



## 6.7 TURBIDITY

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## TURBIDITY 6.7

Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity.<sup>1</sup> Primary contributors to turbidity include clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, plankton, and microscopic organisms (American Public Health Association and others, 1992). The measurement is qualitative and cannot be correlated directly as micrograms per liter of suspended solids.

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**Turbidity: a measure of the collective optical properties of a water sample that cause light to be scattered and absorbed rather than transmitted in straight lines.**

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Determination of turbidity is a common component of water-quality assessments.

- ▶ In surface water, the clarity of a natural body of water is used routinely as an indicator of the condition and productivity of the aqueous system.
- ▶ In ground water, turbidity commonly is measured during well development and well purging to indicate the extent to which particulates occurring as a result of well installation and sampling activities have been removed.

**Turbidity measurements reported for regulatory purposes require a true nephelometric measurement using turbidimeter instruments that meet U.S. Environmental Protection Agency (USEPA) specifications (see 6.7.1).**

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<sup>1</sup>Turbidity measurements have not been systematically researched, tested, compared, or quality assured within the U.S. Geological Survey (USGS). Recommendations in this section were compiled from the references cited, instrument handbooks, field experience, and a limited series of tests on available instruments conducted by the USGS Hydrologic Instrumentation Facility (HIF).

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Turbidity is measured in nephelometric turbidity units (NTU) or Formazin turbidity units (FTU), depending on the method and equipment used. Turbidity measured in NTU uses nephelometric methods that depend on passing specific light of a specific wavelength through the sample. FTU is considered comparable in value to NTU and is the unit of measurement when using absorptometric methods (spectrophotometric equipment). Jackson turbidity unit (JTU) values also approximate NTU but the JTU is no longer in common use. Turbidity values are entered into the USGS National Water Information System (NWIS) database only if the measurement is made in NTU and with instruments that are operated using USEPA-approved methods—not all turbidimeters that display NTU values meet these criteria.

Visible turbidity is found at greater than 5 NTU (Strausberg, 1983). The legal limit of turbidity in drinking water is 0.5 NTU.

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.

## EQUIPMENT AND SUPPLIES 6.7.1

Equipment and supplies commonly used for field measurement of turbidity are listed in table 6.7-1. Before field use of water-quality instruments, become familiar with the manufacturer's instructions for calibration, operation, and maintenance. **Test field instruments before use.**

Table 6.7-1. Equipment and supplies used for measuring turbidity<sup>1</sup>

[≤, equal to or less than; μm, micrometer; mL, milliliters; in., inch]

- ✓ Turbidimeter or spectrophotometer or submersible-sensor instrument (such as a multiparameter instrument with a turbidity sensor).<sup>2</sup>
- ✓ Turbidity stock solutions and standards:
  - Formazin stock suspension, commercially obtained or prepared with hydrazine sulfate and hexamethylenetetramine chemicals.
  - Manufacturer-provided secondary standards.
- ✓ Sample cells (cuvettes), clear colorless glass (supplied from instrument manufacturer).
- ✓ Debubbler (degassing apparatus, commercially available or self-made).
- ✓ Inert (dry) gas (for example, nitrogen) and gas delivery apparatus; tanks must be fitted with regulators and filter.
- ✓ Sample bottle (preferably a bottle that does not sorb suspended material; if the sample will be stored temporarily, use an amber bottle).
- ✓ Silicon oil, optical grade (with same index of refraction as sample cells; supplied by instrument manufacturer).
- ✓ Paper tissues, extra lint free.
- ✓ Turbidity-free water, deionized water filtered through a ≤ 0.2-μm filter membrane with precision-sized pores.
- ✓ Bottle to hold turbidity-free water, cleaned and rinsed three times with filtered water.
- ✓ Volumetric flask, Class A, 100 mL or 500 mL.
- ✓ Volumetric pipet, Class A, 5.0 mL and pipet filler.
- ✓ Filter flask, 500 mL; filter holder; filter pump, aspirator.
- ✓ Rubber stopper, one-hole, No. 7; tubing, 5/16-in. inside diameter.

<sup>1</sup> Modify this list to meet the specific needs of the field effort.

<sup>2</sup> See text for description of USEPA-approved instrumentation.

