

DISSOLVED OXYGEN 6.2

Accurate data on concentrations of dissolved oxygen (DO) in water are essential for documenting changes to the environment caused by natural phenomena and human activities. Sources of DO in water include atmospheric reaeration and photosynthetic activities of aquatic plants. Many chemical and biological reactions in ground water and surface water depend directly or indirectly on the amount of oxygen present. Dissolved oxygen is necessary in aquatic systems for the survival and growth of many aquatic organisms.

Two field methods for determining concentrations of dissolved oxygen in surface and ground waters are the amperometric method and the spectrophotometric method.

- ▶ The amperometric method is the standard procedure for determination of DO concentrations.
- ▶ The spectrophotometric method described in this report (the Rhodazine-D^{TM,1} technique) is recommended for determining concentrations of DO less than 1.0 mg/L.
- ▶ Except where noted, these methods are applicable to unfiltered surface and ground waters, from fresh to saline.
- ▶ The iodometric (Winkler) method generally is not recommended for field determination of dissolved oxygen because the accuracy and reproducibility achieved depend largely on the experience and technique of the data collector. The iodometric method is described under amperometric calibration procedures (6.2.1.B).

Dissolved oxygen:
molecular oxygen
(oxygen gas)
dissolved in water.

Some of the procedures recommended herein for equipment operation may be out of date if the equipment being used is different from that described or incorporates more recent technological advances—follow the manufacturer's instructions.

¹Rhodazine-DTM, a colorless, reduced phenzone dye, is a proprietary product of CHEMetrics, Incorporated, and constitutes approximately 0.01 volume percent of solution in the ampoule. Remaining constituents in the ampoule are water, diethylene glycol, hydroxymethyl aminomethane, and potassium hydroxide.

6.2.1 AMPEROMETRIC METHOD

The most commonly used field method for measuring DO in water is the amperometric method, in which DO concentration is determined with a temperature-compensating instrument or meter that works with a polarographic membrane-type sensor.

6.2.1.A EQUIPMENT AND SUPPLIES

The instrument system used to measure DO must be tested before each field trip and cleaned soon after each use. Battery-powered instruments are recommended. A variety of DO meters and sensors are available—**read thoroughly the instructions provided by the manufacturer.** Every DO instrument and the barometer must have a log book in which repairs and calibrations are recorded, along with the manufacturer make and model description, and the serial or property number.

- ▶ The term “dissolved-oxygen sensor” refers to the entire sensor assembly, including the electrodes, electrolyte solutions, membranes, and thermistor thermometers.
- ▶ Dissolved-oxygen sensors must be temperature compensating: the permeability of the membrane and solubility of oxygen in water change as a function of temperature.
- ▶ The type of membrane selected for the sensor depends on the anticipated rate of flow. **For ground water, “low-flow” membranes should be used.**
- ▶ All built-in thermistor thermometers must be calibrated and field checked before use (see section 6.1, “Temperature”).

Yellow Springs Instrument Company (YSI) DO instruments are used as an example in this chapter because they are in common use by USGS field personnel. The YSI 5700 series sensors have two separate thermistors. The temperature of the solution is measured by the temperature-display thermistor, mounted in a stainless steel tube on the side of the sensor. Next to the temperature-display thermistor is the temperature-compensation thermistor that compensates for temperature-caused changes in membrane-oxygen permeability. **The permeability of the Teflon™ membrane changes about 3 percent for each 1°C change in temperature.**

Table 6.2-1. Equipment and supplies used for amperometric method of dissolved-oxygen determination¹

[DO, dissolved oxygen; YSI, Yellow Springs Instrument Company; mm, millimeter; g, gram; mL, milliliter; L, liter; DIW, deionized water]

