TEMPERATURE 6.1

By **D.B. Radtke, J.K. Kurklin, and F.D. Wilde**

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TEMPERATURE 6.1

Measurements of water and air temperatures at the field site are essential for water-data collection. Determinations of dissolved oxygen concentrations, conductivity, pH, rate and equilibria of chemical reactions, biological activity, and fluid properties rely on accurate temperature measurements.

Accurate water- and air-temperature data are essential to document thermal alterations to the environment caused by natural phenomena and by human activities. Water temperature is subject to environmental monitoring by State and local agencies.

Temperature: a measure of warmth or coldness of a substance with reference to a standard value

The USGS has adopted the Celsius (C) scale for measuring temperature. This section describes methods for measuring temperature in air, surface water, and ground water. The methods are appropriate for fresh to saline waters.

Some of the procedures recommended herein for equipment operation may be out of date if the equipment being used is different from that described or incorporates more recent technological advances—follow the manufacturer's instructions.

6.1.1 EQUIPMENT AND SUPPLIES

Temperature instruments must be tested before each field trip and cleaned soon after use (table 6.1–1). Each instrument must have a log book in which all calibrations and repairs are recorded, along with the manufacturer make and model description and serial or property number.

Table 6.1–1. Equipment and supplies used for measuring temperature[1]

[°C, degrees Celsius; L, liter; µS/cm, microsiemens per centimeter at 25°C]

✓	Calibration thermometer, liquid-in-glass or electronic-thermistor thermometer, either National Institute of Standards and Technology (NIST) certified or manufacturer-certified as NIST traceable. Must carry certificate of NIST traceability; its use not allowed after expiration of certification. Temperature range at least –5 to +45°C 0.1°C graduations (liquid-in-glass) or less
✓	Thermometer, liquid-in-glass sensor, non-mercury for field use Temperature range –5 to +45°C Minimum 0.5°C graduated Calibrated accuracy within 1 percent of full scale or 0.5°C, whichever is less Calibrated and District certified against a properly certified calibration thermometer (see above)
✓	Thermistor Thermometer Calibrated accuracy with 0.1°C to 0.2°C Digital readout to at least 0.1°C Calibrated and District certified against calibration (NIST) thermometer
✓	Dewar flask and (or) plastic beakers (assorted sizes)
✓	Water bath, refrigerated
✓	Soap solution (1 L), nonphosphate laboratory detergent
✓	Deionized water (1 L), maximum conductivity of 1 µS/cm
✓	Flowthrough chamber (for ground-water applications as an alternative to instruments with downhole capabilities)
✓	Paper tissues, disposable, soft, and lint free
✓	Log book, for recording all calibrations, maintenance, and repairs

[1]Modify this list to meet specific needs of the field effort.

► A thermometer is any device used to measure temperature, consisting of a temperature sensor and some type of calibrated scale or readout device. Liquid-in-glass thermometers and thermistor thermometers are most commonly used to measure air and water temperature.

- Extreme field conditions (for example, frigid climates or thermal waters) may require thermometers capable of measuring a broader temperature range.

CAUTION: Do not use mercury-filled thermometers in the field.

The operating instructions for thermometers are provided by the manufacturer.

- **Liquid-in-glass thermometer**—Recommended liquid-in-glass thermometers are total-immersion thermometers filled with alcohol. Thermometers for field use must not be mercury-filled. Before measuring temperature, check the type of liquid-filled thermometer being used. (Partial-immersion thermometers are not recommended: these have a ring or other mark to indicate the immersion depth required.)
- **Thermistor thermometer**—A thermistor thermometer is an electrical device made of a solid semiconductor with a large temperature coefficient of resistivity. An electrical signal processor (meter) converts changes in resistance to a readout calibrated in temperature units. Thermistors commonly are incorporated in instruments used for surface-water and ground-water measurements.

MAINTENANCE, CLEANING, AND STORAGE 6.1.1.A

Thermometers can easily become damaged or out of calibration. Take care to:

- Keep thermometers clean (follow manufacturer's recommendations).
- Carry thermometers in protective cases; thermometers and cases must be free of sand and debris.
- Store liquid-filled thermometers in a bulb-down position and in a cool place away from direct sunlight.

As an additional precaution on field trips, carry extra calibrated thermometers as spares, and a supply of batteries for instrument systems.

6.1.2 CALIBRATION

To calibrate a thermometer, instrument readings are checked across a range of temperatures against those of a thermometer of certified accuracy.