**Turbidity instruments.** Three basic types of instrumentation are used to measure turbidity: turbidimeters (nephelometers), spectrophotometers, and multiparameter instruments with submersible sondes that can accommodate a turbidity sensor (commonly referred to as a turbidity probe). Choice of turbidity instrument depends on site characteristics and intended use of the data in addition to instrument specifications, performance, and reliability.<sup>2</sup>

- ▶ If measuring turbidity for regulatory or compliance purposes, the only method approved by the USEPA employs Method 180.1 (STORET NO. 00076) (USEPA, 1979).<sup>3</sup>
- ▶ For nonregulatory monitoring purposes, either a submersible sensor that measures turbidity using a near-infrared light source or a spectrophotometer in absorbance mode may be used.
  - Turbidity probes (submersible sensors) are available for multiparameter instruments with pH, temperature, conductivity, and other sensors; this is convenient for monitoring turbidity along with other field measurements. For ground-water studies, multiparameter instruments are available with sondes that can be used in 2-in. diameter wells.
  - Field spectrophotometers can be convenient for qualitative turbidity measurements if additional sample properties will be measured spectrophotometrically.

#### USEPA-approved specifications for turbidity instruments

- The light source should be a tungsten lamp operated at a color temperature between 2,200 to 3,000 Kelvin.
- The maximum distance traversed by incident and scattered light within the sample tube is 10 centimeters.
- The detector and any filter system are to have a spectral peak response between 400 and 600 nanometers.
- The detector should be centered at an angle of 90 degrees to the incident light path and must not exceed  $\pm 30$  from 90 degrees.
- Instrument sensitivity should permit detection of a turbidity difference of 0.02 NTU or less in water with less than 1 NTU.

<sup>2</sup>Turbidity instruments are being developed and improved by several companies; investigate instrument performance and reliability before making an equipment selection.

<sup>3</sup>The USEPA also approves the GLI-2 method turbidity instrument system (a microprocessor-based turbidity system using a pulsed-light, four-beam sensor); the GLI-2 provides stable and reproducible turbidity readings to 0.5 NTU but it is not a portable instrument.

Selected turbidity instruments were tested by the Hydrologic Instrumentation Facility. Referring to table 6.7-2, field tests of the Hach DR 2000™ indicated consistently higher FTU values compared with NTU values measured with the Analite 152™, Hach 2100P™, Hydrolab DataSonde 3™, and YSI 3800™. Not available at the time of testing were either the Hydrolab H20™ or YSI 6000™ multiparameter instruments with turbidity probe or the Analite 156™. Refer to Hydrologic Instrumentation Facility (1994) for test details.

Table 6.7-2. Measurement range and laboratory test results of selected turbidity instruments

[This table is meant to serve as a guide by which study criteria for turbidity instruments can be developed. Instruments listed were tested by the USGS Hydrologic Instrumentation Facility (HIF) unless otherwise noted. Turbidity instruments are being improved and new instruments are in development. NTU, nephelometric turbidity units; <, less than; ±, plus or minus; >, greater than; ~, approximately; %, percent; FTU, Formazin turbidity units; ≤, less than or equal to; YSI, Yellow Springs Instrument Company, Inc.; ISO, International Standards Organization]

Instrument	Measurement range	Percent difference from NTU standards
Hach 2100P™. (Handheld portable turbidimeter; 0.01 NTU resolution.) <sup>1</sup>	<10 to 1,000 NTU	~5%, 20 to 950 NTU
Hach Ratio/XR™. (Flowthrough cell, bench turbidimeter—can be adapted for field with a generator; 0.001 NTU resolution on 0-2 scale.) <sup>1</sup>	0 to 2,000 NTU	<5%, 20 to 950 NTU
Hydrolab DataSonde 3™ (DS-3) <sup>2</sup> . (Multiparameter, submersible instrument with internal logging and electronic communications capabilities.)	0 to 1,000 NTU	<2%, 40 to 950 NTU >10%, 20 NTU
YSI 3800™. (Multiparameter, submersible; 1 NTU resolution.)	0 to 1,000 NTU	≤3%, 40 to 950 NTU > 10%, 20 NTU
YSI 6000™. (Multiparameter, submersible instrument with internal logging and electronic communications capabilities; probe equipped with mechanical wiper.) <sup>2</sup>	0 to 1,000 NTU	Manufacturer specifications (not tested by HIF): ±5% of reading or 2 NTU (whichever is greater)
Analite 152™ and 156™. (Fiber optic portable nephelometer with wand-type sensor, 1-foot long.) <sup>2</sup>	<10 to >30,000 NTU	~5% or less, 400 to 950 NTU
Hach DR2000™. (Spectrophotometer; readings in FTU.)	0 to 450 NTU	5% or less, 20 to 400 NTU

<sup>1</sup>Meets USEPA regulatory specifications for turbidity measurements, has 90-degree hatchure and visible radiation.

