampling equipment. If the accessory equipment cannot be put above the expected high water level, it may be necessary to remove the equipment during high water periods in order to prevent potential damage to the equipment by turbulent water and by debris in the water. If velocity and debris movement are the main concerns, a steel deployment tube will protect the sonde (Figure C-5).



Figure C-5. A metal deployment tube may be required in high velocity and high debris flow conditions. Photo: Rod Shead

C.2 Sampling Equipment

This section provides an overview of the sampling equipment used in automated water-quality studies. It is considered in three parts: the instruments used to collect and store the sampling period data, the sources of power, and the ways in which the data can be retrieved. It is important to remember that although the parts are discrete, they must work together. Detailed information on specific connections and compatible components is best discussed with the supplier.

C.2.1 Collecting and Storing the CWQ Sampling Data

The data are collected using sensors and stored in either internal or external data loggers (Figure C-6).

C.2.1.1 Sensors

Sensors can be electrical, electrochemical, or optical. They respond to changing water conditions with an output signal that is processed and either displayed or recorded. The choice of a particular sensor depends on the parameters being studied, the required specifications, and the operating conditions. In addition, it is important to recognize that different sensors have different life spans.

Parameters

Sensors are available to measure a wide variety of variables, but the ones most commonly used at automated water-quality sampling sites are: conductivity, dissolved oxygen, pH, temperature, and turbidity. In addition, chlorophyll *a*, oxidation reduction potential (ORP), and total dissolved gas (or total gas pressure) are now measured at some sampling sites in British Columbia. Also, as the accuracy and detection limits for ion specific electrodes (ISEs) – used to measure chloride, nitrate and ammonium / ammonia – are improved, and as new sensors to detect coliforms and other micro-organisms are refined (e.g. Brown, 2004; Drake and Quist, 2004), more variables may be measured at continuous water-quality sampling locations.

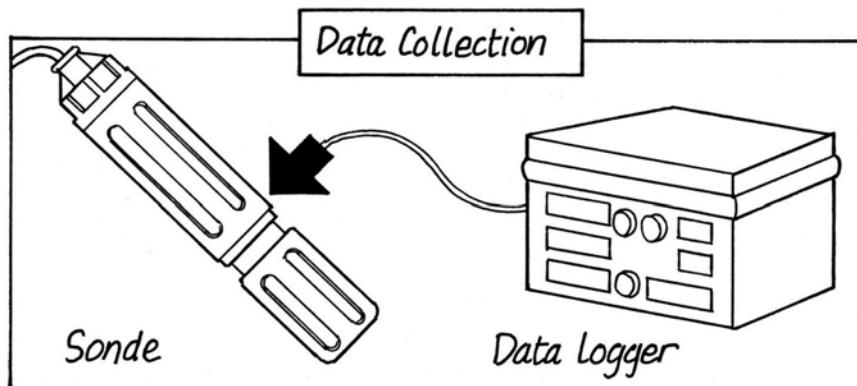


Figure C-6. The equipment used to collect the water-quality data. The sonde (left) may be self-contained or attached to a data logger.

Sensor devices may be individual or multi-parameter; the latter are referred to as sondes. Sensors that measure temperature and turbidity are examples of individual devices, which are used in single-variable studies (e.g. Eads and Lewis, 2002). Some of the newer sondes can measure more than 14 parameters (www.Hydrolab.com; www.YSI.com). Some sensors measure two parameters (e.g. temperature and conductivity, and pH and ORP). In addition, some parameters require readings of other parameters for compensation; dissolved oxygen in salt-water conditions needs to be compensated for both temperature and salinity.

Sensor specifications

These are accuracy, resolution, and range.

1. Accuracy

The accuracy is the difference between the sensor reading in a standard solution and the true value. Accuracy may be recorded as a specific value (e.g. mg/l) and/or as a percent. As a percent, it may be the percent of a reading or percent of full scale (range). The difference is important (Table C-1).

Sensors tend to be least accurate at the extremes of their measurement range. This is because a physical measurement is being converted into an electronic one, and thus any inherent electrical noise from the instrument's own electronics can become a significant component of actual measurement, especially at low signal levels. Instrument manufacturers may identify this aspect by using a two-tier accuracy specification based on sensor range. Turbidity accuracy, for example, may be expressed as ± 2 NTU or $\pm 5\%$ of the reading, whichever is greater. So, for a given measurement of 20 NTUs, the accuracy would be 20 ± 2.0 NTU not 20 ± 1.0 NTU. Once the measurement exceeds 40

NTUs only the $\pm 5\%$ of reading specification would apply because the inaccuracy is now greater than the minimum 2 NTU specification.

Table C-1. The difference between accuracy readings based on percent of reading and a percentage of full scale.

Reported Reading	Range of Sensor	Range of Accurate Readings
100 NTU $\pm 5\%$ of reading	0 to 1000 NTU	$\pm 0.05 \times 100 = 95$ to 105 NTU
100 NTU $\pm 5\%$ of full scale	0 to 1000 NTU	$\pm 0.05 \times 1000 = 50$ to 150 NTU

The data grades (Chapter E) are dictated by the accuracy of the measurements. Therefore, the accuracy of the equipment dictates the highest possible grade for the data. The present grades are dependent on the accuracy of frequently used sensors. As sensor technologies improve and these new sensors become commonly used in British Columbia, the criteria for different data grades may increase as well.

It is critical that the calibration standard solutions used are only those recommended by the manufacturer / supplier. If other solutions are used, the accuracy cannot be assured and no data grade can be assigned.

2. Resolution

Resolution is the smallest interval that the sensor can detect.

3. Range

The range refers to the lowest to highest values that can be detected with the same resolution and accuracy.

Operating environment

The operating environment includes the medium, temperature, and depth. In general, the sensors operate in fresh water, salt water, or polluted water, from -5°C to $+45^{\circ}\text{C}$, and to depths of 200m. The specifics of each sensor should be confirmed; this information is in the manuals (e.g. www.Hydrolab.com; www.YSI.com) and should be confirmed by the suppliers.

Life span

Not all sensors have the same operational characteristics and life span (Table C-2). Sensors such as pH, dissolved oxygen, and various ion-specific electrodes are consumptive. The components of the sensor are used up during the measurement process, and once depleted the sensor must be replaced. As a sensor reaches this endpoint, its ability to respond to changes in the environment diminishes with a resulting reduction in data quality. The sensors are inspected (D.5.4.3) and certain characteristics of some sensors (e.g. millivolt readings of pH sensors) are recorded (D.5.4.5) during each field visit. This information and the information on the expected life spans of the sensors (Table C-2) will aid the operator in assessing the conditions of the sensors.

Table C-2. A summary of sensor types and their typical lifespans

Sensor	Type	Typical Life Span
Temperature	Electrical	5+ years
Conductivity	Electrical	5+ years
pH/ORP	Electrochemical	1 to 3 years
Dissolved Oxygen	Electrochemical	3 to 5 years
Turbidity/Chlorophyll/Dye	Optical	5+ years
ISEs	Electrochemical	6 months to 1 year

C.2.1.2 Sensor Signal: Analogue vs. Digital (Serial) Signal Output

Water-quality sensors reflect changes in their state (electrical, optical, or electrochemical) by altering the strength of their signal output. A continuous increase in the signal output is typical of an analogue signal. The output is usually electrical, normally in volts or amperage (or sub-units of the same), but it may be of very low magnitude and non-linear. Therefore the signal must sometimes be magnified and transformed to a linear output. These analogue sensors typically have no ability to filter or store data internally, and the signal output, in many cases, cannot be adjusted by the end user.

Alternatively, the raw analogue signal can be converted to a digital signal. Digital signals can be massaged by the manufacturer. The manufacturer can filter and average the outputs, and compensate for conditions that would affect the raw values, in order to produce higher quality data. In addition, multiple analogue sensors can be combined into a single multi-parameter device because the individual signals can be converted to digital signals and then combined into a single data string.

Although we refer to these as digital sensors, the signal outputs are most commonly serial because the individual data values from each analogue sensor are sent in a specific sequence. Different devices can communicate with the digital output - PC, external data logger, and hand-held display units – and thus the sensor output may be in a variety of serial data formats. Three common formats are RS232, SDI-12, and RS485.

RS232

RS232 is the most common format. It is used to communicate between a digital sensor and a single serial device (e.g. PC, telephone modem) when calibrating and programming the sensors and retrieving stored data. While the format specifications state a maximum cable length of 15.4 m (50 ft), longer cables, based on manufacturer recommendations, may be used.

SDI-12

SDI-12 is used to communicate from multiple digital sensors to an external data logger. It uses multi-addresses so that each sensor is individually identified. This method is akin to the old telephone party line; all of the sensors are connected to a common three-wire communication and power cable. A master unit, typically the central data logger, issues a command to a sensor's specific (slave) address and that sensor responds. It is important that

no two sensors have the same address, because like the party line scenario, multiple sensors would respond and the master unit would not be able to differentiate among them. The general SDI-12 specification is designed to allow up to 62 m (200 ft) of cable between the sensor and the data logger.

RS485

The RS485 format is useful in situations where longer cables (>100 m or 328 ft) are required; the RS485 format allows for up to 1230 m (4000 ft) of cable to be used. Like the SDI-12, the RS485 has the ability to link multiple sensors to a central data logger or PC. The RS485 is not as popular for field monitoring situations, but it is the standard for on-line and process control operations.

C.2.1.3 Data Storage and Memory

Many digital sensors now have internal memory, which is used to store data and to perform some data processing – temperature compensation or data filtering. The data are most frequently recorded and stored in time intervals. Sensors that are capable of data processing may be able to filter out the maximum and minimum values and calculate mean values. However, in most cases, these types of data processing require a more powerful external data logger.

External data loggers can be viewed as a central collection point for all measured parameters. Although a sensor may have the ability to store data internally, in some situations an external data logger is preferable. External data loggers have four important capabilities:

1. External data loggers have more powerful data processing capabilities than internal data loggers. For example, external data loggers can determine maximum, minimum, or average values over a specific time range.
2. External data loggers can transmit data via telemetry (e.g. GOES Satellite).
3. External data loggers can interface simultaneously with other sensors such as hydrometric or meteorological, and include all of the output as part of total data package.
4. External data loggers can be connected to a large primary power source, which increases the deployment time. This allows for a longer deployment time than sensors with only internal batteries. (*Note: A long deployment time is not necessarily an advantage.*)

The available memory given for an instrument depends on the way that the data are stored. It is best to check with the supplier as to the memory capability and thus the allowable deployment period and the required means of data retrieval. However, it must be emphasized that the deployment time is not dictated only by the available memory or power source (point 4 above). The extent of fouling, variable in-stream conditions such as storms, and possible calibration drift, must be considered as well.

C.2.1.4 Terminology Used in RISC CWQ -01 for the Possible Combinations of the Sensors and Data Loggers

The sensors and data loggers can assume a variety of configurations. The three general configurations are shown in Figure C-7. Arrangement 1 is found at site where there is one multi-parameter sonde attached to an external data logger. Arrangement 2 shows a self-contained system with an internal data logger and batteries. This is the arrangement in Figure C-1. Arrangement 3 is the attachment of two or more separate sensors to an external data

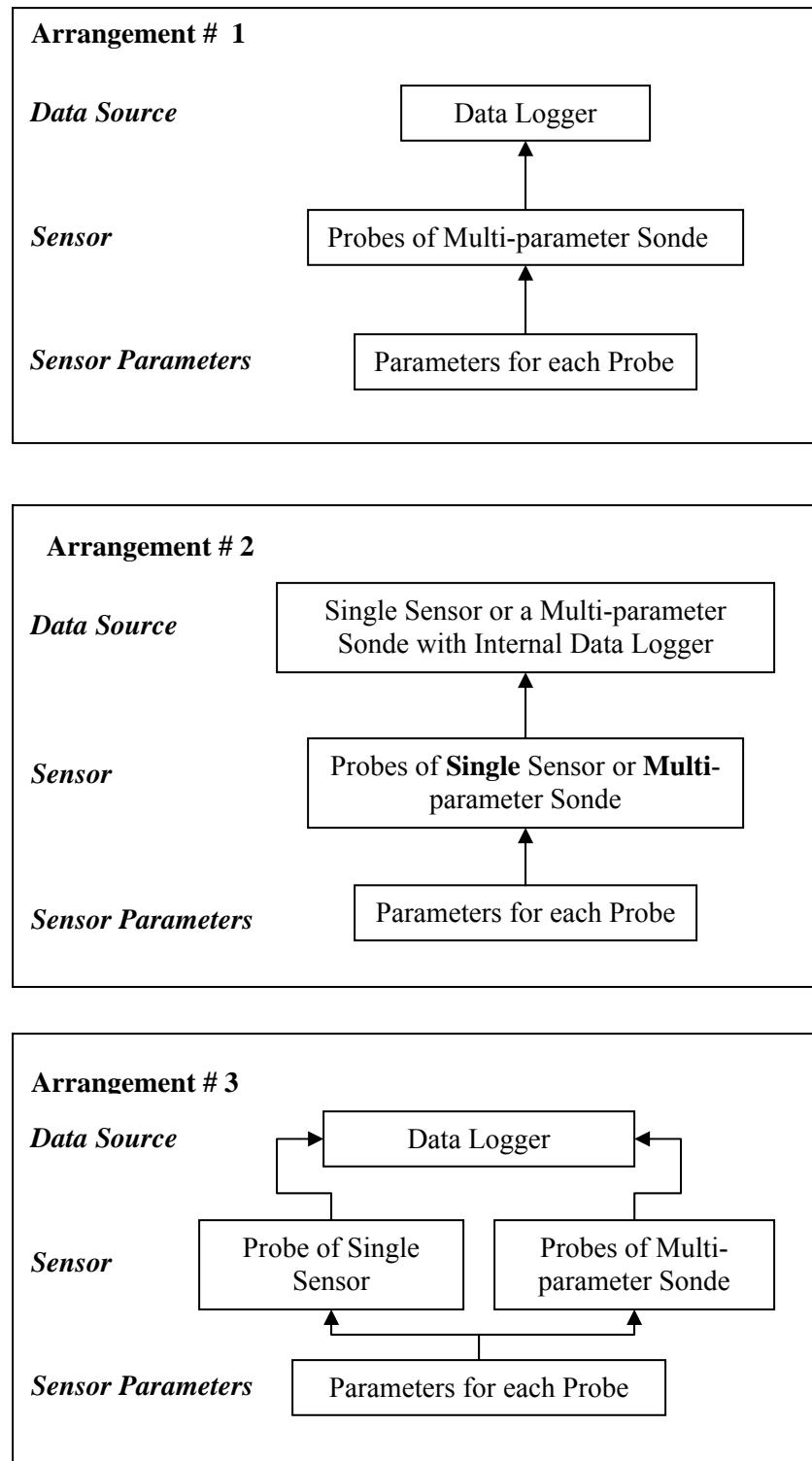


Figure C-7. Summary of the various combinations of data source, sensors, and sensor parameters used in completing RISC CWQ – 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters.

logger. Figure C-4 is an example of two instruments (a sonde and pressure transducer – used to measure water level - connected to an external data logger.

The sensor parameter, sensor and data source at each sampling location must be recorded on *RISC CWQ – 01. Station Design Part 2: Data Source, Sensors, and Sensor Parameters*.

Because the arrangement of the equipment varies (Figure C-7), it is important that the form is completed correctly. The terms – sensor parameter, sensor, and sensor source - are explained in more detail below.

Sensor parameters

In all cases (arrangements 1, 2, and 3), the sensor parameters are the variables or parameters for each probe. Recall that one probe may measure two parameters.

Sensor

The sensor may be the probe of a single sensor (arrangements 2 and 3) or the probes of a multi-parameter sonde (arrangements 1 and 2). In cases where a sensor measures two variables (e.g. temperature and conductivity), the sensor is the same, but the sensor parameters are different.

Data source

The data source is an external data logger (arrangements 2 and 3) or an internal data logger (arrangement 1). Separate discrete sensors may be attached to an external data logger (arrangement 3).

C.2.2 Power Supply

The possible sources of power are shown in Figure C-8. In all cases, batteries power the sonde. If there is an external battery, it is connected to the sonde via a cable and if there is an auxiliary power source such as a solar panel, it is connected to the battery by a cable.

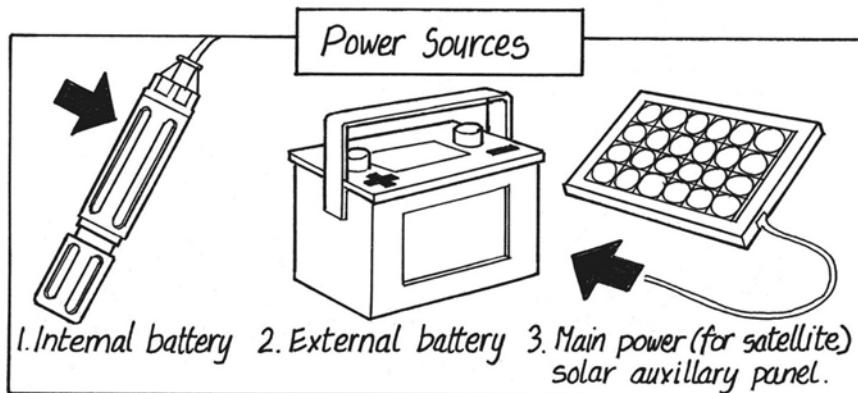


Figure C-8. The different ways that a sonde can be powered. The arrow on the left indicates the location of internal batteries in a sonde. If there is an external battery, it is attached by cable to the sonde. Auxiliary power can be used as shown by the arrow from the solar panel to the battery.

C.2.2.1 Batteries

The power to the sensor is *via* internal or external batteries (Figure C-8). Analogue sensors require an external power supply, which can be provided by a field display unit - such as a hand-held pH or dissolved oxygen meter - or through the data logger to which the sensor is

connected. Depending on the capacity required (amp-hours), external batteries should be either a good quality gel-cell type, or a deep discharge sealed lead-acid style. Automotive batteries are not designed for the repetitive drawing down and recharge cycles that are prevalent at remote stations. Residential (110V) and solar power sources can be used as auxiliary power to the primary battery, for recharge purposes, but should not be connected directly to an instrument because voltage spikes can occur and cause the entire system to fail. The use of a voltage regulator is highly recommended when connecting an auxiliary power source to the primary battery.