- ✓ DO instrument and DO sensor or multiparameter instrument with DO capability
 - Temperature readout display, analog or digital
 - Temperature and pressure compensated
 - Operating range at least -5°C to $+45^{\circ}\text{C}$
 - Measure concentrations ≥ 1 to 20 mg/L
 - Minimum scale readability, preferably 0.05 mg/L DO
 - Calibrated accuracy within 5 percent or ± 0.3 mg/L DO, whichever is less
- ✓ DO sensor membrane replacement kit: membranes, O-rings, filling solution
- ✓ Stirrer attachment for DO sensor
- ✓ Calibration chamber: YSI model 5075A sensor, or equivalent
- ✓ Pocket altimeter-barometer, calibrated; measures to nearest 2 mm, Thommen model 2000
- ✓ Thermometer, calibrated (see section 6.1 for selection and calibration criteria)
- ✓ Zero DO calibration solution²: dissolve 1 g sodium sulfite and a few crystals of cobalt chloride in 1 L DIW
- ✓ Flowthrough chamber for determining DO in ground water
- ✓ Oxygen solubility table (table 6.2-6)
- ✓ Waste disposal container or equivalent
- ✓ Spare batteries, filling solution, and membranes
- ✓ Log books for DO instrument and barometer for recording all calibrations, maintenance, and repairs

¹Modify this list to meet specific needs of the field effort. See table 6.2-3 for equipment list for iodometric DO determination and Table 6.2-5 for equipment list for Rhodazine-D™ DO determination.

²Prepare fresh zero DO solution before each field trip.

Analog YSI instruments have two thermistors that compensate for the effects of temperature. Digital YSI instruments do not contain instrument-compensating thermistors, but rely on the temperature-display thermistor in the sensor to calculate membrane permeability.

CAUTION: Before handling any chemicals, refer to the Material Safety Data Sheet (MSDS) for safety precautions.

Maintenance and storage

Dissolved-oxygen instruments and sensors are sophisticated electronic equipment that require care in handling and operation.

- ▶ Follow the manufacturer's recommendations for short-term (field) and long-term (office) storage of sensors and for performance checks.
- ▶ Protect instruments and sensors from being jostled during transportation, from sudden impacts, sudden temperature changes, and extremes of heat and cold.

Before each field trip:

1. Check the temperature-display thermistor in the DO sensor against a certified thermometer over the normal operating range of the instrument. If a thermistor reading is incorrect, apply a correction or return the instrument to the manufacturer for adjustment.
2. Recondition the DO sensor if it fails a performance check.
3. Check the instrument batteries and all electrical connections.
4. Test the instrument to ensure that it will read zero in a DO-free solution.
 - If the instrument reading exceeds 0.2 mg/L, then the sensor membrane and electrolyte (if present) need to be replaced or the sensor needs to be repaired.
 - Before repairing or replacing the sensor, check zero DO again with a freshly prepared zero DO solution.
5. On analog instruments:
 - Check mechanical zero (if applicable) before turning the instrument on; adjust it if necessary.
 - Check redline and zero readings (if applicable) and adjust as needed.
 - If the instrument cannot be adjusted, recharge or replace the batteries.
6. Calibrate the pocket altimeter-barometer.

CALIBRATION 6.2.1.B

Calibration and operation procedures for the amperometric method differ among instrument types and makes—refer to manufacturer's instructions. Record all calibration information in instrument log books and copy calibration data onto field forms at the time of calibration.

Atmospheric pressure, temperature of the water or water vapor, and conductivity (or salinity) of the water must be known to determine the theoretical amount of oxygen that can be dissolved in water. Although the salinity correction can be made either during calibration or after measurement, **the preferred USGS method is to apply salinity correction factors after calibration and measurement** (recalibration is necessary for each field variation in salinity and temperature if the correction is made during calibration). For salinity-correction procedures, see section 6.2.4.

Atmospheric pressure correction

Ambient atmospheric pressure is true atmospheric pressure at the measurement site, not that which has been adjusted to sea level. Atmospheric pressure reported by the National Weather Service generally is not the true (ambient) value. Weather Service atmospheric readings usually are adjusted to sea level and must be adjusted back to the elevation of the weather station. Upon request, a weather station sometimes provides unadjusted atmospheric pressure.

- ▶ Use a calibrated pocket altimeter-barometer to determine ambient atmospheric pressure to the nearest 1 mm of mercury.
- ▶ Check the accuracy of all field barometers before each field trip, and record readings and adjustments in the log book. If possible, check barometer accuracy with information from an official weather station.
- ▶ Use table 6.2-2 and figure 6.2-1 if the value used for atmospheric pressure has been adjusted to sea level.
- ▶ To correct weather station readings adjusted to sea level to ambient atmospheric pressure: subtract appropriate values shown (table 6.2-2, fig. 6.2-1) from atmospheric readings adjusted to sea level (shown in millimeters of mercury).