<sup>2</sup>Hydrolab DataSonde3™, Analite 152™ and 156™, YSI 6000™ (not tested), and Hydrolab H20™ (not tested) use infrared technology. Instruments that conform to ISO 7027 criteria for back-scatter angle of 90 degrees include the YSI 6000™, Hydrolab DS-3™, and Hydrolab H20™.

The method used for sample handling falls into three general categories, as dictated by instrument capabilities: (1) manual (discrete) sample, using a cuvette-based instrument, with sample decanted into a sample cell (cuvette); (2) pumped sample, in which a sample is pumped through a “flowthrough cell,” which is a turbidity-sensor-containing cuvette that is an internal part of the instrument; and (3) direct determination, by positioning a turbidity probe either in situ or into a flowthrough chamber that receives pumped sample (see NFM 6.0).

**Turbidity-free water.** Turbidity-free water is used for preparation of turbidity standards and is prepared by filtering either sample water or deionized water (DIW) through a 0.2- $\mu\text{m}$  or smaller pore-sized membrane. Turbidity-free water is recommended instead of unfiltered DIW for preparation of standards.

**Turbidity standards.** USEPA (1979) guidelines recommend monthly preparation of the stock turbidity suspension for the calibration standard, and daily preparation of the standard turbidity suspension at the dilutions needed (see 6.7.2). Formazin stock solution is available commercially.

**Debubbler/degassing system.** Bubbles in the sample will give false turbidity readings. A debubbler or degassing system is required if sample contains effervescing gases. The equipment plumbing must be set up to maintain a constant head, resulting in constant velocity through the turbidimeter’s flowthrough cell. When using a turbidity probe within a flowthrough chamber, it might be necessary to direct debubbled water through the chamber.

- ▶ Obtain a debubbler from the instrument manufacturer, or construct one as shown on figure 6.7-2 in section 6.7.3.
- ▶ Probe-based instruments are available with a wiper mechanism that clears bubbles from the optical surface of the submersible sensor (probe).

**Instruments with gas-sweep capacity.** Condensation must be removed or reduced throughout turbidity determination. Some flowthrough-cell instruments have the capacity to continuously sweep the sample compartment with dry gas, reducing condensation on the sample cell; otherwise, condensation is to be removed manually every few minutes.

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## MAINTENANCE, CLEANING, AND STORAGE 6.7.1.A

Check manufacturer's instructions for instrument maintenance, cleaning, and storage. **Test equipment before each field trip and record all repairs in the instrument log book.** Manufacturer's instructions and the log book should accompany the instrument at all times.

**Turbidity instruments.** Protect instruments from extreme temperatures. Shield the instrument LED display panel from direct sunlight. If a bench-top turbidimeter gets wet, allow it to dry thoroughly before the next use (field turbidimeters are constructed to withstand moisture). Check and replace batteries routinely.

**Sample cells (cuvettes).** Handle and store sample cells in a manner to prevent dirt, scratches, or other damage. Follow instrument manufacturer instructions for the maintenance of sample cells. Keep sample cells scrupulously clean, inside and out. After each use, (1) wash with nonphosphate laboratory detergent, (2) rinse repeatedly with deionized water until all detergent residue is removed, and (3) allow cells to air dry in a dust-free environment.

**Submersible turbidity probe.** Exercise care that optical surfaces of probes are not scratched during cleaning, operation, or storage. Scratched or damaged probes must be replaced. Keep optical surfaces free of all foreign material by wiping with moist lens-cleaning paper or cloth.

**Standard solutions.** Discard turbidity standards with elapsed expiration dates. Protect turbidity standards from extreme temperatures. Never pour used standard or a portion of unused standard back into its original (stock) container.

Keep sample cells scrupulously clean and free of scratches.

## 6.7.2 CALIBRATION

Follow the manufacturer's instructions for instrument calibration and record calibration readings and adjustments in the instrument log book.

- ▶ Calibration of turbidity instruments against a Formazin or other approved primary standard usually is done in the laboratory, with instrument checks performed in the field. **Use standards that bracket the range of turbidity anticipated in environmental samples, if possible.**
- ▶ For instruments that are factory calibrated in standard turbidity units, the calibration procedure checks the accuracy of calibration scales provided by the manufacturer.
- ▶ Periodically check the accuracy and precision of your instrument against that of another instrument.
- ▶ Consult the manufacturer if the precision of your instrument deviates 5 percent or more from the manufacturer's specifications.

The USEPA specifies that the turbidimeter must be calibrated with a primary standard (a Formazin or a styrene divinylbenzene polymer standard such as Amco AEPA-1 Polymer™) (U.S. Environmental Protection Agency, 1994). A solid scattering standard provided by the manufacturer for setting overall instrument sensitivity for all ranges should not be relied on unless the turbidimeter is demonstrated to be free of drift on all ranges (U.S. Environmental Protection Agency, 1979).