Calibrate liquid-in-glass and thermistor thermometers in the office at regularly scheduled intervals. **Tag acceptable thermometers with date of calibration**.

Minimum calibration requirements

- **Liquid-in-glass thermometer:**
  —**Every 3 to 6 months**, using a 2-point calibration, and
  —**Annually**, using a 3-point calibration.
- **Thermistor thermometer:**
  Every 3 to 4 months, check calibration
  Annually, using a 5-point calibration.
- The standard thermometer against which all other thermometers are calibrated must be either NIST certified or NIST traceable, and carry a certificate of NIST certification or traceability from the manufacturer. The calibration thermometer may only be used within the period for which it was certified as NIST traceable; once certification has expired, the calibration thermometer either must be replaced or sent to an accredited laboratory for recertification. These protocols apply to electronic thermistor thermometers as well as to liquid-in-glass thermometers. The calibration thermometer must be accurate to at least 0.1°C.

Check the certificate of calibration for the NIST thermometer before calibrating field thermometers. **NIST-certified thermometers are not for field use.**

Thermometers being calibrated must meet NIST specifications to a minimum of three temperatures at approximately 0°, 25°, and 40°C. Thermistors must be calibrated at 5 points within this range. If environmental water or air temperatures will fall below 0°C or rise above 40°C, add additional calibration points to bracket the temperatures to be measured.

Field checking thermometer calibration by comparing readings with another field thermometer does not substitute for required laboratory calibration procedures. When measuring water temperature in the laboratory:

- ► Submerge the bulb and liquid column of the total-immersion thermometer.
- ► Keep the NIST-certified thermometer and the thermistor sensor submerged in the container throughout calibration.
- ► Read the NIST-certified thermometer and record the thermistor readings throughout warming and cooling periods.
- ► Check the meter batteries periodically for proper voltage.
- ► Record the calibration data in the instrument log book for each thermistor thermometer, noting if a sensor has been replaced.

If using a commercial refrigerated water bath:

1. Precool the sensor of the thermometer being tested (test thermometer) to 0°C by immersing it in a separate ice/water bath.
2. Immerse the test and NIST-certified thermometer sensors in the refrigerated bath with a water temperature of approximately 0°C.
3. Position the thermometer sensor(s) so that they are properly immersed and so that the scales can be read. Stir the water bath and allow at least 2 minutes for the thermometer readings to stabilize.
4. Without removing the thermometer sensor from the refrigerated water bath, read the test thermometer(s) to the nearest graduation (0.1 to 0.5°C) and the NIST-certified thermometer to the nearest 0.1°C.
   - Take 3 readings within a 5-minute span for each thermometer.
   - Calculate the mean of the three temperature readings for each thermometer and compare its mean value with the NIST-certified thermometer.
   - If the liquid-filled test thermometer is found to be within ±1 percent of full scale or ±0.5°C of the NIST-certified thermometer, whichever is less, set it aside for calibration checks at higher temperatures.
   - If the test thermistor is found to be within ±0.2°C of the NIST certified thermometer, set it aside for calibration checks at higher temperatures.

5. Repeat steps 1–3 in 25°C and 40°C water. Keep the bath temperature constant. Check the thermistors at two or more additional intermediate temperatures (for example, 15°C and 30°C).
6. Tag acceptable thermometers as "District certified" with calibration date and certifier's initials.

If a commercial refrigerated water bath is not available:

1. Freeze several ice cube trays filled with deionized water.
2. Fill a 1,000-mL plastic beaker or Dewar flask three-fourths full of crushed, deionized ice. Add chilled, deionized water to the beaker. Place the beaker of ice/water mixture in a larger, insulated container or Dewar flask. Place the NIST-certified thermometer into the ice/water mixture and make sure that the temperature is uniform at 0°C by stirring and checking at several locations.
3. Precool the test thermometer sensor to 0°C by immersing it in a separate ice/water bath.
4. Add the test thermometer sensor(s) to the ice/water mixture. Position the sensor(s) so that they are properly immersed and so that the scales can be read. Periodically stir the ice/water mixture and allow at least 2 minutes for the thermometer readings to stabilize.
5. When the readings stabilize, compare the temperature of one test thermometer at a time with that of the NIST-certified thermometer. Without removing the temperature sensor(s) from the test bath, read the test thermometer(s) to the nearest graduation (0.1 to 0.5°C) and the NIST-certified thermometer to the nearest 0.1°C.
   - Take three readings for each thermometer within a 5-minute span.
   - Calculate the mean of the three temperature readings for each thermometer and compare its mean value with the NIST thermometer.
   - If the test liquid-filled thermometer is found to be within ±1 percent of full scale or ±0.5°C of the NIST-certified thermometer, whichever is less, set it aside for calibration checks at higher temperatures.
   - If the test thermistor is found to be within ±0.2°C of the NIST certified thermometer, set it aside for calibration checks at higher temperatures.