Digital sensors with internal memory may also be equipped with an internal battery supply, allowing for a completely stand-alone (self-contained) water-quality station. This package is the simplest to deploy, but lacks some of the advantages of the external data logger that are summarized above.

C.2.2.2 Field and Interface Cables

Depending on the instruments used, a myriad of cables may be required. For example, a cable may be needed to connect the sensor to a hand-held field display, PC, or external data logger, and to connect an external data logger and battery. These cables are instrument-specific, but some important questions should be addressed.

- What cable lengths are required at the particular sampling location?
- Are the cables interchangeable among sensors?
- Is a separate cable required for external power?
- Is a separate cable required for calibration?
- What cable is required to connect to a PC? Where is the connection?
- What cable is required to connect to the external data logger? Where is the connection?

Analogue sensors typically use a single cable that connects the sensor to a display unit or to an external data logger. Digital sensors may connect to a display unit using a field cable, or to a PC or external data logger *via* an interface cable.

If power is supplied through a separate cable, the appropriate connectors must be used, and the connections must be in a weatherproof enclosure (minimum IP – 56 / NEMA 4 rated) located well above the high water level.

C.2.3 External Devices for Communication and Data Retrieval

Communication and data retrieval can be done on-site with a laptop or hand-held display or remotely in real-time *via* a phone or satellite (Figure C-9).

C.2.3.1 On-site Communication and Retrieval

Laptops, hand-held displays, and more recently, personal digital assistants (PDAs) are the main ways used to communicate and operate digital sensors with a serial interface. Most come with a software package. Laptops have the greatest degree of flexibility, but hand-held units are designed for use in the field and are therefore sturdy and can operate in a variety of environmental conditions.

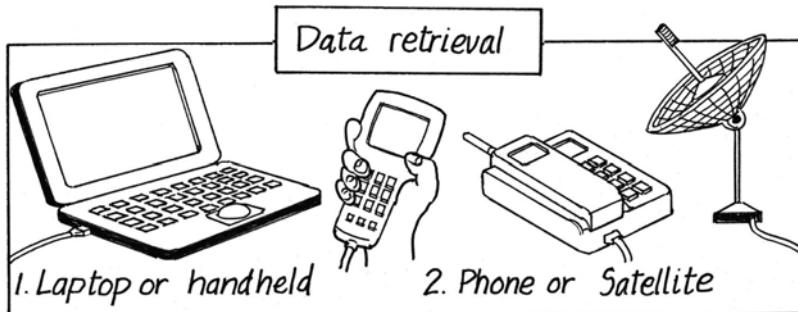


Figure C-9. Options for data retrieval.

Other means of communication include IrDA (infrared) and wireless technology (e.g., Bluetooth) that are used with PDAs. These wireless links allow the PDAs (which are lighter and easier to take into the field) to operate in the same manner as a PC, using specialized software. However, IrDAs do not function well in bright light and Bluetooth is not yet common in the environmental instrumentation market.

C.2.3.2 Real Time Communication and Data Retrieval

Real-time communication occurs when the on-site data are transmitted to a computer that is not at the sampling location. This is sometimes referred to as remote real time communication. Traditionally, telephone modems have been the major means of moving data from one location to another. Hard line or cellular phone coverage is available in urban areas and along main travel corridors. Outside of these areas, satellite phones can be used.

An important advantage to telephone modems is their ability to provide two-way communications between the base station and the field sensor/logger. That is, the same communication conduit can be used to reprogram sampling rates and other system functions, such as downloading the data. Field modems, which are used at the sensor/logger location, are designed to withstand the environmental conditions and power constraints imposed on them, unlike their less expensive office counterparts. Operating costs for this form of telemetry can vary tremendously, with land-lines typically being the least expensive and satellite being the most expensive.

Recently, there has been a movement by telephone service providers to reduce the cost of transmitting data by using a combination of the cellular network and the internet. This form of communication requires digital cellular coverage and uses an IP Modem. The IP modems are issued an IP address that identifies the computers on the Internet. The user calls the station using the appropriate software and the call is routed through the Internet and does not become a conventional cellular signal until the very last link. Users can access sensors in remote locations from any location in the world without incurring expensive long distance fees, because the last link between the tower and the modem is always a local call.

Radio networks are also used to provide two-way communications. A major limitation may be disruption of the signal due to terrain, in which case a number of repeater stations may be required to get the data back to the base station. However for localized networking, the use of spread spectrum radios is an attractive option. These radios are license-free and can transmit over a 20 km distance "line of site." The initial equipment cost of a radio system is

higher than that of telephone modems, but their operational costs are significantly less because there are no service fees.

Satellite radio systems, such as GOES and ARGOS, provide one-way transmission of data, from the field sensor/logger to a base station. They are used most commonly at remote locations that are not readily accessible by road. The on-site data logging devices are programmed to transmit the stored readings at a specific interval; the data is retrieved at the base site via telephone modem. Access to the GOES network is available only to government agencies and their partner corporations, while private companies can apply to ARGOS for the transmission of their data. The initial hardware plus transmission costs for the ARGOS network are fairly substantial compared to the other telemetry options, and therefore are implemented only for special applications.

C.3 Sensor Deployment

Deployment refers to the way that the sensor comes into contact with the ambient water. There are two main deployment methods. The sensor is either placed in the stream or the stream water is brought out of the stream to the sensor; the former is called an *in situ* or "in-stream system" and the latter is called a "flow through system" (Wagner et al., 2006) or a side-stream system.

C.3.1 In-situ Deployment

Two factors must be considered: the design of the deployment tube, and type of deployment.

C.3.1.1 Deployment Tube Design

The sensors are in the stream and must be protected from moving debris (e.g. Figure C-10), sediment, and inquisitive aquatic or terrestrial animals, including humans. Therefore the sensors are housed in PVC or metal deployment tubes and attached to a flexible cable. The deployment tube protects the sonde, and the cable is used to retrieve the sonde. The design of the deployment tube is also important because it must allow free flow of stream water across the tube and the sensors.



Figure C-10. The deployment tube must protect the sensors from debris, such as leaves and branches, in the stream. Photo: Linda Gregory

There are three main designs of deployment tubes. In all cases, only the operator has access to the sonde from the top of the deployment tube because the top is capped and locked (Figure C-1 and C-4) or opens into the locked box (Figure C-3).

Style 1: A solid tube with the guard as the only protection for the sonde (Figure C-11)

In this type of deployment tube, the sensors protrude from the bottom of the sonde and are protected by the guard of the sonde. Because the sensors are protected only by the guard, debris may get trapped in the guard, temporarily or permanently, and damage the sensors, or affect the optical readings. In one case, inquisitive swimmers and rafters tried to investigate a sonde that was deployed in this way, and caused serious damage to the sonde.

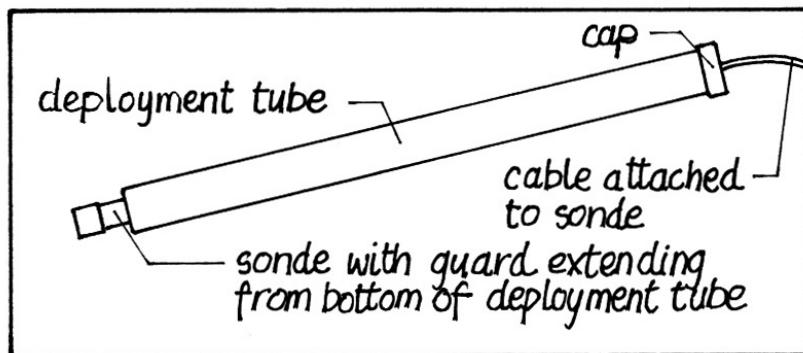


Figure C-11. A solid deployment tube with the sensors protruding from the bottom of the deployment tube and protected only by the guard.

Style 2: A solid tube with additional protection for the guard (Figure C-12)

This deployment tube has additional protection of the sensors from moving debris. The tube is solid, but the downstream half of the tube where the guard and sensors are located is cut out from the tube. There is ample access for the sensors to stream water and additional protection for the sensors, but the sonde is still visible from the bottom. This type of tube is common in British Columbia.

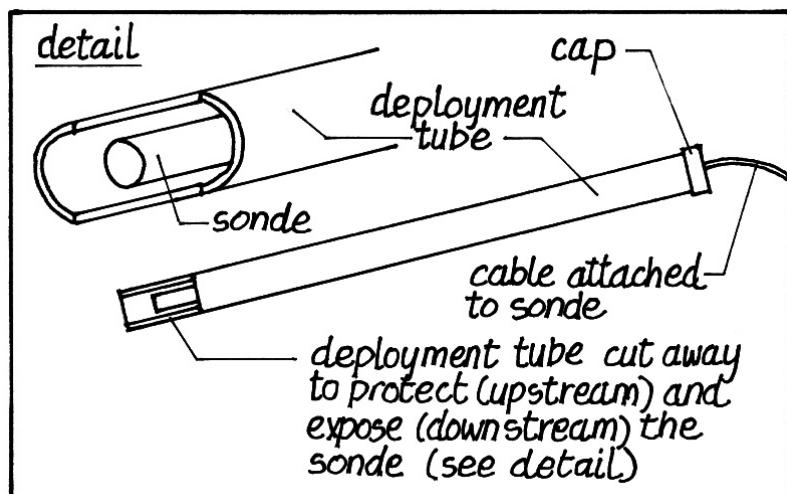


Figure C-12. A solid deployment tube with some additional protection for the sensors.

Style 3: A slotted deployment tube with a cap on the bottom (Figures C-13 & C-14)

In this deployment tube, the tube is slotted to allow free flow of water. Irregardless of the position of the sonde in the tube, the sensors are exposed to the stream water. In addition, both the guard and the deployment tube protect the sensors, and the sonde is protected – from vandalism - at the top and bottom. However, debris may be trapped within the guard as with the first design (Figure C-11) and in the tube.

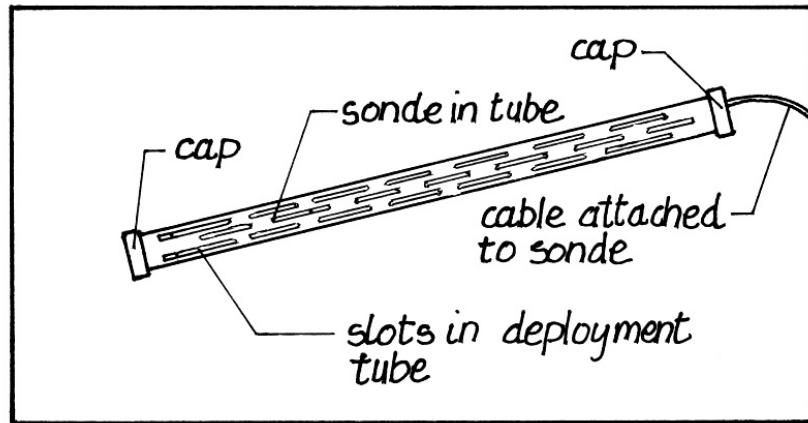


Figure C-13. A slotted deployment tube with a cap at the bottom and top. The slots allow free flow of stream water and the caps prevent access to the sonde.

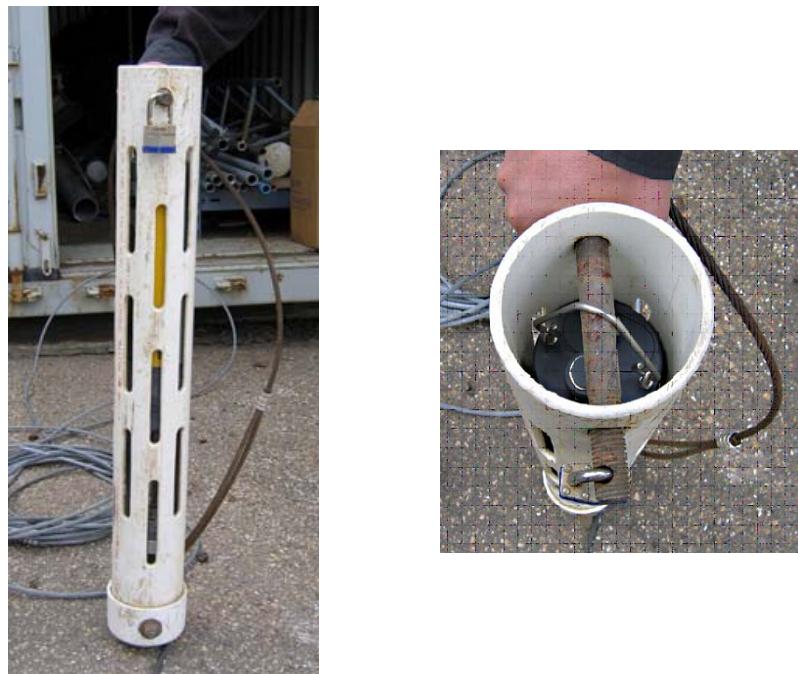


Figure C-14. An example of a slotted deployment tube. The figure on the right shows the bar across the top that both prevents access to the sonde and sensors and helps support the sonde. Photos: Frank van der Have

C.3.1.2 Types of *in situ* Deployment

The deployment tube may be positioned in several different ways. It may be fixed vertically, fixed at an angle to the bank, or contained in a retractable boom. In lakes and slow moving water such as in reservoirs, the deployment tube may be anchored to a buoy or raft. This is referred to as surface deployment and is not considered in this manual. In some cases, the sensors are mounted in frames on the streambed. Unfortunately, the sensor may not be accessible during high flow periods and it may be damaged during bedload movement. This type of deployment is not commonly used in water-quality studies.

Fixed vertical deployment

Sensors that are fixed vertically may be stand-alone (Figure C-1 and Figure C-15) or they may be attached *via* a cable to a data logger. In both cases, the deployment tube is attached to a structure such as a bridge or piling or bedrock. If the sensors are attached to a data logger and / or have an external power source, they must be contained within a walk-in shelter (Figure C-2) or secured in a weatherproof box (Figure C-3).

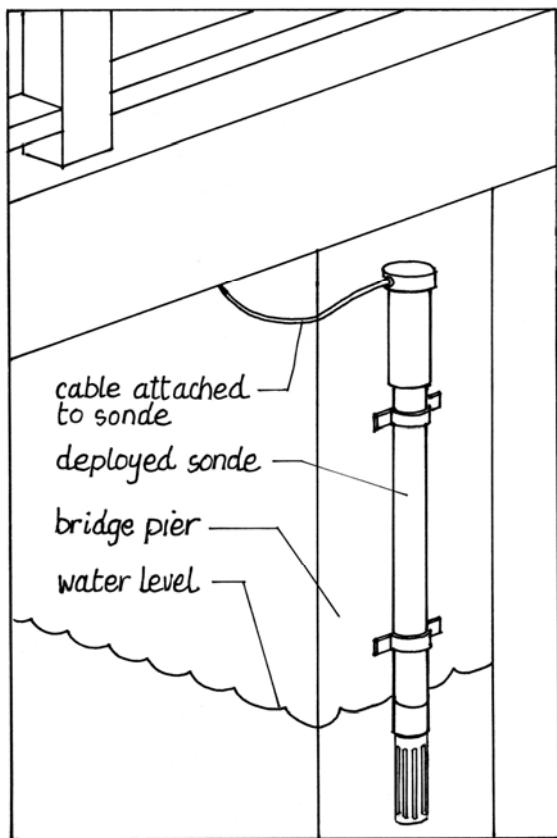


Figure C-15. Fixed vertical deployment. Note that the sensor is self-contained. There is no external battery or data logger.

Fixed angle deployment

The deployment tube is anchored to the stream bank on an angle, usually *via* posts, angle iron or a tree (Figure C-16). This method is useful for sites where the parameters include turbidity and chlorophyll *a*, which are measured using optics, and must have a bubble-free detection window. If the sensors do not have a wiper, keeping the sensor at an angle minimizes the build up of bubbles on the optics.

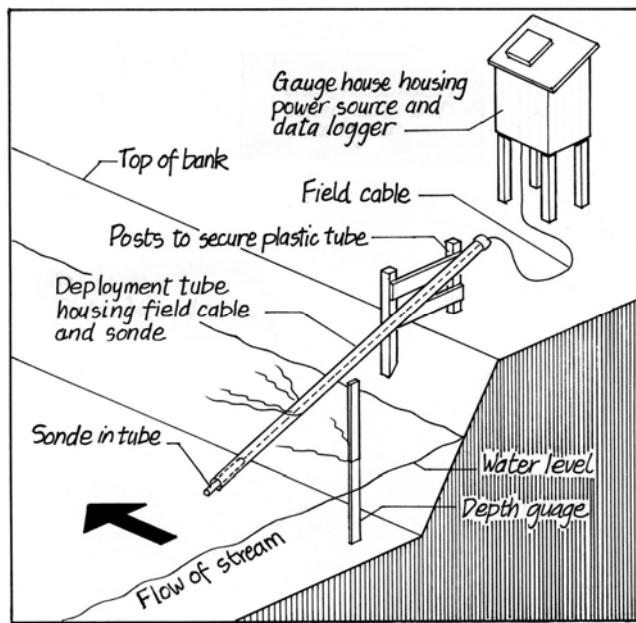


Figure C-16. Fixed angle deployment. Note that an external battery and a data logger are housed in a separate enclosure.

Retractable booms

Booms are articulating levers that allow modification of the orientation and depth of the sensor in the stream and ensure that the sensor remains a consistent distance above the substrate. They may be mounted to a bank, a bridge, or a cross-stream cable. An example of one attached to a bank is shown in Figure C-17. Because the sensor is oriented *with* the stream flow it is subject to hydroplaning at high velocities; therefore, the sensor must be appropriately weighted (Eads and Lewis, 2002).

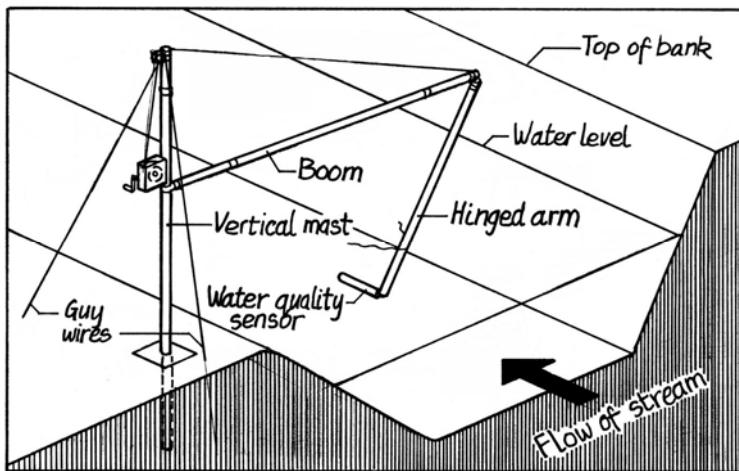


Figure C-17. Retractable boom. Note that the sensor is parallel to the stream-flow.