Temperature changes affect Formazin turbidity standards and the performance of the turbidity instrument.

- ▶ Turbidity instruments are not currently available with an automatic temperature-compensating function.
- ▶ Standards and instruments should be at the same and constant temperature during calibration to achieve stable and accurate results.
- ▶ To avoid the effects of thermal fluctuations on the calibration, perform the Formazin calibration and calibration of the secondary standard (for example, Gelex™) against the primary standard in the office laboratory at room temperature instead of at the field site. At the field site, check instrument calibration using a secondary standard.

### ***Preparation of the stock turbidity suspension and standard dilutions***

Prepare the stock turbidity suspension monthly and standard dilutions on the day of instrument calibration. To prepare and dilute a 400 NTU Formazin stock suspension<sup>4</sup>:

1. Dissolve 1.000 g hydrazine sulfate  $[(\text{NH}_2)_2 \cdot \text{H}_2\text{SO}_4]$  in filtered water and dilute to 100 mL in a volumetric flask.
2. Dissolve 10.00 g hexamethylenetetramine  $[(\text{CH}_2)_6\text{N}_4]$  in filtered water and dilute to 100 mL in a volumetric flask.
3. Mix 5.0 mL of hydrazine sulfate and 5.0 mL of hexamethylenetetramine solutions in a 100-mL volumetric flask and let stand 24 hours at  $25 \pm 3^\circ\text{C}$ ; dilute to the mark and mix. To prepare 500 mL of 400 NTU standard, mix 25 mL of the reagent solutions in a 500-mL flask, dilute to the mark, and mix.
4. For a 40 NTU standard, dilute 10.00 mL of the 400 NTU stock suspension to 100 mL with turbidity-free water (sample or deionized water passed through a filter media of  $\leq 0.2 \mu\text{m}$ ).
  - Dilute stock suspension on the day the standard is needed, use it immediately after preparation, and discard unused standard.
  - Inconsistent techniques used to dilute standards can add as much as 5 percent measurement error.

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## **TURBIDIMETER CALIBRATION 6.7.2.A**

The calibration instructions and procedures that follow are general and should be modified to apply to the instrument being used—check manufacturer's instructions:

1. Prepare Formazin suspensions as described above.
  - Calibrate each instrument range using at least three standard concentrations. Use standards that bracket the range of turbidity anticipated in the sample solution.
  - Prepare dilute standards fresh from the stock at the time of use—after dilution, the stock suspension is stable only for 4 to 6 hours.
  - For turbidity greater than 40 NTU, use undiluted stock solution.
  - **Do not use standards with flocculated suspensions.**

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<sup>4</sup> Refer to American Public Health Association and others (1992) for detailed instructions.

2. Switch the turbidimeter on and allow it to warm up. Put on disposable gloves.
3. Check instrument focus: insert template in the cell holder. The lamp image should just fill the inside circle. Adjustment is required if the image is off center, too large, or too small.
4. Field rinse a clean, dry, scratch-free, index-marked cell with the highest concentration of the standard for the instrument range setting or range of interest.
  - a. Hold the sample cell by the rim (top lip), not beneath the lip.
  - b. Pour standard into the sample cell to the fill mark.
  - c. Wipe the exterior of the cell using a soft, lint-free cloth or tissue to remove moisture (condensation) on cell walls.
  - d. Apply a thin layer of silicon oil (table 6.7-1) onto the exterior of the cell to reduce condensation on the cell and mask slight scratches and nicks. Apply silicon oil uniformly onto the blank cell if it will be used on the cell filled with standard (check manufacturer's recommendations).
5. Select the desired NTU range.
  - Set the calibration adjustment to equal the high value of standard for the range of interest.
  - Before inserting the standard, ensure that no air bubbles are present.
6. Orient the standard cell in the cell holder—the calibration cell and sample cell must have identical orientation when in the instrument measurement chamber.
7. In the instrument log book, record and graph the instrument value for each standard (instrument reading versus standard value—see fig. 6.7-1).
8. Adjust standardization control until the value on the meter equals the NTU value of the standard used.
9. Remove the sample cell and discard the first turbidity standard.
  - a. Rinse and fill a clean cell with the second turbidity standard and orient the cell in the instrument.
  - b. Take a reading without adjusting the calibration.
  - c. Plot this instrument NTU reading against the NTU value of the turbidity standard (fig. 6.7-1).