Although atmospheric pressure does not decrease linearly with increases in elevation, linear interpolation is acceptable within the elevation ranges given in table 6.2-2. Alternatively, plot the values from table 6.2-2 and extrapolate subtraction factors directly from the graph. Section 6.2.4 contains the table of oxygen solubilities at various temperatures and pressures.

Table 6.2-2. Factors used to correct atmospheric pressures adjusted to sea level

Elevation of weather station (feet above sea level)	Value to subtract (millimeters of mercury)
0	0
1,000	27
2,000	53
3,000	79
4,000	104
5,000	128
6,000	151

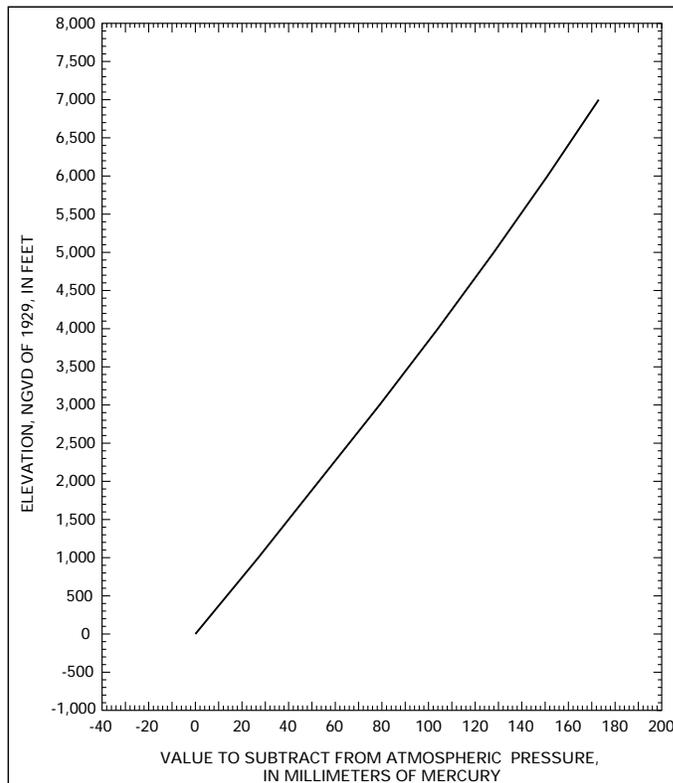


Figure 6.2-1. Factors used to correct atmospheric pressures adjusted to sea level.

Calibration procedures

Four procedures are described below for calibrating a DO system: (1) air-calibration chamber in water, (2) calibration with air-saturated water, (3) air-calibration chamber in air, and (4) iodometric (Winkler) titration.

When using an analog instrument:

- ▶ Do not change scales without either recalibrating or verifying that identical readings are obtained on both scales.
- ▶ Place an analog instrument in its operating position—either vertical, tilted, or on its back—before calibration. More readjustments may be necessary if the operating position is changed, so do not change the position of the meter until DO measurement is complete.

Procedure 1—Air-calibration chamber in water

An air-calibration chamber permits calibration of the DO sensor at the temperature of the water in which DO concentration is to be measured. This calibration procedure minimizes errors caused by temperature differences. Keep the interior of the chamber just moist during the calibration procedure, not filled with water.

1. Dip the calibration chamber into the surface or ground water to be measured; pour out the excess water (leave a few drops).
 - Insert the DO sensor into the wet chamber (this ensures 100-percent humidity).
 - If a YSI model 5739 sensor is used, the pressure-compensating diaphragm on the side of the sensor must be enclosed within the calibration chamber during calibration.
2. Immerse the calibration chamber into the water to be measured. Allow 10 to 15 minutes for the air temperature inside the chamber to equilibrate with the water (see TECHNICAL NOTE at end of Procedure 1).
 - For streams, choose an area of the stream that closely approximates mean stream temperature. In shallow streams, try to place the chamber in an area that represents the stream but that is shaded from direct sunlight.

