DQM Information Paper 3.1.2
Temperature Measurements Principles and Methods

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1.0 About this Information Paper

(This section is essentially common to all DQM Information Papers. If you have seen it already, please skip to Section 2 below). This Information Paper is a new type of guidance. It has been created for our new integrated system of guidance and tools for water quality monitoring called "the Data Quality Management (DQM) System". DQM is implemented by the Clean Water Team (CWT) where needed to support collection of **reliable** data of **known quality** in a fully documented, **scientifically defensible** manner. Most DQM materials are delivered in Parameter-Specific Folders, which provide both the traditional "protocol" materials and new, expanded guidance in three types of inter-related documents: Fact Sheet, Information Paper, and Standard Operation Procedures. Background information on the ecological significance of each parameter and the regulatory benchmarks that have been developed for it is summarized in the FACT SHEET. The technical information on measurement methodology provided in this IP with its method-menu. Then there are several detailed standard operating procedures (SOPs) that provide step-by-step instructions for each instrument or kit, as well as instrument-specific Quality Assurance/Quality Control and CCRR directions and data validation checklists.

This Information Paper (IP), a part of the Parameter-Specific Folder for temperature, provides "big picture" technical information on temperature measurement methodology. If you are a Trainer or a Technical Leader of any monitoring project, this may help you select a good method to measure temperature in your water body.

Section 2 of this IP introduces a "method menu" table with a list of kits and instruments commonly used by citizen monitoring groups, agency staff, or laboratory technicians, with information on the limitations, approximate cost, measurement range and resolution, and associated labor of each device. Next (Section 3), a description of the different physical or chemical principles underlying the commonly used methods to measure temperature is provided. Section 4 provides practical tips and advice on temperature measurement based on our cumulative experience (The Clean Water Team and others). This section is meant to be updated as we learn more. Finally, the "Sources & Resources" section (Section 5) provides a list of available SOPs as well as contact and website leads into further information.

2.0 Ways to Measure Temperature

Table 3.1.2-1 shows the types of devices commonly used to measure temperature. The table does not include all available instruments and the user is encouraged to seek more information. You can look at it for selection of a device based on available resources and operators' skill, e.g., during the initial phases of your group's monitoring activity.

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Table 3.1.2-1: Selected Methods for Measurement of Temperature

Code *(Note a)*	Device	Cost	Labor	Application	Limitations	Major sources of error
TR	Bulb thermometers	$5-20	1 minute	Air, Surface water, or sample in jar	Low resolution (0.5 C to 1 C)	Inaccurate setting by manufacturer, disconnection of capillary tube from scale, air bubbles in tube
TRM	U-shaped Min-Max thermometer	$25	1 minute	Air, incubation chambers	Low resolution (1 C). Not recommended for field use (mercury)	Inaccurate setting by manufacturer, disconnection of capillary tube from scale, air bubbles in tube, incomplete resetting
TT	Digital Thermometer	$25	2 min	Air, Surface water, inside soil or sediment	Needs batteries	Inaccurate setting by manufacturer, drift from original setting
TT	Thermistor probes	var		Vertical gradients	Response depends on length of cable	Inaccurate setting by manufacturer, drift from original setting
TH	Hobo-Temperature Data loggers	$60-100	10 min (program) 10 min download, plus deployment labor	Continuous measurements of temperature in the environment	Requires use of computer, need to buy software	Inaccurate setting by manufacturer, drift from original setting
TTP	Sonde/datalogger probe	~$4,000 for entire Sonde	1 min	Discrete or continuous measurements	Requires use of computer, need to buy software	Inaccurate setting by manufacturer, drift from original setting

Notes: (a) The Codes on the left are consistent with the Instrument codes used in all other DQM materials.

Once you have formulated the monitoring question, decided which parameters you need to measure, developed your sampling design, and determined how much error you can tolerate in your measurements, you can refer to this menu again and find the device that will work for you.

3.0 Principles and Applications of Temperature Measurement Methods

3.1 Temperature-dependent change in volume

A given amount of liquid takes a given space, or volume, at a given temperature. That volume changes when the temperature changes; most liquids expand as they heat up and shrink as they cool down. Bulb thermometers are made of liquid (mercury or dyed alcohol) enclosed within a bulb and a thin capillary protruding from the bulb. The thin capillary is aligned with a scale of temperature units, i.e., degrees Celsius or Fahrenheit. As the material in the bulb expands (when the temperature increases), more material is pushed up the capillary and the top of the material column is aligned with a scale marking that denotes higher temperature. As the material in the bulb cools and shrinks, the top of the material column in the capillary retracts towards the bulb and we see lower temperature readings. Bulb thermometers are used in a variety of household and environmental applications.

Air also changes its volume as temperature changes. U-shaped tube thermometers are usually filled with mercury and have an air reservoir on one end. Movement of the mercury in the U pushes the minimum or the maximum stoppers up where they remain even after the temperature changes.
Note: Mercury thermometers should not be used for field work in or around water.