10. Repeat step (9) for at least one more turbidity standard with NTU value to cover the turbidity range of interest. The greater the number of turbidity standard values used, the greater the reliability of the calibration.
11. Prepare a calibration curve for each range of values to be used if a precalibrated scale is not supplied by the manufacturer. (The accuracy of calibration scales provided with the instrument must be verified by using a precalibrated instrument and appropriate standards.)
  - The plot of instrument reading versus turbidity standard value is a range calibration curve.
  - Verify that any instrument reading (dial setting) within the range calibrated is correct and agrees with correlative points on the calibration curve.
12. Calculate the NTU of a diluted sample:

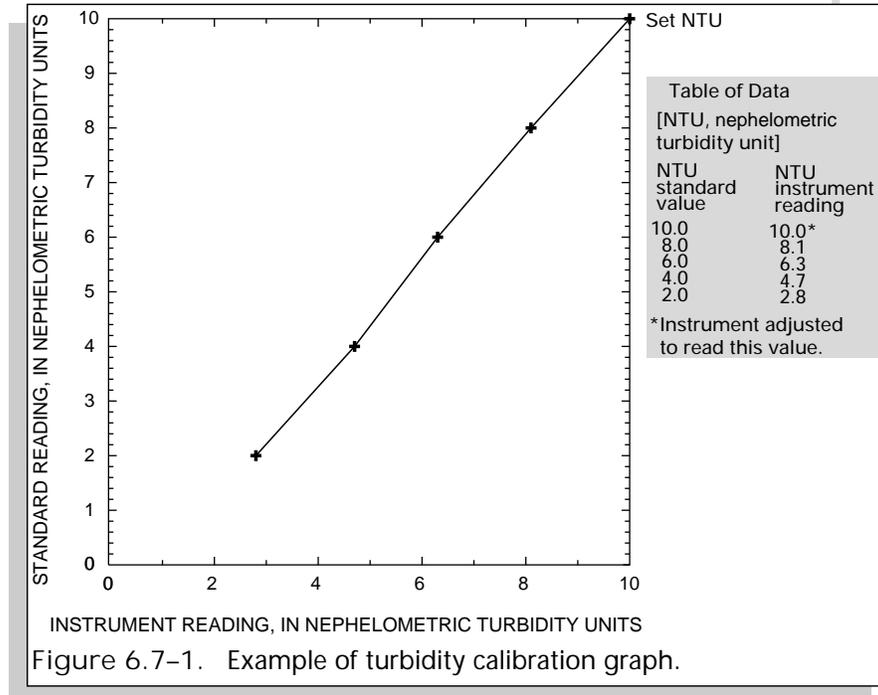
$$NTU = A \times (B+C) / C$$

where

A = NTU found in diluted sample,

B = volume of dilution water, in milliliters, and

C = sample volume taken for dilution, in milliliters.



### 6.7.2.B SUBMERSIBLE TURBIDITY SENSOR CALIBRATION

Most multiparameter instruments with turbidity probe capability are microprocessor-based, with the calibration parameters stored in instrument memory. Turbidity values of the standards are user-selectable in some instruments, but some instruments have internally established standard values that cannot be changed. Low-level check standards in the 1–5 NTU range will allow the user to assess the actual performance of the instrument near the detection limit; **instrument reliability generally decreases at NTU less than 5**—consult manufacturer’s specification for the expected accuracy of the measurement.

Monitor digital output carefully to assure that turbidity readings are stable before confirming the calibration. Note that if the instrument uses signal averaging to smooth instrument output, output response to changes in turbidity readings can be slowed.

**Calibrate the instrument before leaving for the field site.** While in the field, check instrument performance periodically using turbidity standard and turbidity-free water. The optical surface of the probe must be clean before beginning the calibration procedure. Modify the general instructions that follow as necessary so that they are compatible with the manufacturer’s instructions:

1. Prepare a sufficient volume of the Formazin standard, as described previously. Volume of standard required could be 500 mL for some instruments, particularly if the entire sonde bundle instead of just the turbidity probe will be immersed.
2. **Select Procedure (A) or (B).** The same procedure, once tested and selected, also should be used in future studies.

**Procedure A.** Immersion of entire sonde (bundle of field-measurement sensors, including the turbidity sensor)—requires larger volumes of standard; standard is vulnerable to contamination and dilution. The sonde sensor guard may need to be removed.

**Procedure B.** Immersion of turbidity probe only—depending on sonde configuration, isolation of the turbidity probe and achieving a bubble-free optical surface could be difficult. This technique minimizes the volume of standard required for calibration.