C.3.2 Flow-through Systems

Flow-through or side-stream deployment (e.g. Figure C-18) is used when instruments cannot be installed safely in the stream. There are five important conditions that necessitate the use of flow-through deployment:

- Excessive turbulence and bubbles
- Extreme danger of instrument damage from floating debris or bedload
- Insufficient water depth to meet operational requirements
- Unstable bank conditions or no structure available to anchor a deployment tube
- Severe cold and ice during the winter

There are two types of side-stream samplers: gravity-fed and pump-fed. An example of the former is shown in Figure C-18. In both cases, the water is drawn from the stream to the sampler and released by gravity, and the sensors are housed out of the stream in an adjacent shelter. The differences are reflected in the names; gravity-fed systems draw water by gravity, and pump-fed systems use a pump to draw water. The sensor may be contained in an adjacent shelter designed specifically for housing the sensor (Wagner et al., 2006) or the sensor may be housed in a building adjacent to the stream (Ryan et al., 2004).

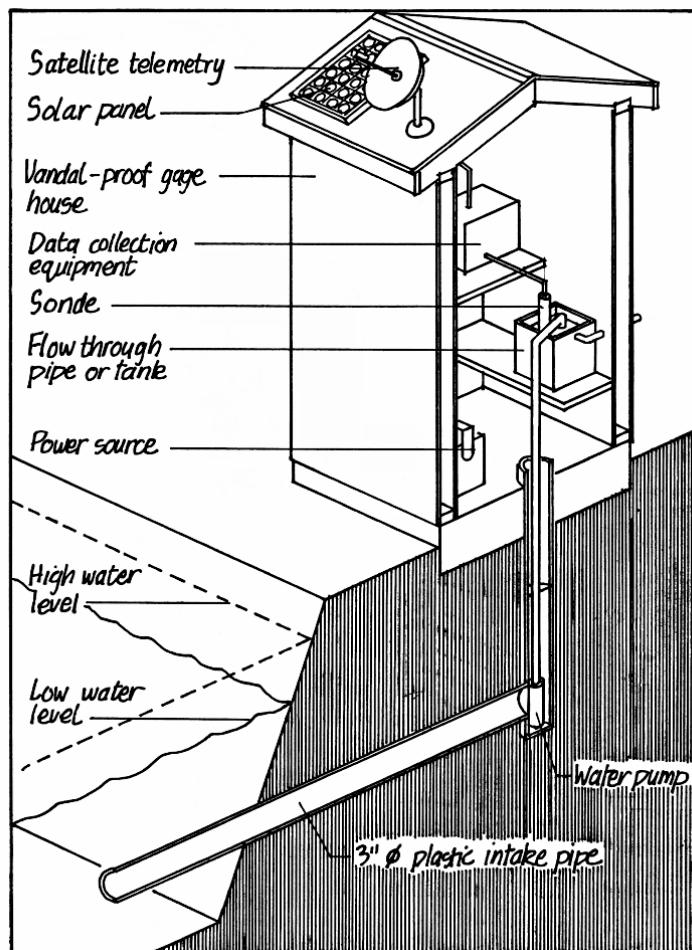


Figure C-18. The general design of a flow-through deployment system.

Several factors must be considered when using flow-through deployment.

- The samplers must be calibrated so that measurements in the sampling chamber and stream are correlated.
- The opening of the intake pipe must have a large diameter (and thus surface area) and be covered with a mesh. This ensures flow into the sampler and reduces the required time between servicing of the intake.
- If the samplers are located where freezing conditions may occur, intake hoses should be submerged or buried, the sampling chamber should not contain metal components, and the sampling chamber must be insulated.
- Because of the location of intake pipes and the possibility of mixing in intake pipes, side-stream samplers are not appropriate for dissolved oxygen or temperature measurements.
- Because the water is pumped into a standing chamber, sediment may precipitate on the bottom of the chamber and ultimately be mixed with the incoming water. This will have a significant effect on parameters such as turbidity. To avoid this problem, the container should be examined frequently for sediment build-up. Alternatively, the inflow should be at the top and the outflow at the bottom of the container and the container should be at an angle with the outflow at the lowest point.

C.3.3 Factors to Consider when choosing a Deployment Method

Several inter-related factors must be considered when choosing the most appropriate deployment method: study purpose, location, in-stream conditions, accessibility for retrieval, and power supply. Many of these considerations must also be assessed when determining the most appropriate site. Of course budget is always a necessary consideration.

C.3.3.1 Location

At remote sites a deployment method that allows communication with the site is recommended, but not always possible. Communication with the data logger on-site reduces potential loss of data.

C.3.3.2 In-stream Conditions

Continuous water-quality sampling sites are used on small streams and large rivers. The stream gradient and seasonal flow patterns affect water depth, bedload and debris movement, and the extent of turbulence.

Depth

A minimum depth of water is required to ensure that the sensors are always in the water column. In addition, within the water column the sensors should be a minimum distance from the substrate - about 20 cm - to obviate effects of bedload transport, and a minimum distance from the surface to eliminate the effects of solar radiation. The latter is particularly important for optical sensors – turbidity and chlorophyll *a* – because their readings are affected by solar radiation on the sensors. If fixed vertical or fixed angle deployment is used, historical information on stream flow should be assessed to determine expected low-flows and high-flows; the location of the deployment tube can then be determined accordingly. In small streams that are subject to rapid changes in flow, the retractable boom is advantageous because the position of the sensor can be readily changed. However, the sensor must be weighted to prevent hydroplaning.

Bedload and debris movement

The movement of bedload and debris are associated with high-flow conditions; both can damage the sensors. It may be expedient to remove the sensors during the high-flow periods. Another possible solution is the careful choice of a quiet pool, which is less likely to be influenced substantially by debris. Ice is a special type of debris. To obviate the problems with ice in a reasonably large river, Ryan et al. (2004) used a flow-through deployment method. Sensors can operate to below freezing temperatures in streams, but the greatest problem occurs when the sensor is removed and exposed to severe freezing temperatures.

Turbulence and bubbles

Turbulence produces bubbles, and bubbles interfere with readings from optical sensors, such as turbidity and chlorophyll *a*. Wipers remove any bubbles immediately before a reading is taken and thus reduce any problems due to bubbles. If the sensor does not have a wiper, angle deployment is preferred because it prevents accumulation of bubbles, which frequently occurs with vertical deployment. Turbulence is greatest in straight high-flow sections of the river and thus deploying the sensor in a protected side area will reduce the effects of turbulence.

C.3.2.3 Accessibility

High flows limit access to sensors deployed on the stream bottom. Accessibility may be limited by water depth and flooding, but this should be considered in the initial station design.

C.3.3.3 Power Supply

Flow-through deployment requires 110 volt AC power. None of the other types of deployment require power.

D. Field and Laboratory Procedures

“Maintenance is the foundation of eternity”

Isaac Asimov

The ultimate purpose of the field and laboratory procedures is to ensure that the sampling equipment is working properly and the sampling period data represent the environmental conditions. Sampling sites differ in stream hydrology (Section C.1), the arrangement of the equipment (Section C.2), the deployment method (Section C.3), and the proximity to an office or laboratory. This means that one set of instructions is not appropriate for all combinations of hydrology, deployment, equipment, and accessibility to a stable environment. Therefore the approach used in this chapter is to outline the recommended procedures and to document the data that should be collected.

It may not always be possible to follow precisely the recommended procedures. This does not negate the value of the data. It means that the operator must recognize potential problems due to any deviations and he/she should attempt to obtain the data in a way that follows closely the recommended procedures. Before any modifications are implemented, the operator should consult with the project supervisor and/or the regional manager.

D.1 Data Collected

The sampling period data are collected on a data logger while the operator is absent. These data document the continuous record of the stream water-quality. The field and laboratory data are collected by an operator during the field visit at intervals during the sampling period (Figure D-1).

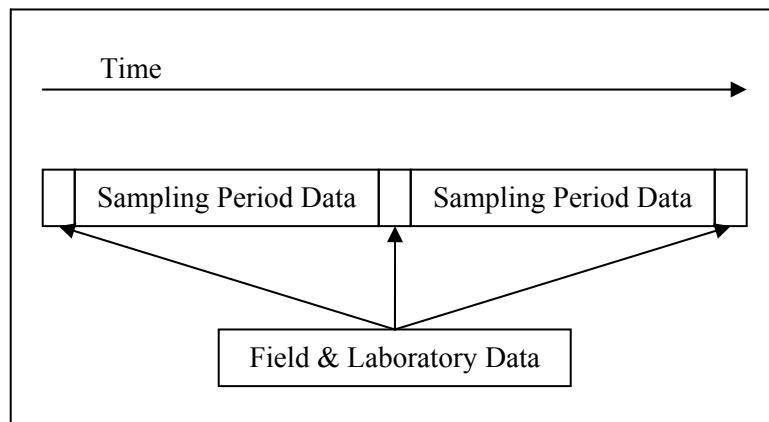


Figure D-1. The sampling period data are collected on a data logger while the operator is absent and the field and laboratory data are collected by the operator at the field site and in a stable environment.

The field and laboratory data include numerical and written information. The written information, called meta-data, summarizes the results of the site inspection (Section D.5.3.2) and the sensor inspection (Section D.5.4.3), and documents the sources of the calibration

standards (D.5.4.4). Accurate and complete metadata are necessary for data management and subsequent stages of data approval and audit. The numerical information is the data used to determine the data grade and to further validate the sampling period data (Chapter E).

D.2 Frequency of Field Visits

If the sampling period data, which are stored in a data logger, are viewed in remote real-time (Section C.2.3), unexpected data points can be recognized immediately and remedial action – an on-site visit – can be taken. However, in British Columbia, many sites are not capable of off-site real time communication and the sampling period data are downloaded and viewed only during field visits. The frequency of the field visits to all sites will depend on the stream conditions and may be changed by the operator. New sites should be visited every two to three weeks or, at least, more often than once per month. In general, at sites where there is not remote real-time communication, ***the frequency should not be greater than the longest period of data that the operator is willing or allowed to lose.***

D.3 Frequency of Separate Laboratory Samples

Historically, stream water samples have been collected during each field visit and submitted to a certified laboratory for analysis. The results are used to assess the readings of the sensors at the time of the field visit. The protocols outlined in this manual do not recommend the consistent use of these laboratory samples because the sensors are inspected and calibrated during each field visit and because readings are obtained from cleaned and calibrated portable and deployed sensors.

The variables that are sampled most commonly in British Columbia (Section C.2.1.1) - and considered in this manual - are conductivity, dissolved oxygen, pH, temperature, and turbidity. Because the measurement of chlorophyll *a* and depth and level are becoming more common, they also are included in this manual. Conductivity, dissolved oxygen, pH and temperature are field variables. Their characteristics will change during transport to a laboratory and therefore the results can not be compared to the field data. Depth and level can be checked only by other hydrometric equipment on-site. Turbidity levels measured in the field can be compared to laboratory results, but they are not required by this methods standard. Their measurement is at the discretion of the operator. Chlorophyll *a* monitoring is recommended only as a complement to more accurate laboratory analyses; therefore laboratory samples for chlorophyll *a* should be collected during every field visit.

D.4 Recommended Sampling Protocols – Background

This section has four objectives:

1. To give the purpose of the field visits.
2. To outline the sources of sensor error – the basis of the data grades - that can contribute to a decrease in accuracy of the sensor readings.
3. To identify and explain the factors considered in developing the sampling protocol.
4. To give an overview of the recommended protocol.

D.4.1 Purpose of the Field Visits

The purpose of the field and laboratory visits is to inspect the sampling site, service the sensors, and obtain the information required to determine the data grades. The data grades, which are based on the data ratings used by Wagner et al. (2006), are a measure of the accuracy of the sensors at the time of the field visit. A decrease in accuracy is called sensor error. The sensor error is measured during the field visit, but the effect of the sensor error is seen in the sampling period data collected between the field visits. After each field visit, sensor error is calculated and used to obtain the data grade.

D.4.2 Types and Sources of Sensor Error and their Effect on the Sampling Period Data

There are four main types of sensor error: fouling, calibration drift, sensor malfunction, and noise. The source of each of these errors and their effect on the sampling period data are summarized below.

D.4.2.1 Fouling

- Fouling results from sediment deposits or biological growth (bacterial, algal) on the active surface of the sensors, or vegetation, debris, or insects lodged within the sensor guard.
- The effects on different sensors are variable and should be discussed with the manufacturer. Recall that the style of deployment tube can affect accumulation biomass inside the guard.

D.4.2.2 Calibration Drift

- Calibration drift happens due to electronic drift in the equipment, and sensitivity loss. It varies among sensors and affects the life span of sensors (Section C.2.1.1).
- In general, the drift is gradual and there is a gradual change in the values of the readings of the affected sensor.
- The data recorded on millivolt differences or Nernst constants (pH sensors) and cell constants (conductivity probe) will help the operator determine potential problems with these sensors (Section D.5.4.5).

D.4.2.3 Sensor Malfunction

- Sensors may be physically damaged due to in-stream movements of debris. For example, the bulb on the pH sensor may be broken, or the Teflon membrane on the dissolved oxygen sensor may be torn. Other situations that result in malfunction are loss of power, damaged cables, and loose reference junctions. Malfunction may also result if the sensors are out of the water.
- The sensors will give erroneous or no readings.

D.4.2.4 Noise

- Noise is due to sensor sensitivity, external influences (e.g. power lines and magnetic fields), and turbulence (Quilty et al., 2004), as well as direct and reflected sunlight.
- The sampling period data will show outliers and unexpected results.

D.4.3 Factors Considered in Developing the Recommended Protocol

The following factors are important prerequisites that were considered in developing the sampling protocol.

D.4.3.1 The deployed sonde must not be disturbed excessively before cleaning

- Pre-cleaning and post-cleaning data are required to determine sensor error due to fouling. If the sonde is disturbed before the pre-cleaning data are obtained, fouling material may be dislodged from the sensors or added from the guard to the sensors. Therefore, the pre-cleaning data must be obtained with the sensor in stream water and on-site.

D.4.3.2 Cleaning and calibration checks must be done in a protected and stable environment

- The sonde and sensors must be carefully and thoroughly cleaned, and the sensors must be calibrated in conditions where the equipment and calibration standards are at a constant temperature, out of sunlight. This requires a stable and protected environment. This area should have the following features:
 - (a) A heater and thermostat for maintaining a stable temperature
 - (b) A bench or table
 - (c) Storage facilities for the calibration standards and de-ionized water
 - (d) Access to water and general cleaning facilities
 - (e) Good lighting

D.4.3.3 Post-cleaning readings must be taken in stream water in a stable environment

- After the sonde and sensors of the deployed sonde are cleaned, but before the sensors are calibrated, post-cleaning readings in stream water are required. This is done in the stable environment mentioned above. To reduce sources of error, stream water must be used for the post-cleaning measurements. This means that stream water must be brought to the stable environment.

D.4.3.4 Calibration standard solutions recommended by the manufacturer must be used

- This is dealt with in more detail in Section D.5.4.4.

D.4.4 Recommended Protocol – an Overview

A stable and protected environment is required for cleaning the sondes and sensors, and for calibrating the sensors. In most cases in British Columbia, the stable environment does not exist at the sampling site and thus the sondes are moved from the sampling site to a laboratory or office. The recommended protocol outlined in Figure D-2 deals with the differences in the time and location of the pre-cleaning and post-cleaning readings. The data are recorded on *RISC CWQ – 04. Field and Laboratory Data*.

Various field procedures are presently used in British Columbia, and an optimal procedure and a modified procedure, for use in rapidly changing conditions, are outlined by Wagner et al. (2006). In most cases, all of the data are collected at the field site. Two important characteristics of the recommended protocol differ from previous procedures.

1. The pre-cleaning data are collected in stream water at the field site, whereas the post-cleaning data are collected in stream water that has been transported to the stable environment, usually an office or lab away from the field site. To deal with the

change in location from the field site to a stable environment, each reading with the deployed (D) sonde is paired with a reading of the portable (P) sonde. The readings of the portable sonde (bottom of Figure D-2) are used to determine the change in the stream water during its transport from the stream to the stable environment.

2. The sensors are always re-calibrated. Even if the sensors are reading within their defined accuracy, they are re-calibrated. This means that each new sampling period starts with calibrated sensors. It also means that error will not gradually creep into the data due to a gradual calibration drift in the sensors over a series of field visits. Any shifts in the sampling period data due to this re-calibration can be adjusted in subsequent processing of the data (Section E.8)

Several additional points about the recommended protocol warrant mention.

- The sensors of the deployed and portable sondes must have the same accuracy, resolution, and range. Or at least the accuracy must be equal to or better than the accuracy of the highest data grade.
- The portable sonde must be cleaned and calibrated before each field visit.
- The series of measurements recorded for the deployed and portable sensors are recorded with a number after the letter. When the numbers after the D and P are the same it means that they are paired and the readings are taken under the same conditions. Either both sondes are in deployment tubes, *in situ*, or both are in a container of stream water, referred to as "in a bucket of stream water". These two conditions, *in situ* and "in a bucket of stream water," represent two options for obtaining the pre-cleaning and re-deployment data. ***Both options should be included in the initial visits.*** The Excel program in Appendix 2 calculates the data grade for both options and compares the two options. The operator can use the comparisons to decide which option is most suitable for a station. The option that is used must remain consistent at a sampling location.
- There are differences in the time and location of the data acquisition during the field visit. The locations are the field site and a stable environment. The time differences depend on the relative locations of the field site and stable environment. Parts 1, 2, & 3 in Figure D-2 are the different locations.
 - (a) Part 1: At the ***field site*** before the deployed sonde is cleaned. These are the pre-cleaning data (D1 & P1) and (D2 & P2).
 - (b) Part 2: In a ***stable environment*** after the sondes and sensors are cleaned. These are the post-cleaning data (D3 & P3) and calibration data (C1 & C2).
 - (c) Part 3: At the ***field site*** when the deployed sonde is re-deployed. These are the re-deployment data (D4 & P4) and (D5 & P5).
- The post-cleaning measurements (D3 & P3) are done in stream water that is transported to the stable environment. Because there is a time lag between the pre-cleaning measurements on site and the post-cleaning measurements in a lab, there may be some changes in the water chemistry of the stream water. However, the chemical dynamics of the stream water sample that is brought to the stable environment is most similar to the stream water sample used on-site.