Use of an air calibration chamber in water is the preferred field procedure.

- For ground water, use temperature-stabilized purge water.
 - Check that no water can leak into the calibration chamber and that the membrane does not have droplets of water adhering to it. The water droplets reduce the rate of oxygen diffusion through a membrane, producing erroneous results. If water has entered the chamber, repeat the procedure from step 1.
3. Determine the ambient atmospheric pressure with a calibrated pocket altimeter-barometer to the nearest 1 mm of mercury.
 4. Read the temperature within the chamber to the nearest 0.5°C.
 - The temperature inside the chamber should approximate the water temperature, measured with a calibrated thermometer.
 - If the two temperatures do not match, allow additional time for equilibration of the chamber with the water temperature.
 - If the temperature in the chamber still does not approximate the water temperature, the thermistor in the DO sensor might be malfunctioning. Measure the water temperature with a calibrated field thermometer.
 5. Use the tables in section 6.2.4 to determine the DO saturation value at the measured water temperature and atmospheric pressure (table 6.2–6). If a salinity correction will be applied during calibration, consult the instructions in section 6.2.4.
 6. Select a proper scale:
 - Analog YSI instruments—0 to 10 or 0 to 20 mg/L.
 - Digital YSI instruments—0.1 or 0.01 mg/L.
 7. Adjust the calibration control until the instrument reads a DO saturation value determined from oxygen solubility (table 6.2–6).
 - The instrument is now calibrated and ready for use. Remove the sensor from the calibration chamber.
 - As long as no excess water is in the chamber, the sensor is ready to be placed in the environment to be measured.

TECHNICAL NOTE: The YSI 5075A calibration chamber is designed to allow the membrane surface of a DO electrode (model 5739) to be at ambient atmospheric pressure while in the chamber. Because the pressure-compensating diaphragm must remain at atmospheric pressure, check the calibration chamber vent tube (from chamber through end of handle) to ensure that it is not plugged with debris or filled with water.

Do not let water leak from or droplets adhere to the dissolved-oxygen membrane.

Procedure 2—Air-saturated water

In this procedure, the DO sensor or instrument system is calibrated against water that is saturated with oxygen at a known temperature and ambient atmospheric pressure.

1. The temperature and conductivity of water used for calibration should be about the same as the temperature and conductivity of the water to be measured.
 - **At the field site**—obtain about 1 L of water from the water body to be measured.
 - **In the laboratory**—obtain about 1 L of deionized or tap water.
2. Place the DO sensor and calibration water in a large beaker or open-mouth container.
 - Allow the sensor to come to thermal equilibrium with the water temperature.
 - Shield the beaker or container from direct sunlight and wind to minimize temperature variations.
3. Aerate the water for 5 to 10 minutes. Using a battery-operated aquarium pump or minnow-bucket aerator and a short piece of tubing, attach a gas diffusion stone to the end of the tubing and place it at the bottom of the beaker of calibration water.
4. Determine if the water is 100 percent saturated with oxygen.
 - Switch the DO instrument to the 0- to 10-mg/L scale on an analog instrument or to the 0.1-mg/L scale on a digital instrument.
 - Adjust the instrument reading to approximately 8 mg/L with the calibration control.
 - Observe the instrument while aerating the calibration water. When no change in the DO reading is observed on the instrument for 4 to 5 minutes, assume that the water is saturated.
5. Read the ambient atmospheric pressure from the pocket altimeter-barometer to the nearest 1 mm of mercury.
6. Check mechanical zero. Adjust if necessary.

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7. Read the temperature of the calibration water to the nearest 0.5°C.

Calibration must be completed with the temperature of calibration water at the value measured, to ensure that the actual DO saturation of calibration water is not less than 100 percent (undersaturated) or greater than 100 percent (oversaturated).

8. Using the oxygen solubility table 6.2–6, determine the DO saturation value at the measured temperature and atmospheric pressure of the calibration water. (Refer to section 6.2.4 and table 6.2–7 for salinity corrections.)
9. Select a proper scale:
 - Analog YSI instruments—0 to 10 or 0 to 20 mg/L.
 - Digital YSI instruments—0.1 or 0.01 mg/L.
10. Turn off the aerator and adjust the calibration control until the instrument reads a saturation value of DO as determined above. The instrument is now calibrated and ready for use.