3. Using a zero NTU standard (turbidity-free water):
  - a. Rinse sonde/probe with deionized water, followed by a portion of turbidity-free water.
  - b. Immerse entire surface of sonde/probe in turbidity-free water.
  - c. Agitate the sonde/probe repeatedly to remove bubbles from the optical surface (activate mechanical wiper, if present).
  - d. Monitor turbidity readings for 1 to 2 minutes or longer to ensure that readings are stable (consult manufacturer's recommendations and signal-averaging information).
  - e. Confirm the zero NTU calibration point using manufacturer's instructions.
  - f. Remove sonde/probe and dry thoroughly to minimize dilution or contamination of the next standard.
  - g. Discard first standard (turbidity-free water).
4. Using the second standard (Formazin suspension):
  - a. Rinse sonde/probe surfaces with a portion of standard. Discard rinsate.
  - b. Immerse entire surface of sonde/probe in a container filled with standard.
  - c. Agitate the sonde/probe repeatedly to remove bubbles from the optical surface (activate mechanical wiper, if present).
  - d. Monitor turbidity readings for 1 to 2 minutes or longer to ensure that readings are stable (consult manufacturer's recommendations and signal-averaging information).
  - e. Confirm the NTU calibration point for the standard used, according to manufacturer's instructions.
  - f. Remove sonde/probe and rinse surfaces thoroughly with deionized water followed by turbidity-free water. Dry sonde/probe thoroughly.
  - g. Discard used standard.
5. Repeat steps 4(a–g) using a different Formazin suspension standard if increased accuracy is desired and instrument software permits use of a third calibration point.

6. By diluting the existing standards, prepare a standard with turbidity, either approximately midway between the calibration points and (or) close to the estimated turbidity of the water to be measured.
  - a. Measure the turbidity of this suspension, making certain that it is within the accuracy specification of the instrument with regard to the true value.
  - b. Repeat the calibration procedure if the measurement is not within the specification.

Once the instrument is calibrated, the accuracy of the recorded measurements can be increased by preparing a calibration graph using dilutions of the Formazin standards, as described previously for calibration of turbidimeters (6.7.2.A).

TECHNICAL NOTE: Multiparameter instruments with turbidity-probe capability use a light-emitting diode in the range of near-infrared wavelength as the radiation source and usually are microprocessor-based. The USEPA has not approved instruments using this method as of this writing, and the accuracy attainable with probe-based instrumentation is substantially less than that of USEPA-approved instruments. ISO turbidity-measurement criteria were developed to improve measurement consistency of instruments using the near infrared technology, and some of the field instruments available meet ISO 7027 recommendations (table 6.7-2).

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## SPECTROPHOTOMETER CALIBRATION 6.7.2.C

Spectrophotometric turbidity measurements are useful to indicate relative values or to monitor changes in turbidity with time. Spectrophotometers are inaccurate for absolute turbidity values, and the instrument sensitivity is unrated.

Spectrophotometers commonly have a stored program for turbidity that has been factory-calibrated. This can be verified but not adjusted. Check the instrument output against that of a different instrument every few weeks while the instrument is in use. Check the relative accuracy of the turbidity measurement before leaving for the field by inserting Formazin standards covering the FTU range needed.

1. Use freshly prepared standards.
  - Be accurate in your dilution of the stock suspension.
  - Prepare standards daily and discard any unused portion after each use.
2. **Wear disposable powderless (vinyl or latex) gloves**—fingerprints or smudges on cuvettes cause false turbidity readings; oils from skin can etch the cuvette glass.
3. Hold the sample cell (cuvette) at the rim (on the top lip), not beneath the lip. Pour standard into sample cell to the fill line.
4. Wipe the exterior of the sample cell with a clean, soft, lint-free cloth or tissue after filling to remove moisture and condensation from cell walls.
  - Check periodically for condensation on the sample cell and wipe it dry.
  - After wiping condensation from cell walls, apply a light coating (two drops) of silicon oil (optical grade) using a lint-free cloth—check recommendations from the instrument manufacturer.
5. Eliminate gas bubbles from standards.
6. Check that the calibration cell and sample cell have the same orientation when placed into the instrument measurement chamber.

## 6.7.3 MEASUREMENT

Three methods for field measurement of turbidity are described in this section: the nephelometric method or “turbidimetric determination,” using a cuvette-based turbidimeter (6.7.3.A); “determination by submersible sensor” using a multiparameter water-quality instrument with a turbidity probe (6.7.3.B); and the absorptometric determination, using a spectrophotometer (6.7.3.C). Procedures are similar for use of turbidity instruments in surface water and ground water, although some applications may differ, as described below.