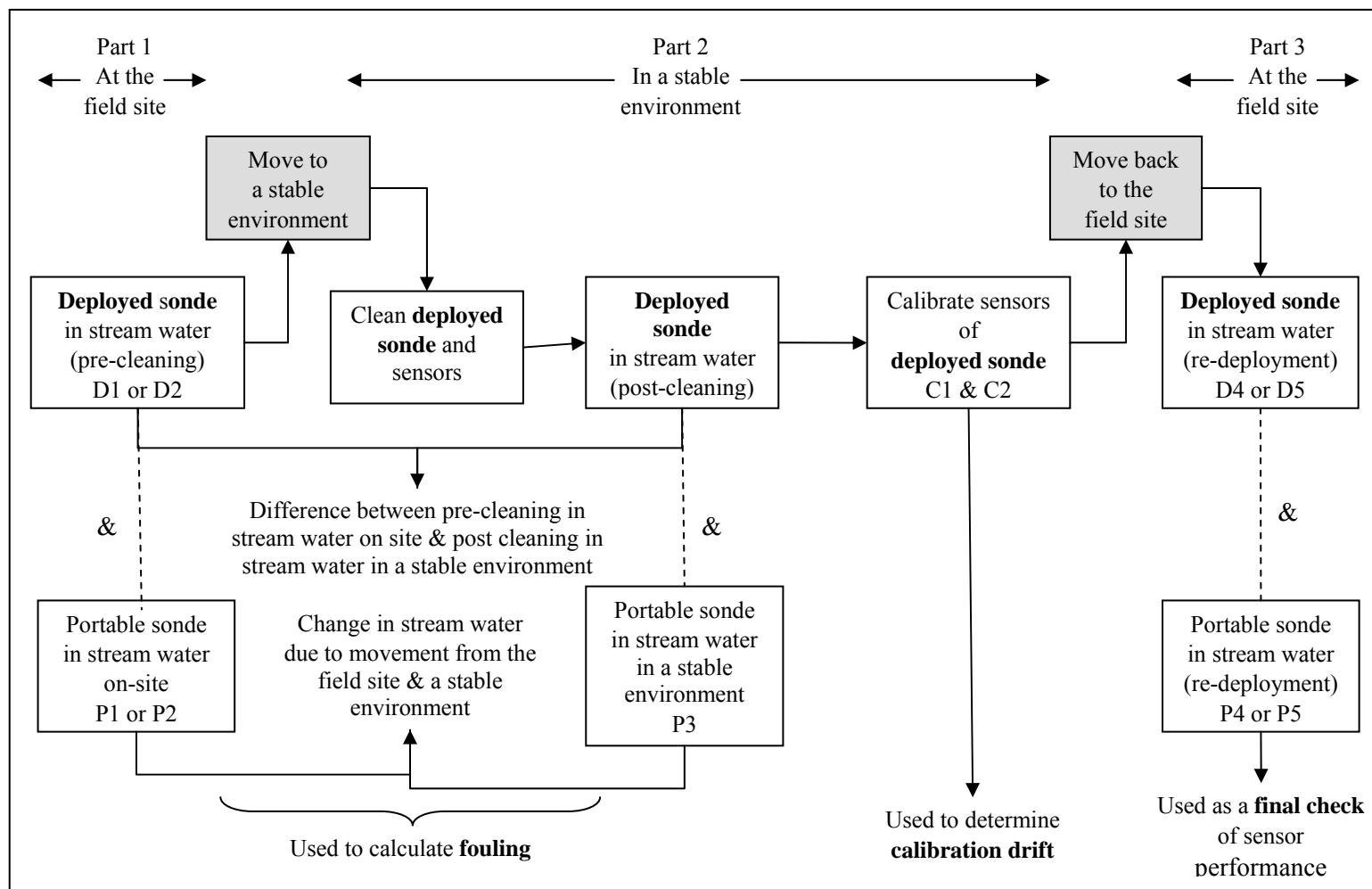


Figure D-2. Overview of the recommended protocol – data collected in pairs (deployed sonde & portable sonde) at the field site and in a stable environment

D1 & P2 = pre-cleaning, in situ

D2 & P2 = pre-cleaning, in a bucket of stream water

D3 & P3 = post-cleaning, in a bucket of stream water

C1 & C2 = pre- & post calibration readings

D4 & D5 = re-deployment, in a bucket of stream water

D5 & P5 = re-deployment, in situ

D.5 Recommended Sampling Protocols – Step-by-Step Procedures

The sampling protocols are divided into two main sections: preparing for a field visit, and collecting the field and laboratory data.

D.5.1 Prepare for a Field Visit

Recall that each field visit has an on-site and a laboratory component. Before beginning a field visit the operator must assemble the necessary field supplies, ensure that the required laboratory supplies are available, and calibrate the sensors of the portable sonde (and the sensors of the deployed sonde, if it is the first field visit). Each site will have different specific requirements, but a generic list of equipment is given below. The operator can use this list to generate his/her own.

Two sondes are required, the sonde (or sensor) that is deployed – called the deployed sonde (D), and a portable sonde (or sensor) brought to the field site – called the portable sonde (P). The only prerequisite for the two sondes is that the characteristics of the sensors (accuracy, resolution, and range) are the same. The information on the deployed sonde is added to *RISC CWQ – 01. Station Design Part 2: Data sources, sensors, and sensor parameters*. The information on the portable sonde is added to *RISC CWQ – 03. Specifications of the Parameters of the Portable Sonde*. Note that the latter has check boxes to confirm that the deployed and portable sensors have the same accuracy, resolution, and range for each parameter.

D.5.1.1 A Generic List of Field Supplies

Equipment

- Portable sonde
- Laptop computer and/or display unit
- Replacement batteries for sondes and display units
- Digital camera
- Global Positioning System (GPS) unit
- Insulated buckets or coolers for on-site measurements and for transporting water back to the lab
- Rubber gloves
- Towels for wrapping sondes
- Tools for repairs
- (If necessary) Laboratory sample bottles, preservatives, and requisition forms

Personal Gear

- Raingear
- Footwear
- Food and water
- First aid kit
- Cell phone

RISC CWQ Forms and Notes

- Station log books
- RISC CWQ – 01: Station Design
- RISC CWQ – 02: Station Log and Maintenance Form
- RISC CWQ – 03: Specifications of the Portable Sensors' Parameters
- RISC CWQ – 04: Field and Laboratory Data

Note:

- Although all of the forms are not needed, keeping a copy of the appropriate forms for each station with the station log book means that the operator can check what equipment is present and he/she can complete the forms as needed.
- Eventually the RISC forms will be computer-based.

D.5.1.2 A Generic List of Laboratory Supplies

- Calibration standard solutions (check expiry dates)
- Distilled (de-ionized) water
- Liquid-in-glass thermometer (NIST or NRC calibrated)
- Bio-degradable cleaning detergent
- Clean soft cloths for cleaning
- Sensor cleaning and maintenance equipment (brushes, rings, etc.)
- RISC CWQ Forms (see above)

Note:

- Recall that the laboratory is the stable environment and must have certain features (Section D.4.3.2).

D.5.1.3 Inspect and calibrate the sensors of the portable sonde

Before each field visit the sensors of the portable sonde must be calibrated. If this is the first field visit, it will also be necessary to inspect and calibrate the deployed sonde. The details for inspecting the sensors are given in Section D.5.4.3 and procedures for calibrating the instruments are outlined in Section D.5.4.5 and provided in detail by the manufacturer. The calibration data are recorded on *RISC CWQ- 04. Field and Laboratory Data Part 3: Sources of standard calibration solutions and the calibration data for the portable sonde*. The calibration data from the previous calibration time should be examined to assess trends in calibration data, which can help the operator recognize any potential problems.

D.5.2 The Field Visit - Introduction

The field and laboratory data are collected during the three parts of the field visit. The reader might want to refer back to Figure D-2 and the overview of the recommended protocol in Section D.4.4. Part 1 is the preliminary visit to the field site. Part 2 is in a stable environment, a lab or an office. Part 3 is the re-deployment visit to the field site. The procedures for the three parts are listed below. The numerical data recorded for both the deployed and the portable sonde are summarized in Table D-1. Detailed procedures are given in subsequent sections and the use of the data during validation is explained in Chapter E.

Part 1. At the Field Site – Preliminary Visit

1. Add the Arrival Information to *RISC CWQ – 02. Station Log and Maintenance Form*
2. Inspect the field site
3. Download the sampling period data
4. Obtain the pre-cleaning data (D1 & P1) *in situ*
5. Obtain pre-cleaning data (D2 & P2) "in a bucket of stream water"
6. Prepare the sondes for transport to a stable environment
7. Collect stream water samples
8. Clean the deployment tube

Part 2: In a Stable Environment (Office or Laboratory)

1. Clean the sondes and sensors
2. Obtain the post-cleaning data (D3 & P3) "in a bucket of stream water"
3. Inspect the deployed sonde and its sensors
4. Record information on calibration standards
5. Collect the calibration drift data in standards (C1 & C2) and calibrate or replace the sensors
6. Run the deployed sonde in tap water
7. Prepare the sondes for transport to the field

Part 3: At the Field Site – Re-deployment Visit

1. Obtain the re-deployment data (D4 & P4) "in a bucket of stream water."
2. Obtain the re-deployment data (D5 & P5) *in situ*
3. Add the departure information to *RISC CWQ – 02. Station Log and Maintenance Form*
4. Prepare the portable sonde for transport

The sampling schedule set up for completing the field and laboratory procedures may vary among operators. In some cases, the operator may complete the three parts in one day. In other cases, the operator may decide to complete part 1 for several sites on one day and complete parts 2 & 3 on subsequent days. Because the sondes and sensors are cleaned in a stable environment no sampling period data are collected during this time. The operator should therefore do her/his best *not* to remove the sondes during rainstorms or other potentially important or unstable in-stream periods.

Two options are given in Table D-1. These are the two possible conditions used to obtain the pre-cleaning and re-deployment data. In option 1, the sondes are *in situ* and in option 2, the sondes are "in a bucket of stream water". **Both option 1 and option 2 should be completed for the first three or four field visits.** The operator can then examine the results of the data grades and comparisons that are calculated in the Excel program and decide which option he/she should continue to use. This is explained in more detail in Chapter E.

Table D-1. Summary of the data recorded for the deployed sonde and the portable sonde during the field and laboratory procedures. In situ is option 1 and "in a bucket of stream water", is option 2.

Measurement conditions	Data Recorded	
	Deployed Sonde	Portable Sonde
Part 1. Arrive at the field site – obtain pre-cleaning data		
<i>Option 1. Pre-cleaning, in-situ</i>	D1	P1
<i>Option 2. Pre-cleaning, "in a bucket of stream water"</i>	D2	P2
Part 2. In a stable environment – obtain post-cleaning and calibration data		
Post-cleaning, "in a bucket of stream water"	D3	P3
Calibration information	C1 & C2	N/A
Part 3. Return to field site - obtain re-deployment data		
<i>Option 2. Re-deployment, "in a bucket of stream water"</i>	D4	P4
<i>Option 1. Re-deployment, in-situ</i>	D5	P5

D.5.3 Field and Laboratory Data Part I: At the Field Site – Preliminary Visit

The eight steps for this stage, which are listed above are explained in this section.

Note:

- Dissolved oxygen is measured in mg/l and thus a re-calibration is not necessary at the field site and is not included in the procedures. If dissolved oxygen is needed as a percentage, the operator should re-calibrate the dissolved oxygen sensor on-site, based on the barometric pressure at the site.

D.5.3.1 Add the Arrival Information to RISC CWQ – 02. Station Log and Maintenance Form

RISC CWQ – 02. Station Log and Maintenance Form is an on-going record of who visited the site, the conditions of the site at the time of arrival and departure, and the purpose of the field visit, including any required maintenance. A copy of the form is included in Appendix 1.

The operator must remember to check the time on the data logger with his/her watch and record this on the RISC CWQ – 02 form. In general all the data are collected at standard time.

D.5.3.2 Inspect the Field Site

Damage to the sampling equipment can necessitate repairs and limit the value of the sampling period data. Table D-2 provides a general list of features to inspect and the reasons for the inspection.

Table D-2. A general list of features to inspect at the field site and the reasons for their inspection

General Inspection	Reasons for Inspection
Station & Equipment	
<ul style="list-style-type: none"> • Damage to the enclosure, wires, junction box, and deployment tube. 	<ul style="list-style-type: none"> • Repairs may be necessary.
<ul style="list-style-type: none"> • Signs that the station or sensors have shifted or moved in any way. 	<ul style="list-style-type: none"> • The deployment tube may have been bumped and shifted orientation. • Sensor may be damaged.
<ul style="list-style-type: none"> • Damage to solar panels or telemetry equipment. 	<ul style="list-style-type: none"> • Batteries will not be charged. • Transmission of data hindered.
<ul style="list-style-type: none"> • Field cables cracked or damaged. 	<ul style="list-style-type: none"> • Improper information to data logger.
<ul style="list-style-type: none"> • If flow-through deployment is used, check the pipes and intake screen, ensure that the intake is clean, that water is flowing, and air bubbles are vented. 	<ul style="list-style-type: none"> • Reduced flow will affect water level in the sampling chamber. • Bubbles will cause a vapour lock – particularly with gravity fed systems.
Stream Conditions	
<ul style="list-style-type: none"> • Signs of flooding or high flow (debris in stream, on deployment tube, or on banks). 	<ul style="list-style-type: none"> • Fouling may be extensive. • Some equipment may be damaged.
<ul style="list-style-type: none"> • Signs of bedload movement. 	<ul style="list-style-type: none"> • Changes may affect depth readings of sampling period data. • Bottom deployment sensor may be damaged or moved. • Sensors may be too close to the substrate.

Each operator should generate his/her own list because the details will depend on the equipment at the site, the deployment method, and the stream and weather conditions. Details of the inspection do not have to be recorded on RISC forms, although it is good field practice to summarize the inspection in the station log book. If unexpected values are apparent in the sampling period data, information in the station log book may help explain the values. If equipment is damaged or needs repairs, this information should be added to *RISC CWQ 02. RISC Station Log and Maintenance Form*.

D.5.3.3 Download the Sampling Period Data

Attach the interface cable from the laptop computer or display unit to the deployed sonde and download and view the sampling period data. ***If the sonde must be removed from the water to attach an interface cable between the sonde and the laptop (or display), the actions listed***

in D.5.3.4 should be completed before the data are downloaded. See Section 5.3.5 about removing the sonde.

D.5.3.4 Obtain the Pre-Cleaning Data (D1 & P1) *in situ*

Remember if the sonde must be removed from the water to attach an interface cable, this step should be completed before the previous step (Section D.5.3.3).

1. Connect an interface cable from the portable sonde to the laptop and deploy the portable sonde beside the deployed sonde. In some streams, it may be possible to simply put the portable sonde near the deployed sonde (Figure D-3). However, we *recommend* that the operator install a second deployment tube, for the portable sonde, parallel to, but above the existing tube (Figure D-4). This ensures that the two sondes (D & P) are in the same position, and it frees the operator to record the data.
2. Record the values of the parameters for both the deployed (D1) and portable sondes (P1) in *RISC CWQ – 04. Field and Laboratory Data Part 1: The pre-cleaning, post-cleaning, and re-deployment data*.

Note:

- If the deployed sonde is attached to an external data logger, it may be necessary to communicate with the data logger to check and change the operational settings.
- The information from the two sondes should be obtained as close together in time as possible.

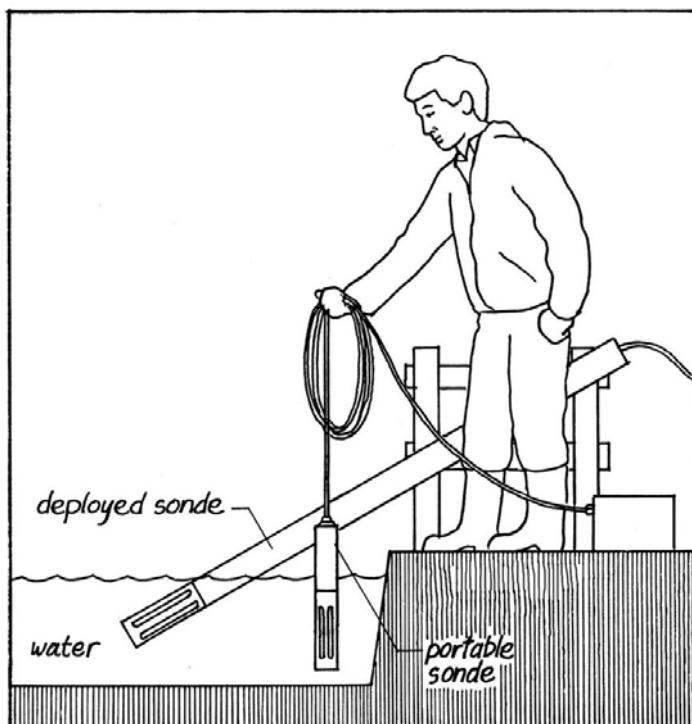


Figure D-3. The portable sonde deployed by the operator beside the deployed sonde.

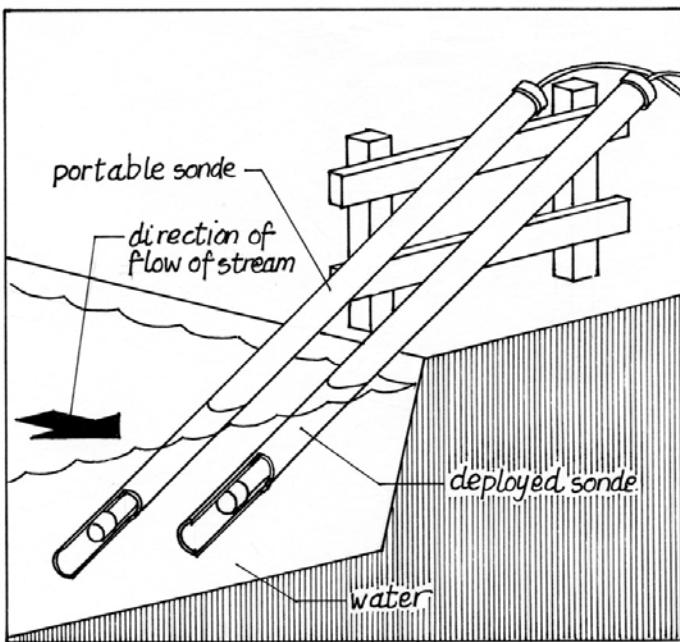


Figure D-4. A second deployment tube for the portable sonde should be installed.