Solids also change their volume as temperature changes. When solids are organized in long rods, that change is best manifested in the length dimension. Different solids have different temperature expansion properties, and if we look at the response of several rods made of different metals we will see that each rod expands by its own characteristic length when the temperature changes by, say, 1 degree C. When rods of two metals with different temperature expansion properties are fused or stuck together, a change in temperature will distort them, i.e., cause a change in their configuration in relation to a reference point. Mechanical bimetal thermometers are based on this principle: differential expansion causes a bimetal shaft to twist and move a pointer on a scale. Bimetal thermometers are often used for temperature higher than boiling point (e.g., in oven thermometers or in “meat” or “candy” thermometers). They are also the basis for many thermostats in high-temperature equipment. This type of thermometer is seldom used for environmental monitoring at the range of ambient temperatures, therefore it has not been included in the Method Menu above.

3.2 Temperature-dependent change in electrical resistance.

As you may remember from the Information Paper on electrical conductivity (IP-3.1.3 in this Compendium), conductivity is highly dependent on temperature – and so is resistance, the physical entity reciprocal to conductivity. The changes in resistance of metal wires as a function of temperature are the basis for the flourishing thermistor technology. Because thermistors can be built into any electrical or electronic equipment – including in miniatures – they have a vast use.

In the realm of environmental monitoring, we find thermistors in these major applications:

- Thermistors embedded in temperature-compensating instruments, unseen by the user
- Probes in multimeters (e.g., DO, SCT) - these are probes on a cable or variable length, with or without other sensors in the same probe.
- Thermistors connected to data loggers/remote sensors, either as a stand-alone (e.g., Hobo) or with other probes on a sonde.

4.0 Practical Advice and Tips

4.1 Quality Control, Check, Record, and Report (CCRR) guidance for temperature

(This paragraph is essentially common to all DQM-IPs. If you have seen it already, please skip to the second paragraph in this Section) The DQM guidance and tools provide ways to Control, Check, Record, and Report (CCRR) the quality of numerous water quality measurements. Essentially, **"Control"** is about things we can do to affect and improve data quality. **"Check"** is about testing how good a measurement actually is. **"Record"** is about the language we use to express the results of our quality checks and about entering our findings into the "placeholders" on DQM forms or spreadsheets. **"Report"** is about the way we calculate the measures of quality, i.e., the data quality indicators, so they can be shared with others. Specific CCRR procedures are added on top of the generic quality assurance procedures such as keeping everything clean, waiting for stabilization of the reading, and keeping good records. Because each type of instrument or kit requires its unique CCRR actions (that cannot be generalized for all measurement devices), the step-by-step instructions for these actions are provided in the instrument-specific standard operating procedures (SOP).

The settings, or "calibration", of temperature measurement devices usually cannot be corrected or adjusted or otherwise controlled by the user. Thus, "Instrument calibration" does not apply, but "accuracy check" does, and usually refers to comparison with a "Standard". The accuracy of any measurement depends on the Standard that is used to assess how close the measurement was to the absolute truth. You can use a natural physical condition as your Standard, or obtain a temperature "Standard" in the shape of a certified thermometer. One of the checks you can do is to measure the temperature of an ice-water bath made with distilled or deionized water (DI). It should read zero degrees C if it is well mixed and as long as there is solid ice in there. To gain access to a certified thermometer, ask your CWT Regional Coordinator about "instrument calibrations parties" given regionally to interested monitors from agencies and watershed organizations. Alternatively, ask your coordinator how to buy an NIST-certified bulb thermometer.

4.2 Thermistors

Tampering with thermistor cables in any way that changes its resistance - changing length, adding devices, splitting, altering wire insulation - will alter the output of a thermistor and the unit needs to be calibrated – both for the constant and for the slope.

4.3 Armored thermometers

Most thermometers are made of glass, and require careful handling. The armour hold water and cannot be dried easily. Avoid using a wet thermometer to read air temperature as the error introduced by evaporative cooling of the bulb can be considerable, especially in windy conditions.

4.4 Mercury phaseout

When buying new bulb thermometers, get the kind with alcohol (and red pigment if possible). Avoid using mercury thermometers out in the field, keep all mercury thermometers away from animals and small children, and never deploy a mercury min-max thermometer to record temperatures outdoors (the raccoons will get them!).

5.0 Sources and Resources

This IP is an integral part of the Data Quality Management (DQM) System implemented by the Clean Water Team, the Citizen Monitoring Program of the California State Water Resources Control Board.

For an electronic copy, to find many more CWT guidance documents, or to find the contact information for your Regional CWT Coordinator, visit our website at www.swrcb.ca.gov/nps/volunteer.html

If you wish to cite this IP in other texts you can use "CWT 2004" and reference it as follows: "Clean Water Team (CWT) 2004. Temperature Measurements Principles and Methods, DQM IP-3.1.2. in: The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment, Version 2.0. Division of Water Quality, California State Water Resources Control Board (SWRCB), Sacramento, CA."

Available SOPs (2004 Compendium)

- SOP-3.1.2.1 Temperature measurements with bulb and min-max thermometers
- SOP-3.1.2.2 Thermistors

Sampling technique that allows for temperature measurement during collection of a water sample, also included in this Compendium, is SOP-2.1.1.2.