- ▶ **Turbidity is time sensitive**—Measure sample turbidity on site to avoid biased values that can result from (1) biodegradation, settling, or sorption of particulates in the sample; or (2) precipitation of humic acids and minerals (carbonates and hydroxides, for example) caused by changes in sample pH during transport and holding.
- ▶ **Biased or erroneous readings can result from unmatched cell orientation, colored sample solutions, gas bubbles, condensation, and scratched or dirty sample cells** (see TECHNICAL NOTE). Condensation on the sample cell commonly occurs on hot days when humidity is high.

TECHNICAL NOTE: Causes of low-biased readings include particulate settling or sorption on container surfaces, biodegradation, and sample solutions with true color (color from dissolved substances that absorb light—some instruments are designed with optics to eliminate bias from color). High-biased or false turbidity readings can be caused by the presence of condensation and finely-divided air or other gas bubbles in the sample or on the cell or probe surface, and scratches, fingerprints, or dirt on the surface of the sample cell or turbidity probe.

Be sure that sample cells are marked to indicate orientation—match orientation so that cells yield the same value when light passes through.

### ***Surface Water***

Collect samples for turbidity measurement or make in situ measurements using either discharge-weighted, pumped-sample, or grab-sample procedures, as appropriate for site characteristics and for study objectives (see NFM 6.0).

- ▶ If taking discrete samples from a churn splitter or other sample-compositing device, remove samples for turbidity measurement when the water volume in the compositor is near maximum.
- ▶ Verify the turbidity determination by measuring turbidity on two or more samples, if samples are removed from a compositing device or collected as grab samples from the surface-water body. Collect turbidity sample directly into the cuvette for immediate measurement or into a clean amber glass bottle for short-term storage.
- ▶ If turbidity is measured in situ, take three or more sequential turbidity readings, until readings stabilize to within  $\pm 10$  percent (see NFM 6.0).

### ***Ground Water***

Turbidity in ground water generally is less than 5 NTU. Natural ground-water turbidity of up to 19 NTU has been reported for some environmental settings (Nightingale and Bianchi, 1977; Strausberg, 1983; Puls and Powell, 1992). Contaminated ground-water systems, however, can have considerably higher turbidity (Wells and others, 1989; Gschwend and others, 1990; Puls and Powell, 1992; Backhus and others, 1993).

- ▶ **During well development**—Monitor turbidity caused by well installation, recording consecutive measurements to document decreases in turbidity as development proceeds.
- ▶ **During well purging**—Monitor changes in turbidity by taking sequential readings until purging criteria are met (NFM 6.0). The final stabilized turbidity value should be equal to or less than the value recorded at the end of well development. A decrease in turbidity values during purging indicates mitigation of subsurface disturbance caused by well installation and by deployment of data-collection equipment in the well.
- ▶ Report the median of the final five or more sequential measurements that meet the  $\pm 10$ -percent criterion for stability (NFM 6.0).