D.5.3.5 Obtain the Pre-cleaning Data (D2 & P2) "in a Bucket of Stream Water"

1. Collect a sample of stream water in a cooler. A cooler is insulated and will help to maintain the water at a stable temperature. Remember to rinse the cooler with stream water.

2. Carefully remove the deployed sonde and examine the guard for attached debris.

Note:

- The sonde should be removed more slowly than the velocity of the stream. This should prevent any material that contributes to fouling from being dislodged.
- It is good practice to take a picture of the sonde.

If there is noticeable debris, this will suggest that this option for obtaining the pre-cleaning data is probably not as suitable as the in situ procedure.

3. Place the deployed sonde beside the portable sonde in a bucket of water (Figure D-5)
4. Record the values of the variables for both the deployed (D2) and portable (P2) sensors in RISC CWQ – 04. Field and Laboratory Data Part 1: Pre-cleaning, post-cleaning, and re-deployments data.

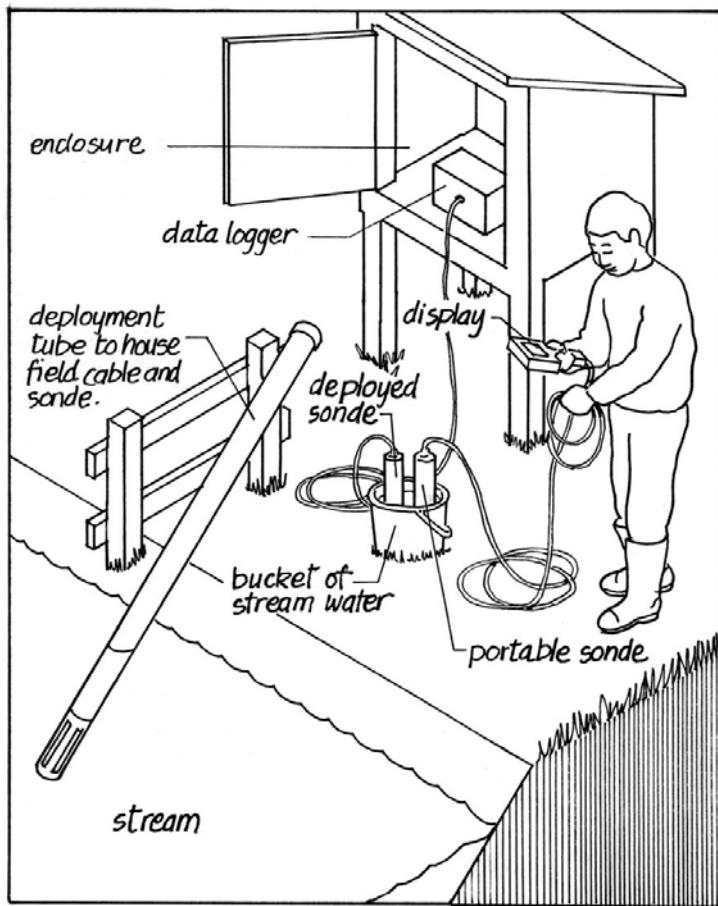


Figure D-5. The deployed sonde and the portable sonde are in a bucket of stream water. Note that the deployed sonde is connected to a data logger.

D.5.3.6 Prepare the Sondes for Transport to a Stable Environment

It is important that the sensors remain moist.

1. Carefully remove the portable sonde from the bucket and prepare it for transport back to the stable environment.

Note:

- Wrap the guard in a damp towel. Another option is to replace the guard with the calibration cup and place a moist sponge on the bottom of the calibration cup.
- Remember to put the cap on the sonde to protect the electronic connections (Figure D-6).

2. Carefully remove the deployed sonde from the bucket. Carefully remove the guard and examine the sensors for fouling and debris. It is good practice to take pictures.

Note:

- A more thorough inspection of the sensors is done in the lab/office.

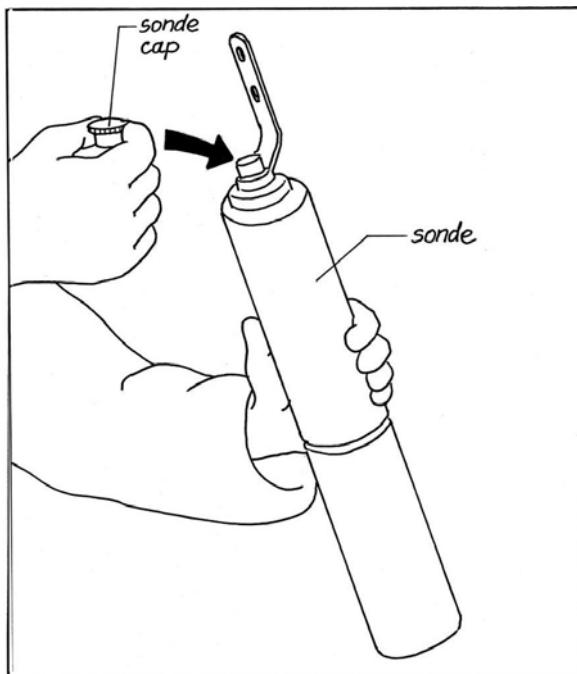


Figure D-6. Recap the sonde to prevent the entry of dirt and moisture.

4. Prepare the deployed sonde for transport to the lab or office. Use the same procedure as for the portable sonde. Remember to re-cap the sonde to protect the electronic connections.

D.5.3.7 Collect Stream Water Samples

1. Collect a stream water sample in a cooler for use in Part 2 and prepare it for transport to the lab or office. The volume must be so that the two sondes can be placed in the cooler.
2. If applicable, collect a stream water sample to submit to a certified laboratory, prepare it for transport, and complete the required forms.

D.5.3.8 Clean the Deployment Tube

Algae, debris and sediment may adhere to the inside of the deployment tube. The tube should be cleaned by sliding a mop down the inside of the tube to remove any debris (Figure D-7) and rinsed by pouring a bucket of stream water down the tube. In addition, check that there is water flowing freely across the stream-opening end of the tube.



Figure D-7. A mop is used to clean the deployment tube. The tube being cleaned is the one housing the deployed sonde. Photo: George Butcher

Go to the next field site and repeat the field steps or move to a stable environment to complete the next steps.

D.5.4 Field and Laboratory Data Part 2 - In a Stable Environment

D.5.4.1 Clean the Sondes and Sensors

The portable sonde and sensors are cleaned and calibrated before the field visit. The deployed sonde is cleaned and calibrated during this second part of the field and laboratory data collection.

The following steps outline the general procedures that should be followed; however, each operator should add to this list as necessary, using the manufacturer's recommended procedures.

1. Ensure that the waterproof cap is still tightly secured on the sonde connector.
2. Prepare the cleaning mixture in a clean bucket. The mixture is warm water and a small amount of biodegradable detergent. A soft cloth is used to do the cleaning.
3. Remove and clean the guard.
Note:
 - Handle the instrument very carefully, particularly when the guard is removed. If the sonde is dropped and knocked against anything (e.g. the bench), the sensors could be damaged.
4. Clean the body of the sonde and then rinse it with distilled water.
5. Carefully clean all of the sensors and examine them to ensure that all of the debris and precipitated salts (e.g. Figure D-8) are removed. If there is extensive fouling, the probes might have to be removed and cleaned.



Figure D-8. A conductivity / temperature sensor before cleaning. Note the cleaned conductivity / temperature probe in Figure D-9. Photo: Linda Gregory

6. Clean the chambers on the conductivity probe. There should be a brush provided by the manufacturer. Do not use a pipe cleaner because it has a wire tip that could damage the sensor.

7. Gently wipe the face of the optics with moist lens paper (or kimwipes).
8. Inspect the pH probes and make sure that the glass bulb and platinum button are free of any foreign material.
9. For both depth and level sensors, use a syringe filled with DI to clean the pressure port. Ensure that the water comes out the other side. For level-vented sensors, ensure that the desiccant is active and regenerate it as necessary. Check the manufacturer's instructions for the specific procedures required for different types of depth and level sensors.
10. Thoroughly rinse the guard and sonde in distilled water.

D.5.4.2 Determine the Post-Cleaning Values in a Bucket of Stream Water.

The stream water that was collected on-site in a bucket / cooler and brought to the lab is used in this step. Recall that stream water is used to reduce the sources of error. Some characteristics of the water will change during transport of the water, but the chemical dynamics of the water will be more similar than another source of water.

1. Place both sondes in the cooler / bucket of stream water as was done at the field site.
2. Record the results for the deployed sensors (D3) and the portable sensors (P3) in *RISC CWQ – 04. Field and Laboratory Data Part 1. Pre-cleaning, post-cleaning, and re-deployment data.*

D.5.4.3 Inspect the Deployed Sonde and its Sensors

Several specific inspections should be completed. If there is a problem with a sensor, the information should be added to *RISC CWQ – 02. Station Log and Maintenance Form*. The details of the inspection are outlined below. The probes of one type of sonde are shown in Figure D-9.

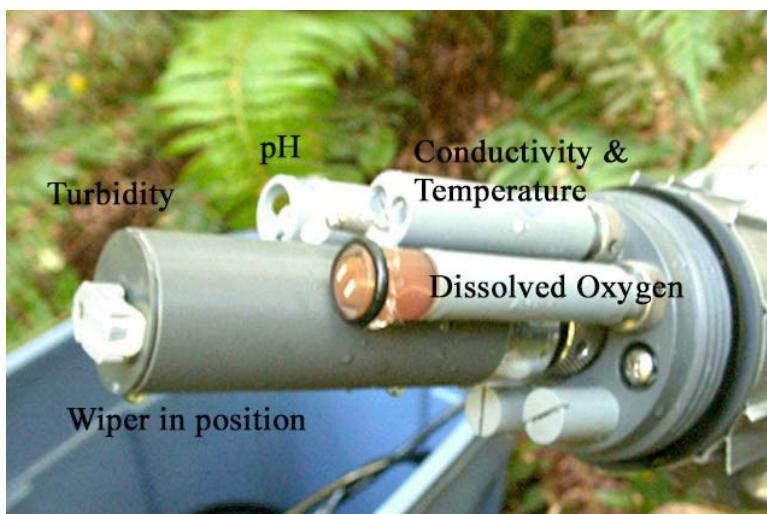


Figure D-9. Examples of some probes used in one kind of sonde. Photo: Judith Burke

The sensor maintenance should be completed AFTER the calibration drift data (C1) are added to *RISC CWQ – 04. Field and Laboratory Data Part 3*, but before the final calibration values (C2) are obtained. In most cases, the data obtained during the calibration procedures will show whether or not further cleaning or maintenance is required.

1. Check the O-rings of the battery chamber to ensure that the seal is still waterproof. If there is any suggestion of water entry, replace the O-ring seal.
2. If there is a gradual decrease in the dissolved oxygen values in the sampling period data, it may be because the Teflon membrane is damaged. Information on changing the membrane is given in Section D.5.4.5 under *Dissolved Oxygen*.
3. Check the anode surface on the dissolved oxygen probes. If there is any tarnish, the probes must be cleaned again using the specific instructions of the manufacturer. (Note the clean anodes in Figure D-9)
4. Check the faces of the optical probes (turbidity and chlorophyll *a*). They should be free of fingerprints and grease. If they are not clean, re-clean with mild detergent and rinse three times with de-ionized water. This can be done before the C1 data are obtained.
5. Check for deposits or contaminants on the glass and/or platinum surfaces of the pH probe, and for any material on the reference electrode junction. This may be the case if the response time is slow, or if the required range of millivolt reading is not obtained. The probe must be removed and cleaned according to the manufacturer's instructions, or replaced.
6. Check the wiper blades. It is highly recommended that turbidity probes with wiper blades are used if there is obvious fouling. If the wiper blades are dirty or worn, they must be replaced because this can affect parking of the wiper. In some cases, it is necessary only to replace the sponge. In other cases, the whole assembly must be replaced. Check with the manufacturer.
7. Check the voltage of the internal batteries. The expected life span of the batteries in different instruments will vary and the minimum allowable voltage will vary. The operator should record these numbers in the logbook. If it is a self-contained sonde, the batteries will have to be replaced at each field visit.

D.5.4.4 Calibration Standards

Standard calibration solutions must be used and recorded on *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*. The standards should be certified by National Research Council (NRC) Canada or National Institute for Standards and Technology (NIST). Appropriate standards for conductivity and pH are available from a variety of suppliers. Distilled water is used to rinse the sensors and to calibrate zero turbidity. A liquid-in-glass thermometer is used to check temperature. At present, there are only four allowable sources of the turbidity standards.

Sources of Turbidity Standards

1. AMCO-AEPA^R polymer bead turbidity standard is available from GFS Chemicals and instrument manufacturers.
2. Formazin prepared as per Standard Methods for the Examination of Water and Wastewater in a certified lab.
3. Dilutions of 4000 NTU formazin concentrate that is purchased from Hach.
4. Hach StablcalTM (stabilized formazin turbidity standard) in different concentrations up to 4000 NTU.

Several important points about turbidity standards warrant mention.

1. Formazin is a polymer solution that has been the accepted primary turbidity standard for several decades. Apart from its excellent light scattering capability, it has three important limitations:
 - (a) Formazin requires agitation or stirring to keep the polymer in suspension. If it is not stirred frequently, the concentration may increase as aliquots are removed.
 - (b) Formazin is only stable at high concentrations. Standards above 400 NTU are stable for \geq 1 year, standards between 20 and 400 NTU are stable for \sim 1 month, standards between 2 and 20 NTU are stable for \sim 12-24 hours, and standards < 2 NTU are stable for 1 hour or less.
 - (c) Formazin is hazardous to human and environmental health. Safe handling precautions are necessary as the precursor compounds are carcinogenic, mutagenic, teratogenic, and tumorigenic (MSDS Sheets, GFS Chemicals Inc.).
2. Hach StablcalTM uses the same polymer as traditional formazin but in a different matrix to enhance stability. All StablcalTM standards (1- 4000 NTU) remain stable for a minimum of 2 years. StablcalTM standards come in varying NTU concentrations and do not require dilution or other preparation other than agitation.
3. Polymer bead turbidity standards (produced by GFS Chemicals Inc.) are non-toxic, stable and do not require agitation. Polymer bead turbidity standards are distributed by the instrument manufacturers and are instrument-specific, i.e. they are specially formulated for each sensor. *These are recommended. Generic polymer bead standards are cheaper to purchase but are not calibrated for sensor type and their use is not RISC standard acceptable.*
4. Different turbidity sensors will give different readings in the same standard but accurate readings in the stream. For example, the YSI 6026 turbidity sensor should be calibrated to 100 NTU in YSI 6073 turbidity standard, but the sensor 6136 should be calibrated to 123 NTU in YSI 6073. This is one example of why it is critical that the information on turbidity standards be obtained from the manufacturer.

D.5.4.5 Collect the Calibration Data

General Comments & Instructions

The sensors should be calibrated in the sequence recommended by the manufacturer and using the procedures recommended by the manufacturer. The sequence used in the manual is as follows:

1. Temperature
2. Conductivity & specific conductivity

3. pH
4. Chlorophyll *a*
5. Turbidity
6. Dissolved oxygen
7. Depth or level (if applicable)

This sequence is used because of some of the characteristics of the parameters.

- Several parameters are temperature-dependent and temperature-compensated and thus temperature should be done first.
- The conductivity standard is 1413 $\mu\text{S}/\text{cm}$ and the pH standards have conductivity values more than five times higher. Therefore conductivity should be done before pH to avoid any possible contamination of the conductivity probe by the pH standards.
- Dissolved oxygen is salinity-compensated and temperature-compensated and therefore dissolved oxygen must be done after both temperature and conductivity. Because it must be left to stand for a period of time it is usually done last.
- Chlorophyll *a* is calibrated in DI and should be done before turbidity.
- Depth or level is done in air and can be done at any time. It is given as the final calibration in the procedures.

The following general procedures should be followed:

- The sensors should be rinsed with distilled water and then with the standard solution. **All rinses should be done three times.** For each rinse, add 3 to 4 cm of solution to the calibration cup and the rotate or swirl the instrument so that the probes are well rinsed. Discard the solution after each rinse.
- The measurement to obtain (C1) and to do the calibration (C2) is in fresh standard solution. This solution is then saved to use as the rinse standard in subsequent measurements. Saving the measurement solution will ensure that there is sufficient standard solution for subsequent rinses.
- In many cases the sondes can be calibrated either upright (Figure D-10, probes down) or upside-down (Figure D-11, probes up). The optical measurements – turbidity and chlorophyll *a* – must be done with the sonde upright. Except for dissolved oxygen, the sensor being calibrated must be immersed in the standards.

The data are recorded on *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*. Remember that the portable sonde is calibrated before the initial field-visit and these data are recorded on *RISC CWQ – 04. Field and Laboratory Data Part 3: Sources of standard calibration solutions and the calibration data for the portable sonde*.

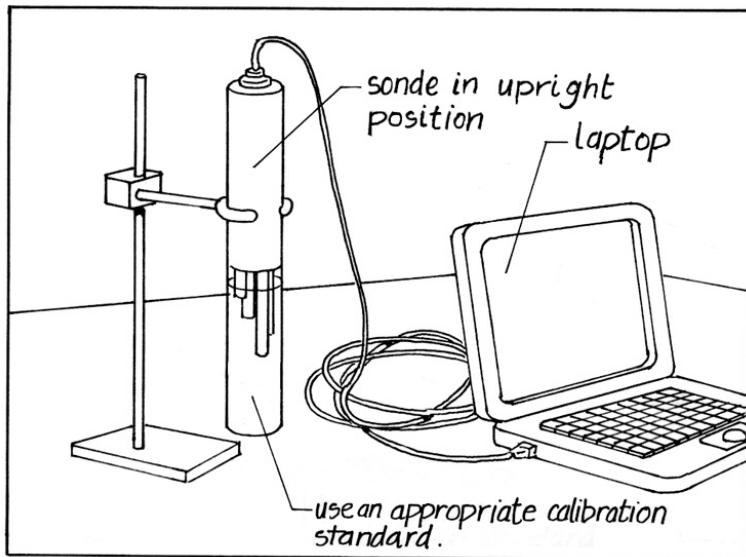


Figure D-10. An upright sonde. This is how the sonde must be positioned for the optical measurements. The volume of solution will vary depending on the sensor being calibrated.