For accurate calibration, be sure that the water is 100 percent saturated with oxygen (step 4 above).

Procedure 3—Air-calibration chamber in air

This procedure is similar to the procedure for air-calibration chamber in water, except that the calibration chamber is in air rather than in water.

- ▶ The air-calibration-chamber-in-air procedure requires sensors in which the temperature-sensing thermometer is adjacent to the membrane.
 - ▶ The DO instrument used must be able to automatically compensate for temperature changes. The YSI analog and digital DO instruments are automatically temperature compensating for changes in the solubility of oxygen in water and in the permeability of the sensor membrane.
1. Wet the inside of the calibration chamber with water—pour out the excess water (leave a few drops) and insert the sensor into the chamber (this ensures 100-percent humidity).
 2. Allow 10 to 15 minutes for the DO sensor and the air inside the calibration chamber to equilibrate.

3. Read the ambient atmospheric pressure (from the pocket altimeter-barometer) to the nearest 1 mm of mercury.
4. Check mechanical zero. Adjust if necessary.
5. Measure the temperature in the calibration chamber and observe the readings until the instrument stabilizes. Read the temperature to the nearest 0.5°C.
 - The temperature inside the chamber should approximate the water temperature, measured with a calibrated thermometer.
 - If the two temperatures do not match, allow additional time for the chamber and the water temperature to equilibrate.
 - If the temperature in the chamber still does not approximate the water temperature, the thermistor in the DO sensor might be malfunctioning. Measure the water temperature with a calibrated field thermometer.
6. Use the oxygen-solubility table 6.2–6 to determine the DO saturation at the measured temperature and atmospheric pressure. (Refer to section 6.2.4 and table 6.2–7 for salinity corrections.)
7. Select a proper scale:
 - Analog YSI instruments—0 to 10 or 0 to 20 mg/L.
 - Digital YSI instruments—0.1 or 0.01 mg/L.
8. Adjust the calibration control until the instrument reads the DO saturation value determined from the oxygen-solubility table. The instrument is now calibrated and ready for use.

Do not use the air-calibration-in-air procedure if the calibration chamber temperature differs from the temperature of the water to be measured.

Procedure 4—Iodometric (Winkler) titration

The iodometric (Winkler) procedure is excellent for calibrating DO instrument systems in a laboratory environment (see TECHNICAL NOTE).

The USGS currently uses the Alsterberg-Azide modification to the Winkler titration procedure for iodometric determination of DO. **The accuracy of measurements using this method should be within at least ± 0.05 mg/L.**

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Equipment and supplies needed for the iodometric titration are listed in table 6.2–3. The procedure involves the use of reagent packets that are available in premeasured pillow packets from QWSU and from commercial suppliers, or they can be prepared as described in Skougstad and others (1979) and American Public Health Association and others (1992). Clean all equipment before use.

Table 6.2–3. Equipment and supplies used for the iodometric dissolved-oxygen determination

[mL, milliliter; *N*, normal; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius]

- ✓ Beaker, 2,000 mL, glass or Teflon™
- ✓ Bottles for biological oxygen demand (BOD) analysis, glass stoppered, 300 mL
- ✓ Stirrer, magnetic
- ✓ Stirring bars, Teflon™ coated
- ✓ Cylinder, graduated, 250 mL
- ✓ Flask, Erlenmeyer, 250 mL
- ✓ Buret, 25-mL capacity with 0.05-mL graduations and Teflon™ stopcock
- ✓ Buret, support stand
- ✓ Buret, clamp, double
- ✓ Alkaline iodide-azide reagent
- ✓ Manganous sulfate reagent
- ✓ Sulfamic acid granules
- ✓ Phenylarsine oxide (PAO), 0.025 *N* titrant
- ✓ Starch indicator solution
- ✓ Clippers, for opening reagent pillows
- ✓ Appropriate safety gloves, glasses, and apron
- ✓ Waste disposal container
- ✓ White background sheet
- ✓ Deionized water (maximum conductivity of 1 $\mu\text{S}/\text{cm}$)
- ✓ Bottle, squeeze dispenser, for deionized water
- ✓ Thermometer, calibrated (see NFM 6.1 for selection and calibration criteria)
- ✓ Pocket altimeter-barometer, calibrated, Thommen model 2000™ or equivalent

TECHNICAL NOTE: The iodometric procedure might be appropriate under some circumstances for making field measurements of DO. It is not recommended for routine determination of DO in surface and ground water because (1) the accuracy achievable can be variable and is dependent on the experience and technique of the data collector, and (2) field conditions can make preventing exposure of the sample to atmospheric oxygen difficult.