6. For “room temperature” calibration (about 25°C), place a Dewar flask or container filled with about 1 gallon of water in a box filled with packing insulation. (A partially filled insulated ice chest can be used for multiparameter instruments.) Place the calibration container in an area of the room where the temperature is fairly constant (areas away from drafts, vents, windows, and harsh lights).
7. Properly immerse the NIST-certified and test thermometer sensor(s) in the water. Cover the container and allow the water bath and thermometers to equilibrate. Stir the water and check every couple of hours for temperature uniformity using the NIST certified thermometer—it may be necessary to let the bath equilibrate overnight.
8. Compare one test thermometer at a time with the NIST-certified thermometer. Calibrate as described in step 5 above.
    - For greater than 25°C temperature calibration, place a beaker (1,000 mL or more) of warm water (about 40°C) on a magnetic stirrer plate and repeat procedure as described in step 5 above.
    - Tag acceptable thermometers as “District certified” with calibration date and certifier’s initials.

Corrections can be applied to measurements made with a thermometer that is within ±1 percent of full scale or ±0.5°C of the calibration thermometer. Corrections should be applied by using a calibration curve or table, which is plotted in the log book for the instrument. **Thermistors found to be out of calibration by more than 0.2°C must be recalibrated per manufacturer’s instructions or returned to the manufacturer for proper calibration and (or) repairs.**

Thermistors included in other field-measurement instruments must be calibrated routinely. Accurate determination of other field measurements depends on accurate temperature measurements. This must be underscored for thermistors incorporated in specific electrical conductance, dissolved-oxygen, and pH instruments, because these thermistors are used for automatic temperature compensation of the measurement being made.

Tag and date acceptable thermometers.

6.1.3 MEASUREMENT

Water-quality sampling should include an air-temperature measurement and a water-temperature measurement. Before measuring temperature:

- ► Inspect liquid-in-glass thermometers to be certain liquid columns have not separated.
- ► Inspect bulbs to be sure they are clean.
- ► Inspect protective cases to be sure they are free of sand or debris.

6.1.3.A AIR

Read air temperature with a dry, calibrated thermometer.

- ► Place the thermometer about 5 ft above the ground in a shaded area protected from strong winds but open to air circulation. Avoid areas of possible radiant heat effects, such as metal walls, rock exposures, or sides of vehicles.
- ► Allow 3 to 5 minutes for the thermometer to equilibrate, then record the temperature and time of day.
- ► Measure the air temperature as close as possible to the time when the water temperature is measured.
- ► Report routine air temperature measurements to the nearest 0.5°C. If greater accuracy is required, use a thermistor thermometer that has been calibrated to the accuracy needed.

SURFACE WATER 6.1.3.B

The reported surface-water temperature must be measured in situ—**do not measure temperature on subsamples** from a sample compositing device. Measure temperature in such a manner that the mean or median temperature at the time of observation is represented (consult NFM 6.0 and fig. 6.0–1). Record any deviation from this convention in the data base and report it with the published data.

To measure the temperature of surface water:

- ► Make a cross-sectional temperature profile to determine temperature variability—A thermistor thermometer works best for this purpose.
- ► Determine from the cross-sectional profile and from study objectives which sampling method to use (see NFM 6.0).
- ► Measure temperature in those sections of the stream that represent most of the water flowing in a reach. Do not make temperature measurements in or directly below stream sections with turbulent flow or from the stream bank (unless this represents the condition to be monitored).

1. Use either a liquid-in-glass thermometer tagged as "District certified" within the past 12 months, or a thermistor thermometer tagged "District certified" within the past 4 months.
2. Record on field forms the temperature variation from the cross-sectional profile, and the sampling method selected.
    - **Flowing, shallow stream—**wade to the location(s) where temperature is to be measured. To prevent erroneous readings caused by direct solar radiation, stand so that a shadow is cast on the site for temperature measurement.
    - **Stream too deep or swift to wade—**measure temperature by lowering from a bridge, cableway, or boat a thermistor thermometer attached to a weighted cable. Do not attach a weight to the sensor or sensor cable.
    - **Still-water conditions—**measure temperature at multiple depths at several points in the cross section.