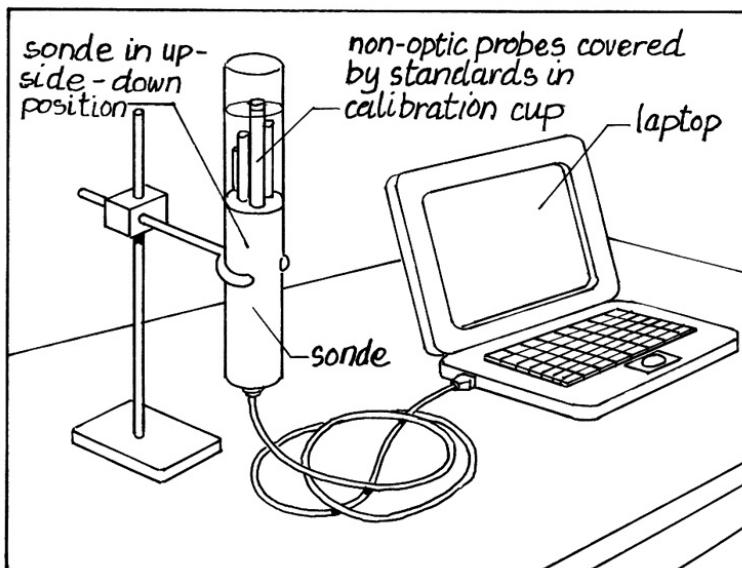


Figure D.11. An upside-down sonde. The volume of solution in the calibration cup depends on the sensor being calibrated. Because optical probes are usually the longest and these measurements must be taken with the probes down, it will not be necessary to cover these probes with the solution.

Temperature

1. Rinse the calibration cup with DI and fill it with DI to cover the temperature probe.
2. Record the temperature in column C1 in *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*.
3. Insert the calibration thermometer (liquid-in-glass & NIST- or NRC-calibrated) in the DI and record the temperature in column C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.
4. If the temperature probe (C1) is not the same as C2, it is not giving the correct temperature and will have to be replaced. If the temperature probe must be replaced, do so before continuing with the calibrations.

Note:

- If the temperature probe is defective and is replaced, it means that the temperature dependant sensors will not have recorded realistic sampling period data. This *must be indicated in the validation report* (Chapter E).

Conductivity / Specific Conductivity

Specific conductivity is the conductivity at 25°C. These sensors are temperature-compensated and thus the result is specific conductivity. However, the temperature dictates the *expected conductivity reading as indicated on the side of the bottle* (Figure D-12). This number must be used as the expected value during the calibration.

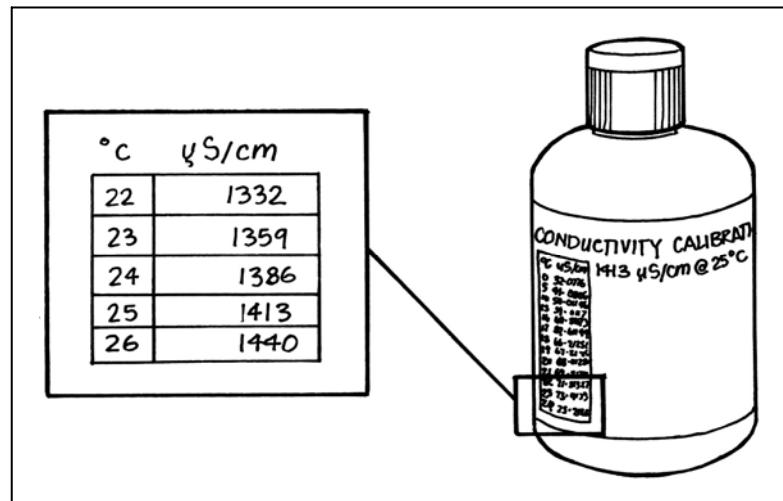


Figure D-12. The expected conductivity value depends on the temperature. Use the correct value from the bottle, based on the temperature of the standard solution.

1. Rinse the probe with DI and then dry the probe.

Note:

- Dry with a kimwipe or hairdryer. Do not use tissues.

- This should give zero $\mu\text{S}/\text{cm}$. If not the sensor may be malfunctioning. Check with the manufacturer.
2. Rinse with the conductivity standard ($1413 \mu\text{S}/\text{cm}$ standard solution is recommended for most freshwaters in British Columbia).
 3. Add the conductivity standard to the calibration cup. The vent hole on the conductivity probe and the temperature probe must be immersed.
 4. Gently move the sonde to remove any bubbles.
 5. Allow the values to stabilize and record the specific conductivity in column C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2*. Remember to give the expected value from the bottle containing the standard calibration solution (Figure D-12) as the correct value.
 6. Re-calibrate if necessary. Record the value in column C2 of *RISC CWQ – 04.: Field and Laboratory Data Part 2*.
 7. Record the cell constant in *RISC CWQ- 04. Field and laboratory Data Part 2*.
 8. Save the standard solution for subsequent rinses.

pH

This is a two-point calibration. The first is always pH 7. If the values in the stream are less than pH 7, the second calibration is pH 4. If the stream values are greater than pH 7, the second standard is pH 10.

The pH depends on temperature and the expected reading at different temperatures is on the bottle of pH buffer. *Enter the expected value from the bottle as the correct pH* (Figure D-13) in the display or laptop, during the calibration procedure.

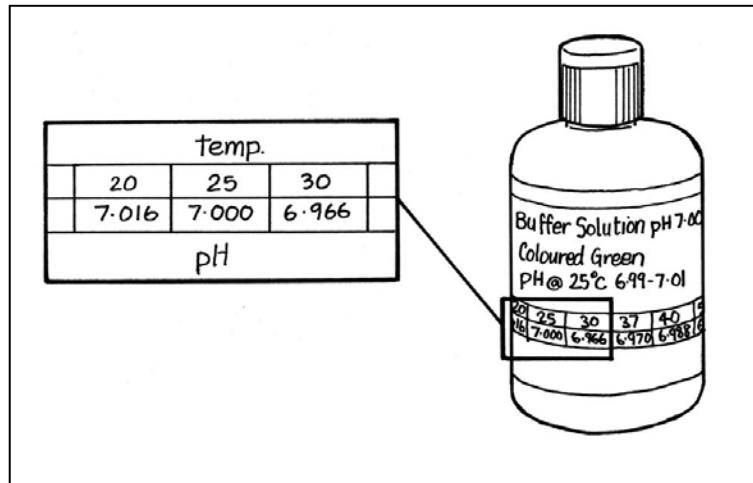


Figure D-13. Check the temperature and use the expected pH value as the correct value.

1. Rinse the probe with DI and then with pH 7 standard.
2. Add pH 7 solution to the calibration cup.
3. When the temperature and pH values stabilize record the pH in column C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*.
4. Re-calibrate if necessary. Remember to use the value based on the temperature that is on the bottle (Figure D-13). Record the value in column C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*. Record the millivolt reading or indicate whether KCl was added to the sensor.
5. Rinse the probe with DI and then with the second pH standard solution (e.g., pH 4)
6. Add the second pH standard solution to the calibration cup and repeat steps 3 & 4 for the second pH. Remember to use the pH value on the bottle based on the temperature of the solution (Figure D-14)

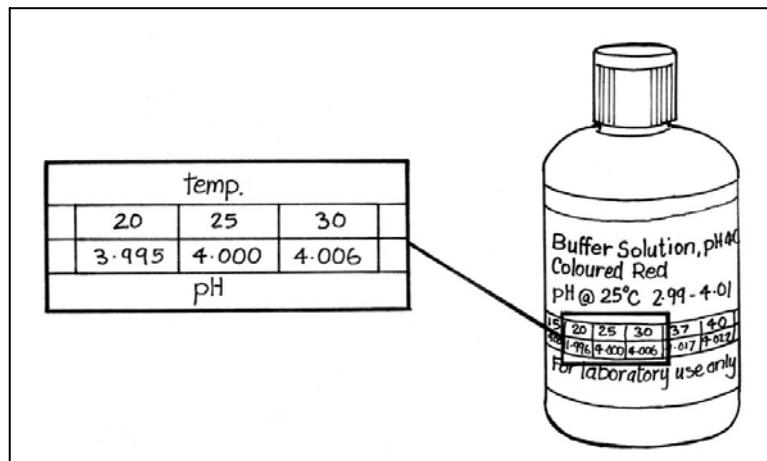


Figure D-14. Check the temperature and use the expected pH as the correct value

7. Record the millivolt reading or indicate whether KCl was added to the sensor.
8. If the mV reading is available use the values given in the RISC form (*RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*) to determine if the probe is operating effectively.

Chlorophyll a

Chlorophyll *a* fluoresces when it is exposed to a particular wavelength of light. There should be no fluorescence in distilled water, an expected fluorescence in a dye, and an expected fluorescence in a pre-measured chlorophyll sample. Calibration drift is determined in distilled water. It is up to the operator to decide the best way to calibrate for the second point. The use of a pre-measured chlorophyll *a* sample is recommended.

1. Rinse the probes with DI water.
2. Add fresh DI and record the reading in C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*.
3. Re-calibrate to zero if necessary. Record the value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*.

Turbidity

This is a two-point calibration: 0 NTU using DI, and a second standard such as 100 NTU. The general recommendation is 100 NTU, but the operator can use a different concentration. In all cases the calibration for 0 NTU is done first.

It must be emphasized again that the proper standards must be used and the expected value in different standards must be known. The operator must know the appropriate standard and the expected value. The expected value for different sensors is on the bottle of the standard solution. **Please refer to point 4 in Section D.5.4.4**

Use the calibration cup provided by the manufacturer. Do not use white or opaque cups as reflection from light-coloured surfaces can cause incorrect high readings in low NTU water.

Add solutions to the calibration cup very slowly so that there are no bubbles. It helps if the calibration cup is held at an angle.

1. Rinse the probes with DI and then add DI to the calibration cup.

Note:

- If the probe has a turbidity wiper, ensure that the wiper is parking properly . Check with the manufacturer as to the correct parking position (Figure D-15).



Figure D-15. A turbidity probe with a wiper in the correct position. Photo: Hoskin Scientific

2. Clear the optics by activating the wiper.
3. Record the value in column C1 of *RISC CWQ – 04. Field and Laboratory Data Part 2: Sources of standard calibration solutions and the calibration data for the deployed sonde*.

4. Re-calibrate if necessary and record the calibrated value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.
5. Rinse the probes with DI and then with the second standard (e.g. 100 NTU).
6. Add the second standard to the calibration cup.
7. Re-calibrate if necessary. Record value in C2 of *RISC CWQ – 04. Field and Laboratory Data Part 2*.

Dissolved Oxygen

This is a one-point calibration in a saturated environment.

1. If there is a sleep mode and warm up time when the sonde is deployed this must be modified during calibrations.
2. Rinse the calibration cup with DI water.
3. Add distilled water to the calibration cup as instructed by the manufacturer. This varies among manufacturers so be sure that the correct amount of water is added.
4. Loosely add the calibration cup to the sonde. The seal must be loose to allow ambient barometric pressure equilibration. Wait 10 to 15 minutes.
5. When the temperature stabilizes, record the temperature and the dissolved oxygen (%) and mg/l in *RISC CWQ – 04. Field and Laboratory Data Part 2*.
6. Check and record the barometric pressure (BP) in *RISC CWQ – 04. Field and Laboratory Data Part 2*.
7. Using the BP, re-calibrate the sensor. Record the calibrated values in % and in mg/l.

Note:

- If % dissolved oxygen is recorded the sensor must be re-calibrated for barometric pressure in the field. However, % DO is not required as a field parameter for a data grade, only mg/l is included.
- **If the dissolved oxygen membrane is damaged it must be replaced.** After the membrane is replaced it must be allowed to relax. In general, the membrane should be changed the day before a field visit, but new membranes can be burned in more rapidly, in some cases. The operator should check with the manufacturer on the required times and procedures.

Depth and Level (if appropriate)

The calibration for both depth and level sensors is done in air. Depth sensors are non-vented and are affected by changes in barometric pressure while they are deployed. Level sensors are vented and do not vary with changes in barometric pressure during deployment. However, in both cases, the calibration is in air (zero depth or level) at the barometric pressure at the time of calibration.

1. Determine the depth reading in air. Record the value in the field notes.

2. Calibrate the sensor to zero for the given barometric sensor.

D.5.4.6 Run the Calibrated Sensors in Tap Water

After the sensors are calibrated and the calibration drift data are recorded it is recommended that the sensors are put in tap water and data recorded for 0.5 to 1 hour (Figure D-16). The data should be examined to ensure that they are reasonable and consistent. If they are not, one or more sensors may have to be replaced.

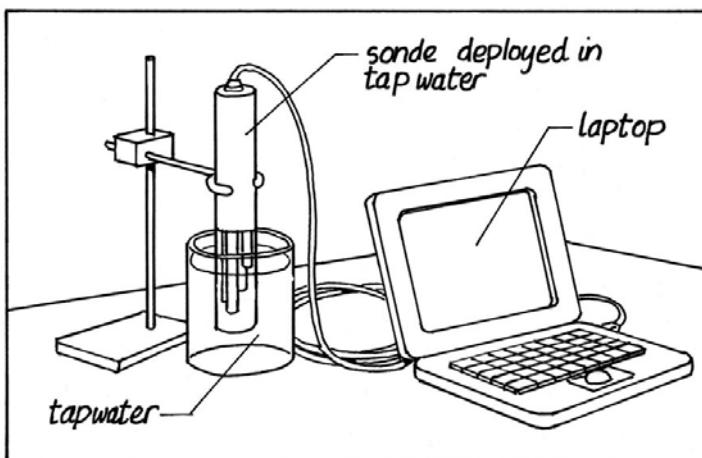


Figure D-16. Put the calibrated sensors in tap water to ensure that they are recording consistent and reasonable values.

D.5.4.7 Prepare the sondes for transport to the field site

The sondes should be transported back to the field site in the same way they were transported from the field site to a stable environment.

Return to the field site to re-deploy the sondes

D.5.5 Field and Laboratory Data, Part 3: At the Field Site – The Re-deployment Visit

There are three steps to the third stage:

1. Obtain the re-deployment data (D4 & D5) "in a bucket of stream water"
2. Re-deploy the sonde and obtain the re-deployment Data (D5 & P5) in situ
3. Prepare the portable sonde for transport

D.5.5.1 Obtain the re-deployment data (D4 & D5) "in a bucket of stream water"

These data are collected to ensure that the deployed sonde is working correctly on-site before the sondes are re-deployed.

1. Collect a stream water sample in a bucket.
2. Place the deployed sonde and portable sonde in the bucket (Figure D-17). Attach an interface cable from the sonde to the laptop or display, and record the data for both the deployed sonde (D4) and the portable sonde (P4) in *RISC CWQ – 04. Field and Laboratory Data Part 1: The pre-cleaning, post-cleaning and re-deployment data*.

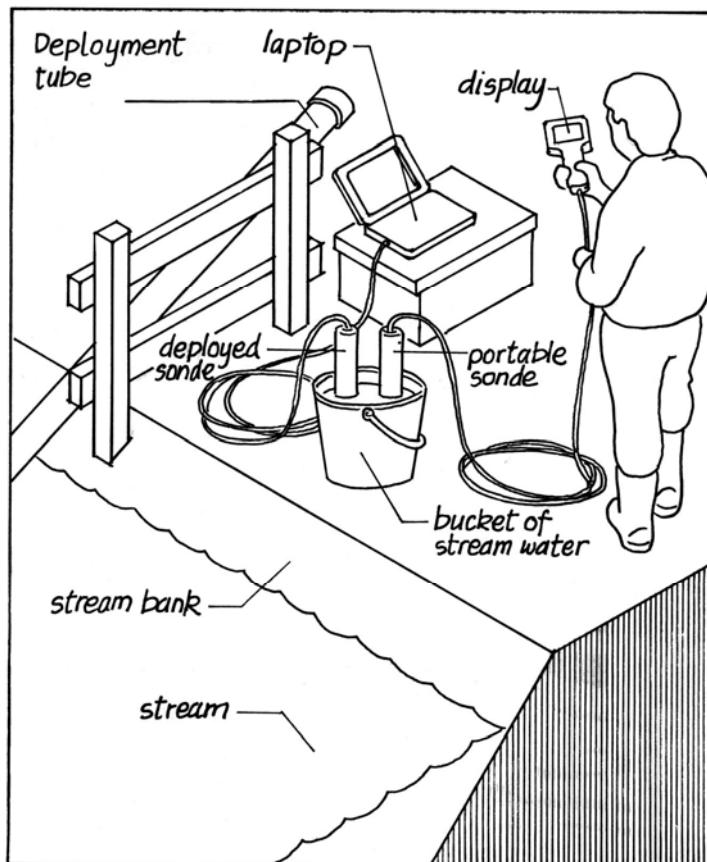


Figure D-17. The deployed sonde and the portable sonde in a bucket of stream water. Note that the deployed sonde is self contained. Also see Figure D-5.

D.5.5.2 Obtain the Re-deployment Data (D5 & P5) in situ

These are the first values for the new set of sampling period data.

1. Deploy the deployed sonde and obtain a reading. Record the readings in column D5

RISC CWQ – 04. Field and Laboratory Data Part 1: The pre-cleaning, post-cleaning, and re-deployment data.

Note:

- If the deployed sonde is attached to an external data logger (e.g. Figure D-5) it may be necessary to communicate with the data logger and check the operational settings. If this is done, make sure that the settings are returned to the deployed mode after the reading is taken.

2. Put the portable sonde in the second deployment tube (Figure D-18).

Note:

- As in the preliminary visit, we recommend that the portable sonde is in a deployment tube as shown in Figure D-18.
- In cases where the water is slow moving, it may be possible to put the portable sonde near the deployed sonde (Figure D-4).

3. Record the readings in P5 of *RISC CWQ – 04. Field and laboratory Data Part 1: The pre-cleaning, post-cleaning, and re-deployment data.*



Figure D-18. Deploy the portable sonde in its own deployment tube. Photo: George Butcher

D.5.5.3 Prepare the Portable Sonde for Transport

Remove the portable sonde and prepare it for transport to the next site or to the stable environment. Remember to put the cap on the sonde. If the portable sonde is returned to the stable environment, the sensors must be stored as recommended by the manufacturer.