- ▶ **When calibrating instruments in the laboratory using the Winkler procedure, the DO instrument is calibrated against deionized water (or the pure saline solution equivalent to that of the ambient water to be measured) in which the DO concentration has been determined iodometrically.**
- ▶ **If a saline solution is used to approximate the environmental water, do not apply a salinity correction factor.**

Measure DO on at least two subsamples, for quality control. Results of two iodometric titrations should agree within 1 mg/L. If they do not agree, repeat the titration on a third subsample.

1. Fill a 2,000-mL beaker with deionized water that is near DO saturation. The water temperature should be close to the ambient laboratory temperature.
2. Prepare the DO instrument system for operation per the manufacturer's instructions.
3. Place the DO sensor in a beaker of distilled water. With a magnetic stirrer, maintain a velocity of at least 1 ft/s past the DO sensor.
4. Monitor the DO concentrations of the deionized water with the DO instrument system. After the DO instrument reading has stabilized, fill two BOD bottles with deionized water from the beaker.
5. Determine the DO concentration of the water in each BOD bottle, as follows:
 - a. Add one each of the following dry reagent pillow packets:
 - alkaline iodide-azide (white powder).
 - manganous sulfate (pinkish-colored powder).
 - b. Recap the bottle. **Do not allow air bubbles to be trapped in the bottle.**

- c. Invert the bottle 25 times or more to completely dissolve the reagents.
 - A brown flocculent indicates the presence of DO.
 - Allow the brown flocculent to settle halfway down the bottle (approximately 5 minutes).
 - Invert the bottle 25 times again; let the flocculent settle again.
- d. Invert the bottle another 25 times; add one reagent pillow of sulfamic acid (grayish granules, the longest of the three pillows).
- e. Recap the bottle without introducing air or air bubbles. Invert the bottle 25 times, until all of the flocculent and granules are dissolved.
- f. Fill a clean 25-mL buret with 0.025 *N* phenylarsine oxide (PAO) titrant. Remove any air bubbles beneath the stopcock and zero the meniscus.
- g. Use a clean graduated cylinder to measure 200 mL of the sample and pour the sample into a clean, wide-mouth Erlenmeyer flask.
- h. Place the flask on a magnetic stirrer. Add a clean Teflon™ stirring bar and stir the sample at a moderate rate **without aerating the sample**.
- i. Add increments of PAO titrant until the color turns pale straw-yellow.
- j. Add 1 to 2 mL of starch solution (this causes the sample to turn blue).
- k. Very slowly add more PAO titrant until the sample just turns clear (a white background behind the bottle will help you see the color change).
- l. Record the volume of PAO titrant used, in milliliters.
 - For a 200-mL sample, the volume of titrant added is directly proportional to the amount of DO in milligrams per liter.
 - To calculate DO for a sample volume greater or less than 200 mL,

$$DO(\text{mg/L}) = \left(\frac{200}{\text{sample volume}} \right) \times \text{titrant added (in mL)}$$
- m. Record the DO value. Rinse the equipment with deionized water.
- n. **Quality control**—Repeat steps 1 through 5 on a second subsample. Both titration values should agree within 0.1 mg/L. If they do not, repeat titration on a third bottle.
- o. Recheck the field instrument for proper functioning per the manufacturer's instructions: adjust the calibration control until the DO instrument system reads the DO concentration determined.

MEASUREMENT 6.2.1.C

The solubility of oxygen in water depends on the partial pressure of oxygen in air, the temperature of the water, and the dissolved-solids content of the water.