3. Immerse the sensor in the water to the correct depth and hold it there for no less than 60 seconds until the sensor equilibrates thermally. The sensor must be immersed properly while reading the temperature; this might require attaching the thermistor to a weighted cable.

   TECHNICAL NOTE: For in situ measurement with liquid-filled thermometers—the water depth must be no greater than twice the length of the liquid column of the thermometer in order to make an accurate measurement.

4. Read the temperature to the nearest 0.5°C (0.2°C for thermistor readings)—**do not remove the sensor from the water.**
   - Using a liquid-in-glass thermometer, check the reading three times and record on field forms the median of these values.
   - Using a thermistor thermometer, wait until the readings stabilize to within 0.2°C, then record the median of approximately the last 5 values.
5. Remove the temperature sensor from the water, rinse it thoroughly with deionized water, and store it.
6. Record the stream temperature on field forms:
   - **In still water—median** of three or more sequential values.
   - **EDI—mean** value of subsections measured (use median if measuring one vertical at the centroid of flow).
   - **EWI—mean or median** value of subsections measured.

GROUND WATER 6.1.3.C

Measurements of ground-water temperature must be made downhole at the end of purging for temperature to represent aquifer conditions (consult NFM 6.0 for guidance).

To measure the temperature of ground water:

► Select either the downhole or flowthrough-chamber sampling system of measurement (see NFM 6.0, fig. 6.0–4) and record on field forms. **Do not report a temperature value measured from a bailed sample.**

► Measure temperature with a thermometer that has been District certified and is calibrated within the temperature range to be encountered.

1. Prepare the instruments for either the downhole or the flowthrough-chamber system.
   - **Downhole system—**lower the sensor in the well to just below the pump intake (the intake location depends on the sampling objectives).
   - **Flowthrough-chamber system—**properly immerse the thermistor or liquid-in-glass thermometer in the chamber. Keep the tubing from the well to the chamber as short as possible, out of direct sunlight, and off the ground.
2. Begin water withdrawal from the well.
3. Allow the thermometer sensor to equilibrate with the well water for no less that 60 seconds; record the readings and time intervals throughout the period of purging.
4. Toward the end of purging, record five measurements, spaced at increments of 3 to 5 minutes or more.
   - If the thermistor temperature is stable within the 0.2°C criterion (for a liquid-in-glass thermometer, there should be only slight fluctuation within the 0.5°C interval), report the median of the final five measurements (table 6.0–1).
   - If the stability criterion has not been met, extend the purge time and consult the well-purging objectives of the study. Report the median of the last five (or more) sequential measurements and record any instability on field forms.
5. Remove and clean the temperature sensors.

Replacement page, 7/29/2005. Revise #3 to read "no less than 60 seconds."

6.1.4 TROUBLESHOOTING

Contact the instrument manufacturer if the suggestions on table 6.1-2 fail to resolve the problem.

When using thermistor thermometers:

► Check the voltage of the batteries.

► Start with good batteries in instruments and carry spares.

Table 6.1–2. Troubleshooting guide for temperature measurement

Symptom	Possible cause and corrective action
Liquid-in-glass thermometer doesn't read accurately	• Check thermometer to see that the liquid is not separated—if separated, take back to the office to reunite column.
Thermistor thermometer doesn't read accurately	• Dirty sensor—remove dirt and oil film. • Weak batteries—replace with new batteries.
Erratic thermistor thermometer readings	• Bad or dirty connection at meter or sensor—tighten or clean connections. • Break in the cables—replace cables. • Weak batteries—replace with new batteries.
Thermistor thermometer slow to stabilize	• Dirty sensor—clean sensor to remove dirt and oily film.

REPORTING 6.1.5

Report temperature measurements in the data base to the nearest 0.5°C.

- For studies for which greater accuracy is desired, temperatures can be reported to the accuracy requested, provided the thermometer has been calibrated to that accuracy.
- Enter field measurements of air and water temperature on NWQL Analytical Services Request forms, and in the data base under the correct parameter code.
- Record the accuracy range of the instrument in the data base, if possible. Report accuracy range with the published values.

Report only those water temperature values that were measured in situ.