D.5.5.4 Compete the departure information on RISC CWQ – 02. Station Log and Maintenance Form

This is the same form used to add the arrival information (Section D.5.3.1).

This completes the collection of the field and laboratory data.

E. Validation

“All things are ready, if our minds be so.”

William Shakespeare

Validation is the set of procedures used to complete the quality assessment requirements of a continuous water-quality sampling program (Chapter B). It is a systematic evaluation of all of the data (meta and numerical) to find and deal with errors and to assign data grades. The validation process is completed by the operator after each field visit. There are five steps, each of which is explained in a section of this chapter. All of the calculations are completed in Excel programs. The Excel programs for steps 2 and 3 are in Appendix 2 and the programs for steps 4 and 5 are in Appendix 3. Appendix 4 is a check list of the validation steps. The operator should use Appendix 4 to document the completion of each step and to add comments as necessary about the validation results. Ultimately, Appendix 4 will be generated within the data repository (Section E.8).

1. Examine the RISC forms to ensure that they are complete.
2. Determine the data grade for each parameter.
3. Compare field data collected *in situ* vs. "in a bucket of stream water".
4. Examine the sampling period data for data gaps and data anomalies and flag the data, if necessary.
5. Determine the percent of the sampling period data (for each parameter) that are flagged.

Steps 1 to 3 use the field and laboratory data, and steps 4 and 5 use the sampling period data. As in all cases, the laboratory data are those obtained in a stable environment.

This chapter outlines each of the given steps. It concludes with sections on the use of the data grades and the storage of the data and subsequent analyses.

E.1 Validation Step 1 – Examine the RISC Forms

The operator or the person working for the operator completes the RISC Forms. The first step in validation is to confirm that the forms are complete for each station. There are four forms, but only two are completed during each field visit. *RISC CWQ – 01. Station Design* is completed when the station is first established and if any of the equipment is updated or replaced. Similarly, *RISC CWQ – 03. Specifications of the Portable Sensors* is completed initially and then if the sonde or sensors are replaced. Data are added to *RISC CWQ – 02. Station Log and Maintenance Form* and to *RISC – CWQ – 04. Field and Laboratory Data* during each field visit.

The operator should review forms to ensure that they are complete and then check the appropriate boxes and add comments as necessary in the validation summary (Appendix 4).

E.2 Validation Step 2 - Determine the Data Grades

Data grades rate the sensor performance. They are based on sensor error due to fouling and calibration drift. During the laboratory procedures in a stable environment, sensor malfunction will be detected and will be incorporated into the measure of calibration drift.

E.2.1 Criteria for Data Grades

The data grades are based on the accuracies of the sensors, similar to the ratings used by Wagner et al. (2006). Four important points about the data grades are given below.

1. There are *five* levels in Table E-1 (excellent, very good, good, fair, and poor). Each level is a multiple of the accuracy – to the nearest tenth, when applicable – of the sensors commonly used in British Columbia.
 - As sensor technology improves, the grades may be modified. For example, new turbidity sensors have a better accuracy at low turbidity values. These sensors are not yet common in British Columbia so the new accuracy level is not used for the data grade.
2. The accuracy used for specific conductivity is *not* the accuracy given for the conductivity sensors.
 - The accuracy specification for the conductivity probe is $\pm 0.5\%$ of the reading + 1 $\mu\text{S}/\text{cm}$ (e.g. <http://www.hydrolab.com>; <http://www.YSI.com>). The criteria chosen for the highest data grade for specific conductivity are $\pm 3 \mu\text{S}/\text{cm}$ for values $\leq 100 \mu\text{S}/\text{cm}$ and $\pm 3\%$ of the reading for values $> 100 \mu\text{S}/\text{cm}$. These criteria exceed the calculated criteria specified by the manufacturers for conductivity, but several factors were considered.
 - (a) At low conductivity values 3 % of the reading is less than the resolution and accuracy of the sensors, therefore 3 $\mu\text{S}/\text{cm}$ is used.
 - (b) Specific conductivity depends on temperature and the ions present. The temperature is measured, but the ions present are not known and thus the algorithm used to determine specific conductivity from conductivity is an approximation.
 - (c) Specific conductivity is used as an indication of total dissolved solids. It is not generally a water-quality objective.
3. In cases where the accuracy is specified as a set value or a percent of the reading, whichever is greater, the dividing point where the accuracy goes from the set amount to a percent is given.
 - This applies to dissolved oxygen (0.2 mg/l or 5% of reading, whichever is greater), turbidity (2 NTU or 5% of reading, whichever is greater), and specific conductivity (see above). At levels $\leq 4 \text{ mg/l}$ dissolved oxygen, $\pm 2 \text{ mg/l}$ is greater than 5% of the reading. Above 4 mg/l, 5% of the reading is greater than 2 mg/l. Similarly, for turbidity levels $\leq 40 \text{ NTU}$, $\pm 2 \text{ NTU}$ is greater than 5% of the reading and $> 40 \text{ NTU}$, 5% of the reading is greater than 2 NTU.
4. No data grades are given for chlorophyll *a* or depth and level.
 - YSI does not give the accuracy for chlorophyll *a*. Hydrolab says $\pm 3\%$ for signal level equivalents of 1 ppb rhodamine WT dye. The operator should develop her/his curve for known levels of chlorophyll *a*.
 - The accuracy of depth and level sensors depends on the sensor type and depth. The operator can develop his/her own data grades. See point number 1.

Table E-1. Data grades are based on sensor error. See text for criteria used to obtain the grades.

Parameter	Data Grade Criteria				
	Excellent	Very Good	Good	Fair	Poor
Temperature	$\leq \pm 0.2^{\circ}\text{C}$	$> \pm 0.2 \text{ to } 0.4^{\circ}\text{C}$	$> \pm 0.4 \text{ to } 0.6^{\circ}\text{C}$	$> \pm 0.6 \text{ to } 0.8^{\circ}\text{C}$	$> \pm 0.8^{\circ}\text{C}$
Specific conductance ($\leq 100 \mu\text{S}/\text{cm}$)	$\leq \pm 3 \mu\text{S}/\text{cm}$	$> \pm 3 \text{ to } 6 \mu\text{S}/\text{cm}$	$> \pm 6 \text{ to } 9 \mu\text{S}/\text{cm}$	$> \pm 9 \text{ to } 12 \mu\text{S}/\text{cm}$	$> \pm 12 \mu\text{S}/\text{cm}$
Specific conductance ($> 100 \mu\text{S}/\text{cm}$)	$\leq \pm 3\%$ of reading	$> \pm 3 \text{ to } 6\%$ of reading	$> \pm 6 \text{ to } 9\%$ of reading	$> \pm 9 \text{ to } 12\%$ of reading	$> \pm 12\%$ of reading
pH	$\leq \pm 0.2$ pH units	$> \pm 0.2 \text{ to } 0.4$ pH units	$> \pm 0.4 \text{ to } 0.6$ pH units	$> \pm 0.6 \text{ to } 0.8$ pH units	$> \pm 0.8$ pH units
Turbidity ($\leq 40 \text{ NTU}$)	$\leq \pm 2 \text{ NTU}$	$> \pm 2 \text{ to } 4 \text{ NTU}$	$> \pm 4 \text{ to } 6 \text{ NTU}$	$> \pm 6 \text{ to } 8 \text{ NTU}$	$> \pm 8 \text{ NTU}$
Turbidity ($> 40 \text{ NTU}$)	$\leq \pm 5\%$ of reading	$> \pm 5 \text{ to } 10\%$ of reading	$> \pm 10 \text{ to } 15\%$ of reading	$> \pm 15 \text{ to } 20\%$ of reading	$> \pm 20\%$ of reading
Dissolved oxygen ($\leq 4 \text{ mg/l}$)	$\leq \pm 0.2 \text{ mg/L}$	$> \pm 0.2 \text{ to } 0.4 \text{ mg/L}$	$> \pm 0.4 \text{ to } 0.6 \text{ mg/L}$	$> \pm 0.6 \text{ to } 0.8 \text{ mg/L}$	$> \pm 0.8 \text{ mg/L}$
Dissolved oxygen ($> 4 \text{ mg/l}$)*	$\leq \pm 5\%$ of reading	$> \pm 5 \text{ to } 10\%$ of reading	$> \pm 10 \text{ to } 15\%$ of reading	$> \pm 15 \text{ to } 20\%$ of reading	$> \pm 20\%$ of reading

* The sensors may be less accurate for values $> 20 \text{ mg/l}$.

E.2.2 Calculate and Record the Data Grade

Five steps are required to determine the data grade for each sensor. These are explained below, *but all of the calculations and the assignment of the data grade are completed in the Excel program (Appendix 2)*. The final data grade can be added to the validation summary table (Appendix 4).

1. Calculate fouling.
2. Calculate calibration drift.
3. Change the fouling and calibration drift to a percent of the reading, if required.
4. Use the fouling and the calibration drift values to determine sensor error.
5. Determine and record the data grade.

E.2.2.1 Calculate Fouling

The data that are used to complete the calculations are in *RISC CWQ – 04. Field and Laboratory Data*. These should be transferred to page 1 of the Excel program in Appendix 2. Eventually, this will be completed in the data repository. The reader might want to refer to Figure D-2 and Table D-1 to review the data that are collected.

Option 1: The pre-cleaning data for both sondes (D1 & P1) are collected in situ. The post-cleaning data (D3 and P3) are collected "in a bucket of stream water" that is transported to the stable environment (lab).

$(D1 - D3) = \text{fouling of deployed sensor plus changes in the stream water due to transport to the stable environment}$. Although stream water is used for both measurements, the pre-cleaning data are collected in situ and the post-cleaning data are collected "in a bucket of stream water" that is transported to the lab.

$(P1 - P3) = \text{Change in stream water due to transport to the stable environment}$.

$(D1 - D3) - (P1 - P3) = \text{fouling (F)}$. The change in stream water due to transport to the stable environment is subtracted from the fouling plus the change in the stream water.

Option 2: The pre-cleaning data for both sondes (D2 & P2) are collected "in a bucket of stream water". The post-cleaning data (D3 and P3) are collected "in a bucket of stream water" that is transported to the stable environment.

$(D2 - D3) = \text{fouling of deployed sensor plus changes in stream water due to transport to the stable environment}$. The explanation is the same as for $(D1 - D3)$, except that the pre-cleaning data are obtained with the sonde "in a bucket of stream water".

$(P2 - P3) = \text{Change in stream water due to transport to the stable environment}$.

$(D2 - D3) - (P2 - P3) = \text{fouling (F)}$. The change in stream water due to transport to the stable environment is subtracted from the fouling plus the change in the stream water.

E.2.2.2 Calculate Calibration Drift

$(C1 - C2) = \text{calibration drift (CD)}$ in standard calibration solutions.

Note:

- $(D3 - P3)$ is the difference between the cleaned deployed sensor and the cleaned and calibrated portable sensor. Therefore it is a measure of calibration drift in stream water plus differences between sensors. This calculation is not included in Appendix 2, but the operator might want to compare the difference to $(C1 - C2)$.

E.2.2.3 Change the total amount to a percent of the reading, if required.

The data grades are expressed either as a set value or as a percentage of the reading (Table E-1). The grades for temperature and pH are always a set value, whereas those for specific conductivity, turbidity, and dissolved oxygen are a percentage of the reading, except at the low end of the range. The difference - specific amount *vs.* percentage of the reading - is a result of the type of relationship between the observed and the expected values as the concentration increases (Figure E-1). In cases where the observed value is a consistent percent greater or less than the expected value, the actual deviation increases as the concentration of the parameter increases (Figure E.1a). In other cases, the observed value is a consistent amount less or greater than the expected value (Figure E.1b).

In cases where there is both a set value and a percent, the set value is used at the lower concentrations due to the decreased accuracy (increased possible electrical noise) of the sensors at the extremes (e.g. low end) of the measurement range (Section C.2.1).

Determine fouling as a percent of the reading

Fouling as a percentage of the reading is the observed value minus the expected value divided by the observed value, converted to a percent. The observed value minus the expected value is the arithmetical difference. It is the fouling (F) that is calculated as shown in Section E.2.2.1. The observed value is D1 (pre-cleaning value *in situ*) in option 1 and D2 (pre-cleaning value "in a bucket of stream water" in option 2. The calculation for options 1 and options 2 are given below.

Option 1

Fouling as a % of the reading = $100(F / D1)$

Where:

$F = (D1 - D3) - (P1 - P3)$ from Section E.2.2.1

D1 = pre-cleaning value of the parameter *in situ*

Option 2

Fouling as a % of the reading = $100(F / D2)$

Where:

$F = (D2 - D3) - (P2 - P3)$ from Section E.2.2.1

D2 = pre-cleaning "in a bucket of stream water"

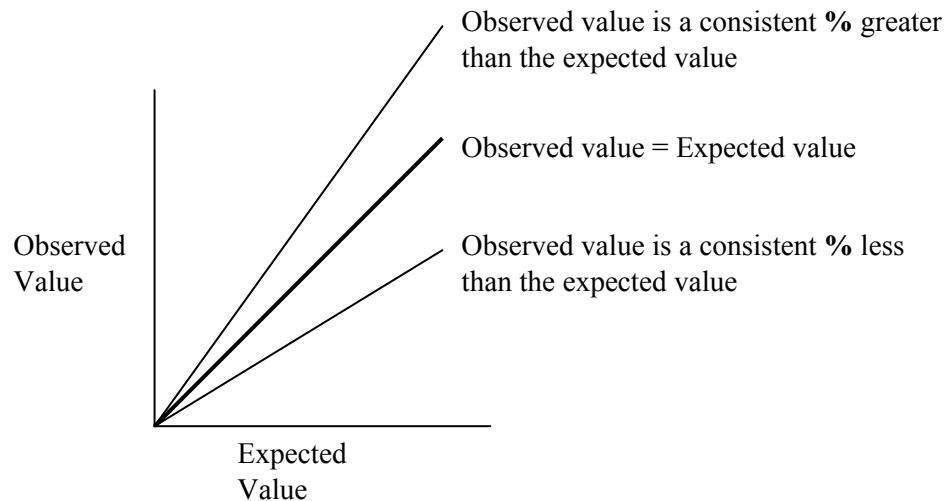
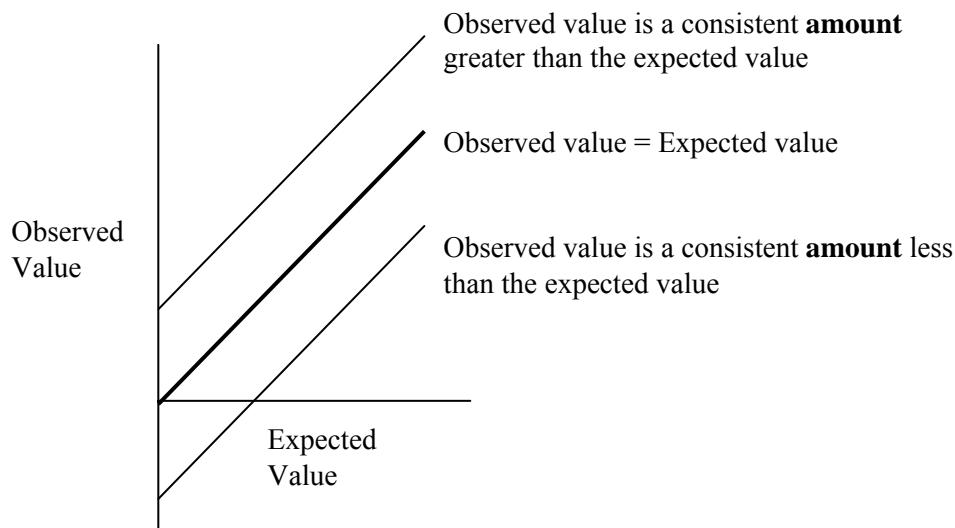
(a) Data Grade as a Percent of the Reading**(b) Data Grade as a Specific Amount**

Figure E-1. The relationship between the observed values and expected values when for parameters for which the data grade is (a) a percentage of the reading and (b) a specific amount. See text for details.

Determine calibration drift as a percentage of the reading

Calibration drift as a percentage of the reading = $100 \times (CD / C1)$

Where:

CD = calibration drift from Section E.2.2.2

C1 = value from cleaned sensor before calibration

E.2.2.4 Use the fouling and the calibration drift values to determine sensor error.

Sensor error is used to obtain the data grade. It is either a set amount or as a percentage of the reading. In both cases (set amount and % of reading), it is the sum of the absolute values of the two sources of error. The absolute values are used so that the two errors are not artificially reduced or cancelled. Separation of the sources of error is important in assessing how the data should be corrected.

Sensor error as a set value

$$\text{Sensor error} = |F| + |CD|$$

Where:

F is from option 1 or 2 in Section E.2.2.1

CD is from Section E.2.2.2

Sensor error as a percentage of the reading

$$\text{Sensor error} = |F \text{ as a \% of the reading}| + |CD \text{ as a \% of the reading}|$$

Where

F as a % of the reading is from option 1 or 2 in Section E.2.2.3

CD as a % of the reading is from Section E.2.2.3

E. 2.2.5 Determine and record the data grade.

The sensor error is compared to values for the different grades in Table E-1. The data grade is recorded in Appendix 4.

E.3 Validation Step 3 - Compare data obtained in situ with those obtained "in a bucket of stream water".

There are two times that the measurements are made both in situ and "in a bucket of stream water". These two sets of data are collected during the visits to the field site to obtain the pre-cleaning data and the re-deployment data.

The comparisons are completed by the Excel program in Appendix 2. In all cases, the difference between the two readings is divided by the accuracy of the sensor. This is the value given for the "excellent" data grade. If the resulting value is ≤ 2 , the comparison is acceptable. This means that the difference is equal to or less than two times the accuracy of the sensor. The factor of 2 is used because the data are from two sensors (portable and deployed). The differences between the two sensors should cancel out in the calculations, but 2 times the accuracy is used to ensure that positive (acceptable) results are not rejected.

Both the *in situ* and "in a bucket of stream water" measurements are taken for the first three or four visits to the site. If the differences are acceptable for the data collected during these three to four visits, the operator can use the procedure he/she finds most appropriate for a given site. If the comparisons are not acceptable, the operator should use her/his knowledge of the equipment and the site to determine why the comparisons are different. Some reasons for an unacceptable comparison are listed below.