- ▶ The higher the atmospheric pressure and the lower the temperature and conductivity, the more oxygen can be dissolved in the water.
- ▶ Degassing, mineral precipitation, and other chemical, physical, and biological reactions can cause the DO concentration of a water sample to change significantly within minutes after sample collection.
- ▶ The solubility of oxygen in water decreases as salinity increases. Correction factors for salinity normally are applied after measuring DO. Information about oxygen solubility and salinity and a salinity correction factors table are in 6.2.4.

Surface water

Standard DO determination for surface water represents the cross-sectional median or mean concentration of dissolved oxygen at the time of observation.

- ▶ Measuring DO concentration at one distinct spot in a cross section is valid only for flowing water with a cross-sectional DO variation of less than 0.5 mg/L.
- ▶ Determining DO in a single vertical at the centroid of flow at the midpoint of the vertical is only representative of the cross section under ideal mixing conditions.
- ▶ Do not measure DO in or directly below sections with turbulent flow, in still water, or from the bank, unless these conditions represent most of the reach or are required by the study objectives.
- ▶ Apply salinity correction, if needed, after measurement.

Dissolved oxygen must be measured in situ.
Never measure DO in subsamples from a sample splitter.

Follow the 7 steps below to measure DO in surface water:

1. Calibrate the DO instrument system at the field site and check that the temperature thermistor has been District-certified within the past 4 months (within 12 months if a liquid-in-glass thermometer is used).
2. Record the DO variation from the cross-sectional profile and select the sampling method (NFM 6.0):
 - **Flowing, shallow stream**—Wade to the location(s) where DO is to be measured.
 - **Stream too deep or swift to wade**—Lower a weighted DO sensor with calibrated temperature sensor from a bridge, cableway, or boat. (Do not attach the weight to the sensors or sensor cables.)
 - **Still-water conditions**—Measure DO at multiple depths at several points in the cross section.
3. Immerse the DO and temperature sensors directly into the water body and allow the sensors to equilibrate to the water temperature (no less than 60 seconds).
 - If the water velocity at the point of measurement is less than about 1 ft/s, use a stirring device or stir by hand to increase the velocity (to hand stir, raise and lower the sensor at a rate of about 1 ft/s, but do not break the surface of the water).
 - Very high velocities can cause erroneous DO measurements.
4. Record the temperature without removing the sensors from the water. Turn the operation switch to the range that was used during instrument calibration.
5. After the instrument reading has stabilized (allow 1 to 2 minutes and ± 0.3 mg/L), record the median DO concentration (see NFM 6.0).
6. For EWI or EDI measurements, proceed to the next station in the cross section and repeat steps 3 through 5. When measurements for the stream have been completed, remove the sensor from the water, rinse it with deionized water, and store it according to the manufacturer's instructions.
7. Record DO concentrations on the field forms:
 - **In still water—median** of three or more sequential values.
 - **EDI—mean** value of all subsections measured (use the median if measuring one vertical at the centroid of flow).
 - **EWI—mean (or median)** of all subsections measured.

Ground water

To determine the concentration of DO in an aquifer, the water being measured must not contact air. Study objectives and site characteristics will dictate the specific procedures selected. **If the DO concentration is less than 1 mg/L, refer to the spectrophotometric method (section 6.2.2).**

- ▶ Throughout measurement, use equipment that avoids aeration, and operate equipment to mitigate losses or gains of dissolved gases (consult NFM 6.0 for proper downhole and flowthrough-chamber sampling procedures).
- ▶ Use a positive-displacement submersible pump and high-density plastic sample tubing that is relatively gas impermeable, if possible.
- ▶ Use optically clear materials for the tubing and chamber (to check that entrained bubbles are not present). Air bubbles that adhere to the sides of the tubing and flowthrough chamber will add significant error to low-level DO measurements (A.F. White, U.S. Geological Survey, written commun., 1993).

Never use a bailed or other discrete sample for DO determination.