- A malfunctioning sensor in either the deployed or the portable sonde
- Rapidly changing in-stream conditions
- Bubbles on the sensor
- A dirty deployment tube
 - Recall that the deployment tube must be cleaned at the end of the preliminary field visit. Debris in the tube may be added to the sonde as it is removed. This would affect the pre-cleaning values "in a bucket of stream water"
 - If the tube is not properly cleaned, the sonde and sensors may collect debris during the re-deployment and this would affect the *in situ* readings
- Improper flow across the bottom of the deployment tube(s)
- This may be due to sediment deposition, some upstream blockage of water flow, or a poorly designed deployment tube (Figure E-2)

Both options should be continued until the operator can reasonably explain the differences.



Figure E-2. A poorly designed deployment tube. The section of the tube that covers the guard of the sonde is a heavy metal with slots that are easily clogged with debris, preventing a good flow of water across the tube. Photo: George Butcher.

E.3.1 Comparison of pre-cleaning data obtained *in situ* vs. "in a bucket of stream water"

As a set value

$$((D1 - P1) - (D2 - P2)) / \text{accuracy of the sensor}$$

As a percent of the reading

$$((100(D1 - P1) / D1) - (100(D2 - P2) / D2)) / \text{accuracy of the sensor}$$

Where:

- (D1 – P1) = the difference between the pre-cleaning value of the deployed sensor and the portable sensor measured *in situ*
- (D2 – P2) = difference between the pre-cleaning value of the deployed sensor and the portable sensor measured "in a bucket of stream water".

E.3.1 Comparison of re-deployment data obtained *in situ* vs. "in a bucket of stream water"

As a set value

$$((D4 - P4) - (D5 - P5)) / \text{accuracy of the sensor}$$

As a percent of the reading

$$((100(D4 - P4) / D4) - (100(D5 - P5) / D5)) / \text{accuracy of the sensor}$$

Where:

- (D4 – P4) = the difference between the re-deployment value of the deployed sensor and the portable sensor measured *in situ*.

- (D5 – P5) = difference between the re-deployment value of the deployed sensor and the portable sensor measured "in a bucket of stream water".

This is a final check that the sensors are functioning properly and that there is no effect due to re-deploying the sonde. *The D5 values are the start of a new set of sampling period data.*

E.4 Validation Step 4– Examine the Sampling Period Data

The sampling period data are the data collected on a data logger while the operator is absent. These data provide information about the water chemistry of the stream. If there is minimal sensor error and the data grade for the sensors is excellent, the sampling period data should be excellent. However, the sampling period data should be plotted and examined for unreasonable values, abrupt changes, prolonged changes, and data gaps. These are discussed below.

E.4.1 Unreasonable (Suspect) Values

Some sampling period data may be unreasonable or suspect and should be flagged and removed from subsequent analyses. Four categories used to identify unreasonable values. The abbreviations used in the tables and the Excel program are the check (✓) statements.

- Values that exceed the range of a sensor. This is called ✓range.
- Values that are truncated. This is called ✓truncation.
- Cases in which adjacent values exceed the accuracy of the sensor. This is called ✓accuracy.
- Values that are negative - except for temperature.

The criteria and calculations for each of these categories are discussed in the following four sections. The sampling period data are added to the Excel program in Appendix 3. These are done after each field visit and thus the sampling period data should be easily accommodated

in the Excel spreadsheet. Note that there is one sheet for each parameter. After the data are flagged, *it is the responsibility of the operator to accept or reject the flagged data.*

The criteria used to check for unreasonable (suspect) data are based on the information for the sensors commonly used in British Columbia. The accuracy and range of the sensors is given in RISC CWQ – 01. Station Design. If any of these criteria differ from the ones used in the Excel programs, they can be modified, but *only after consultation with Ministry of Environment staff.*

E.4.1.1 Values exceed the range of the sensors

The Excel program given in Appendix 3 uses the heading \checkmark range to flag values that exceed the range of each sensor. The criteria for the main sensors that are incorporated into the Excel program are summarized in Table E.2.

E.4.1.2 Truncated values

The Excel program in Appendix 3 uses the column heading \checkmark truncation to determine if values are truncated. This occurs when the sampling period data values exceed the range of the sensors. If a spike stays at the upper or lower range of the sensor, the values may be truncated. The criteria used in the Excel program are summarized in Table E-3.

E.4.1.3 Adjacent measurements exceed accuracy range of the sensor.

The Excel program in Appendix 3 uses the column heading \checkmark accuracy for this test. The criteria incorporated into the Excel program are based on the sensors commonly used in British Columbia. These are summarized in Table E-4.

E.4.1.4 Negative Values (except temperature)

This will be apparent in the \checkmark range test below, because the low range is zero, except for temperature. If the turbidity is very low negative values may result; it should be checked by the operator.

Table E-2. Criteria used to flag sampling period data that are off scale (\checkmark range)

Parameter	Units	\checkmark range
Temperature	°C	If temperature = < -5 or > 45°C, flag the value. If not, use the given value.
Specific Conductivity	µS/cm	If spec. cond. < 0 or > 100 000, flag the value. If not, use the given value.
pH	pH units	If pH < 0 or > 14, flag the value. If not, use the given value.
Turbidity	NTU	If turbidity < 0 NTU or > 1000 NTU, flag the value. If not, use the given value.
Dissolved Oxygen	mg/l	If DO < 0 mg/L or > 50 mg/L, flag the data If not, use the given value.

Table E-3. Criteria used in ✓ truncation to determine if the values are truncated.

Parameter	Units	✓truncation
Temperature	° C	If temperature = -5 or 45°C, flag the value. If not, use the given value.
Specific Conductivity	µS/cm	If spec. cond. = 0 or 100 000, flag the value. If not, use the given value.
pH	pH units	If pH = 0 or 14, flag the value. If not, use the given value.
Turbidity	NTU	If turbidity = NTU or 1000 NTU, flag the value. If not, use the given value.
Dissolved Oxygen	mg/l	If DO = 0 mg/L or 50 mg/L, flag the data If not, use the given value.

Table E-4. Criteria used in ✓ accuracy (Appendix 3) to determine if adjacent measurements exceed the accuracy range of the sensors.

Parameter	Units	✓accuracy
Temperature	° C	If the difference in temperature between adjacent values is > 0.2, flag the first value. If not, use the given value.
Specific Conductivity	≤100 µS/cm	If the difference in spec. cond. between adjacent values, is > 3, flag the value. If not, use the given value.
	> 100 µS/cm	If the difference between adjacent spec. cond. values, divided by the first of the two values, is > 0.03, flag the value. If not, use the given value.
pH	pH units	If the difference in pH between adjacent values is > 0.2, flag the first value. If not, use the given value.
Turbidity	≤ 40 NTU	If the difference in turbidity between adjacent values is > 2, flag the value. If not, use the given value.
	> 40 NTU	If the difference between adjacent turbidity values, divided by the first (of the two) values, is > 0.05, flag the value. If not, use the given value.
Dissolved Oxygen*	mg/l	If the difference between adjacent dissolved oxygen values, divided by the first (of the two) values, is > 0.05, flag the value. If not, use the given value.

* ✓accuracy for dissolve oxygen is checked only for the accuracy of 5% of the reading.

E.4.2 Abrupt Changes

Abrupt changes in the levels of different parameters are frequently related to changes in flow, but may also be affected by groundwater input and biological activity. If possible, the reason for the abrupt change should be documented. If there is no apparent reason for the abrupt change, the value(s) should be flagged. This should be apparent from the flags in ✓ accuracy.

E.4.3 Prolonged Changes

Prolonged changes may be due to an in-stream event that damaged the sensor, fouled the sensor, or to a malfunctioning sensor. This may be apparent in a sudden and continued increase (e.g. turbidity), a gradual decrease (e.g. dissolved oxygen), or inconsistent (unstable) readings (e.g. pH or specific conductivity). This should be apparent from the data grade. It can be used to assist in correcting the data because the starting point of the change can be identified.

E.4.4 Data Gaps

Missing data may prevent reliable calculations of the daily mean, mean minimum or mean maximum, which is particularly important if these daily results are published on-line as they are frequently done for data collected by the United States Geological Survey (Wagner et al. (2006)). Therefore Wagener et al. (2006) provide criteria for allowable missing data. In British Columbia, there is not yet any protocol for the on-line publication of water-quality data. However, data gaps may also prevent accurate calculations of more long term data summaries – monthly mean, mean minimum, mean maximum – and should be considered before the data are released.

Data gaps may be due to malfunctioning or damaged equipment, which should be reflected in the data grades, and may be apparent from the station log and maintenance record and the field notes. However, the data gaps should be flagged and quantified. This is done in the Excel program in Appendix 3.

The importance of the cumulative effect on the monitoring data due to unreasonable values, abrupt changes, prolonged changes, and data gaps is considered in the following section.

E.5 Validation Step 5 – Determine the Percentage of the Sampling Period Data (for each parameter) that are Flagged

The data grade represents the sensor performance at the time of the field visit. A high data grade does not obviate the presence of unreasonable values in the sampling period data (Section E.4). For example, the sensor may be out of water, or unexpected high values that exceed the range of the sensors may occur even though the sensor is functioning accurately. In all cases, these values must be flagged and not used in subsequent calculations. This is completed in the Excel program in Appendix 3. The Excel program in Appendix 3 also identifies data gaps, gives the number of flags per parameter per sample point, and indicates whether the parameter at the end of each sampling period is flagged. The percentage of the sampling period data that is flagged is simply the number of flags divided by the number of data points.

E.6 Validation Report & Release of Sampling Period Data

The results of the five validation steps must be summarized in Appendix 4. This step is completed by the operator, although it should ultimately be generated within the data repository. Once the data are validated, they are available for release to the public. The data grades are released with the data. *Flagged data that are confirmed by the operator as unreasonable should not be released.*

E.7 Use of the Data Grades and Data Comparisons

The data grades and data comparisons provide quantitative information on the length of the sampling period, the quality of the sampling period data, and the accuracy of the re-deployed sensors. Each of these is explained below.

Length of the sampling Period

The data grades are calculated *after each field visit*. If the grades for one or more of the parameters are consistently low, the operator can identify the error and modify the sampling schedule accordingly. For example, if the data grade is low due to extensive fouling, the operator should decrease the time between field visits. If the grade is consistently high, the operator may increase the time between field visits.

Quality of the sampling period data

The data grades measure sensor error at the end of the sampling period. An excellent or very good data grade indicates that the sensors are operating correctly and the sampling period data are not affected by sensor malfunction, calibration drift, or fouling. This does not obviate some event during the sampling period that may have produced unexpected results, but it does mean the operator can be *confident about the quality of the data*.

Accuracy of the re-deployed sensors

The procedures and calculations in this manual give *quantitative* information on the performance of the sensors when they are re-deployed. In all cases they are re-calibrated. This means that the sampling period data obtained at the beginning of the sampling period – when the sensors are re-deployed – have no sensor error.

E.8 Data Storage and Subsequent Analyses

The RISC forms in Appendix 1 will be contained in a data storage system (currently WIDM). The calculations that are presently completed in Excel (Appendices 2 & 3) will be stored in this database, as will subsequent calculations. The components of this storage system as they relate to the information collected during these standards operating procedures are summarized in Figure E-3.

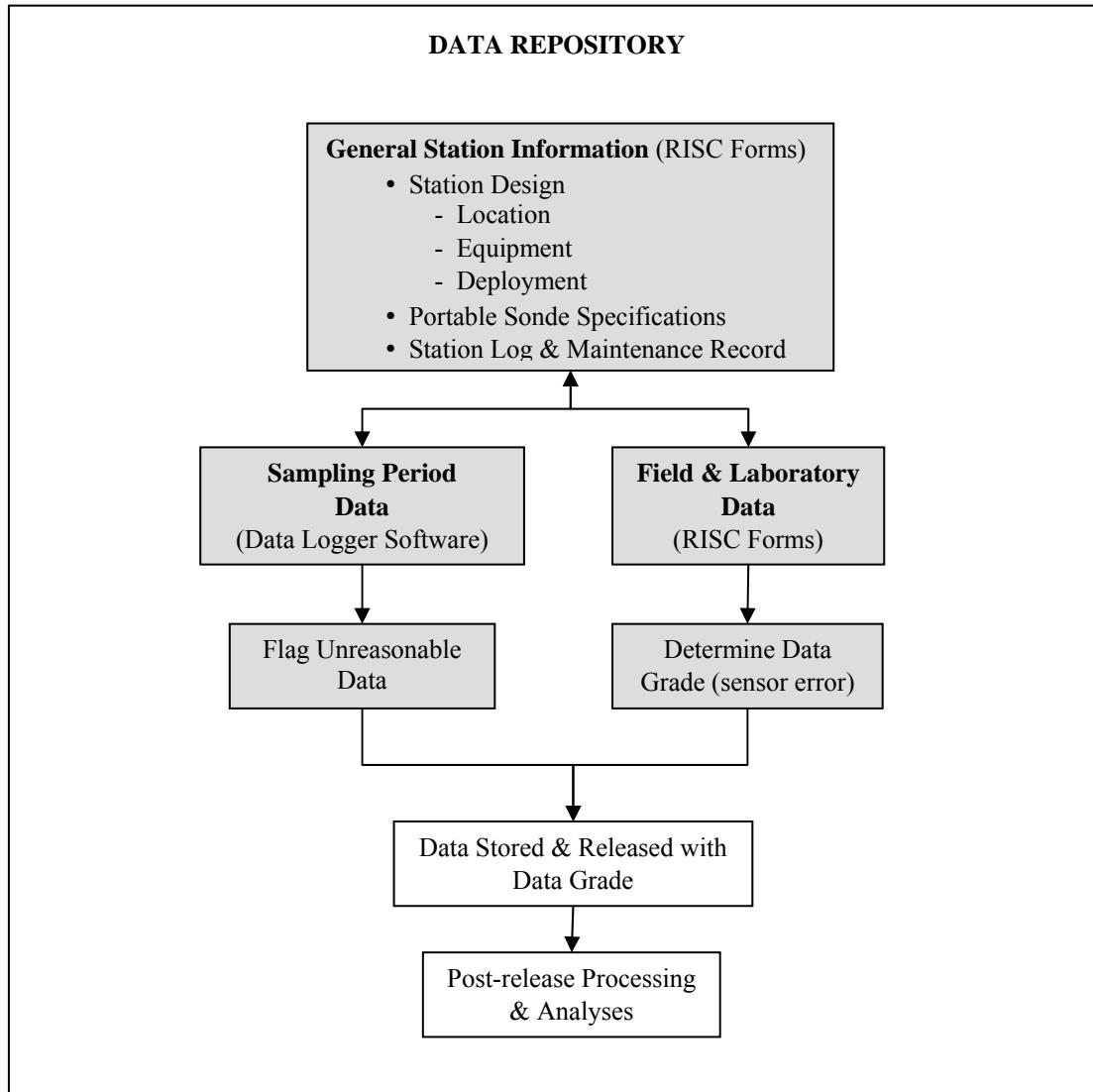


Figure E-3. An outline of the storage and flow of the meta data, sampling period data and field and laboratory data in a data storage system. The shaded boxes represent the data collected, recorded and/or analyzed according to the procedures given in this manual.

* The laboratory is the stable environment.

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G. Glossary of Terms

“Words are tools which automatically carve concepts out of experience.”

Julian S. Huxley

Accuracy: The difference between the reading in a standard solution and the true value.

Calibration drift: The change in the response of the sensors over time. It may be due to electronic drift in the equipment or sensitivity loss.

Data grades: Quantitative ranking of sensor performance based on the extent of sensor error at the time of the field visit.

Data logger: An instrument used to record the monitoring data. It may be internal or external.

Deployed sonde: The sonde that is deployed at the sampling site. It collects the monitoring data.

Deployment: The way in which the stream water comes in contact with the sensors.
Deployment method is the way that the sensors are placed in the stream.

Deployment tube: A tube used to house and thus protect the deployed sonde and flexible cable.

Field and laboratory data: Data collected on-site and in a stable environment, respectively, at intervals during the monitoring period.

Fouling: The accumulation of sediment or algal deposits on the active surface of the sensors or the presence of vegetation, debris or insects within the sensor guard.

Laboratory samples: Discrete water-quality samples collected and submitted to a certified laboratory.

Life span (of a sensor): The expected time period that a sensor will operate effectively.

Meta-data: The written non-quantitative information recorded during the field and laboratory procedures. They include the results of the site and sensor inspections, the sources of calibration standards, and any photographs taken during the field visits.

Operating environment (of a sensor): The medium, temperature, and depth in which a sensor can operate effectively.

Operator: The person in charge of the sampling site. He or she may not be the one who collects the data but he / she is ultimately responsible for ensuring that the data are recorded, validated and corrected.

Pool: Areas in a stream that are deeper and have a slower velocity than other areas, and have a concave shaped bottom, a near-zero gradient on top, and relative fine sediment.

Portable sonde: A sonde that has sensors with the same accuracy, resolution and range as the deployed sonde. It is moved from site to site during each field visit.

Quality assessment: The system of activities used to ensure that the quality assurance procedures are implemented and the quality control elements are evaluated.

Quality assurance: All of the procedures used to *control* the components of a water-quality sampling program.

Quality control: All of the data collected and used to measure bias and variability.

Range: The lowest to the highest values that a sensor can detect with the same resolution and accuracy.

Resources Inventory Standards Committee (RISC): A committee that ensures that required standard method are developed and used in environmental sampling.

Resolution: The smallest interval that a sensor can detect.

Sampling period: The time between field visits.

Sampling period data: The data that are collected on-site while the operator is absent and stored in an internal or external data logger.

Sensor: An instrument used to measure one or more water-quality parameter.

Sensor error: Incorrect readings due to fouling, calibration drift, noise, or malfunction of the sensor.

Sensor malfunction: Inaccurate sensor readings due to physical damage to the sensor or to the connections between the sensor and the data logger. Sensor malfunction can also occur if the sensors are out of water.

Sensor noise: Changes in the response of a sensor due to external influences (e.g. power lines and magnetic fields), sensor sensitivity, and direct and reflected sunlight.

Sonde: An instrument that contains ports for several sensors.

Standard calibration solutions: Solutions supplied by the manufacturer that have known and consistent characteristics.

Stable environment: A laboratory or office with appropriate facilities to clean, calibrate and inspect the sampling equipment and with a controlled temperature and good lighting.

Validation: The set of procedures used to complete the quality assessment requirements of a continuous water-quality sampling program. It is a systematic evaluation of all of the data (meta and numerical) to find and deal with errors and to assign data grades.