Follow the 7 steps below to measure DO in ground water:

1. Calibrate the DO system on site. Check that the thermistor thermometer has been District certified within the past 4 months.
2. Install the DO equipment (see section 6.0.3, “Ground Water”):
 - **Downhole system**—Lower the DO and temperature sensors to the sampling point, followed by the pump, to monitor DO variation during purging. If a downhole system will be used only for final DO determination after the samples are collected and the pump is removed, attach a stirrer to the DO instrument before lowering it to the sampling point.
 - **Flowthrough-chamber system**—Refer to section 6.0.3 for installation guidelines. Be sure to:

- a. Install the DO sensor through an air-tight grommet, checking that the seal is intact. Check that the sensors are properly immersed.
 - b. Flush air bubbles from the tubing walls and flowthrough chamber—Tap the tubing with the blunt end of a tool to dislodge entrained air bubbles (see TECHNICAL NOTE).
 - c. Check for and eliminate backpressure in the chamber.
3. Keep flow passing the DO sensor laminar and constant.
 4. Measure and record DO at regular intervals throughout purging. Allow the sensors to equilibrate with ground water for 5 minutes or more at the flow rate to be used for sampling.
 5. Check the stability (variability) of DO toward the end of purging.
 - The stability criterion is met when five consecutive readings made at regularly spaced intervals of 3 to 5 minutes or more are within 0.3 mg/L. (For each reading, monitor fluctuations for 30 to 60 seconds and record the median value, if necessary.)
 - If the ± 0.3 mg/L criterion is not met, lengthen the purge period in accordance with study objectives and continue to record measurements at regularly spaced time intervals.
 6. Report sample DO as the median of the final five DO readings recorded. Record any difficulty with stabilization on field forms.
 7. Remove the sensor from water and rinse it with deionized water.

TECHNICAL NOTE: Anomalously high DO measurements commonly are caused by aeration of ground water during pumping. This can result from air leakage through loose fittings on production-well pumps (for example, turbine pumps) and also if drawdown in the aquifer introduces air into the cone of depression or through well-screen perforations. To avoid these problems, review information about the pump, well-construction and drawdown data, and previous data records (A.F. White, U.S. Geological Survey, written commun., 1993).

Air bubbles in the lines and flowthrough chamber can add significant error to low DO readings.

TROUBLESHOOTING (AMPEROMETRIC METHOD) 6.2.1.D

The troubleshooting suggestions given in table 6.2–4 are not exhaustive; consult the instrument manufacturer for additional guidance. Faulty batteries can cause erratic readings.

- ▶ Check the voltage of the batteries.
- ▶ Start with good batteries in the instrument and carry spares.

Table 6.2–4. Troubleshooting guide for amperometric determination of dissolved-oxygen concentration

Symptom	Possible cause and corrective action
Instrument does not adjust to red line	<ul style="list-style-type: none"> • Weak batteries—replace. • Faulty meter compensation thermistor (analog instruments only)—repair.
Instrument drifts or takes excessive time to stabilize	<ul style="list-style-type: none"> • Thermal equilibrium of DO sensor with water has not been reached—wait longer. • Weak batteries—replace. • DO sensor needs maintenance—recondition.
Erratic instrument readings	<ul style="list-style-type: none"> • Break in cable—replace cable. • Faulty connection at instrument or sensor—clean contact and tighten connection. • Hole in membrane—replace membrane, recondition. • Air bubble in sensor—recondition sensor. • Weak batteries—replace with new batteries.
Instrument is slow to react	<ul style="list-style-type: none"> • Gold cathode tarnished—buff with pencil eraser and recondition sensor. • Fouled membrane—recondition sensor and replace membrane.
Instrument will not read zero in sodium sulfite solution.	<ul style="list-style-type: none"> • Solution contains oxygen—add additional sodium sulfite. • Instrument still does not read zero—recondition sensor. • Faulty oxygen or polarizing thermistors (analog instruments only)—replace or repair.
Instrument cannot be calibrated to read standards	<ul style="list-style-type: none"> • Unable to adjust upward—check if more than one membrane is on the sensor. • Unable to adjust downward (membrane is probably too tight or too thin)—replace membrane. • Faulty polarizing voltage thermistor (analog instruments only)—repair. • Faulty meter compensation thermistor (analog instruments only)—repair. • Faulty oxygen thermistor (analog instruments only)—repair.
Instrument shows inaccurate temperature	<ul style="list-style-type: none"> • Faulty or uncalibrated temperature thermistor—calibrate, repair, or replace.