***For discrete-sample measurement using a turbidimeter or spectrophotometer:***

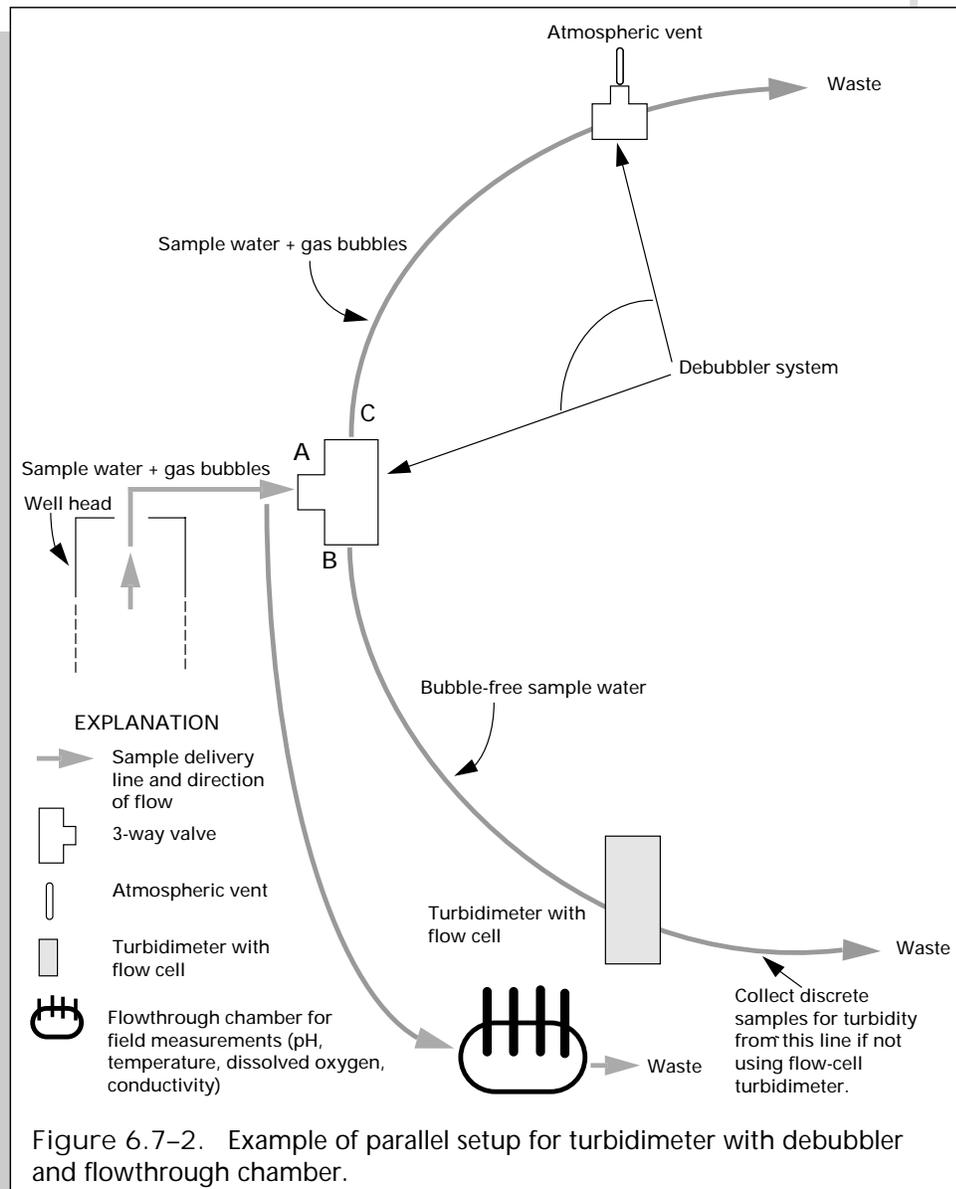
- Pump the ground-water sample directly from the sample discharge line into a precleaned glass or polyethylene sample-collection bottle.
- Bailers are not recommended for collecting turbidity samples, as bailer deployment can cause turbidity.
- Do not collect the discharge passing through the flowthrough chamber in which pH, conductivity, or other field-measurement sensors are installed.

***For turbidimeter measurement using a flowthrough cell:***

1. Split the sample flow from the well between the turbidimeter and the flowthrough chamber used for other field measurements, as illustrated in figure 6.7–2 (parallel lines are not needed if field measurements are made using a downhole or other in situ method, or when discrete samples are split from a composite). **The turbidimeter requires greater flow velocity than is appropriate for the flowthrough chamber.**
  - a. Position the sample-line split to the turbidimeter/debubbler system in front of (closer to the well) the flowthrough chamber to avoid sediment in the flowthrough chamber. (The higher velocity flow required through the turbidimeter can result in mobilizing sediment—see TECHNICAL NOTE.)
  - b. Set up the debubbler plumbing to maintain a constant head and constant velocity through the turbidimeter's flowthrough cell.
2. To construct a debubbler, use a short length of rigid plastic tubing with one perpendicular tee through which sample enters, another tee at the top end (the atmospheric vent), and hose clamps to secure the tubing. The diameter of the tubing and fittings needed for the debubbler is proportional to the rate at which sample flows through the turbidimeter. Referring to figure 6.7–2:
  - Water entering debubbler at "A" must exit at both "B" and "C."
  - Flow exiting at the top ("C") must be greater than the flow exiting at the bottom ("B").
  - The tubing extending from the debubbler bottom ("B") to the turbidimeter will probably need a smaller diameter than the top tubing to ensure a minimum velocity of 0.46 to 0.61 meters per second (1 1/2 to 2 feet per second).

- The atmospheric vent should be located at the highest point in the debubbler system to prevent siphoning.

TECHNICAL NOTE: Backpressure must not be allowed in a flowthrough chamber containing pH or dissolved-oxygen sensors, and the line to the flowthrough chamber must be disconnected or bypassed until any appreciable volume of sediment clears from the line. **Water should never discharge from the atmospheric vent.**



### 6.7.3.A TURBIDIMETRIC DETERMINATION

The nephelometric method for making turbidimetric determinations that is described in this section requires a photoelectric turbidimeter that meets USEPA specifications.<sup>5</sup> This method is applicable in the range of turbidity from 0 to 40 NTU without dilution, and from about 40 to 1,000 NTU with dilution. The method has been tested for drinking and process water and yields real values in NTU.

***Check the turbidimeter against a standard before measuring sample turbidity:***

1. Warm up the turbidimeter according to the manufacturer's instructions.
2. Rinse a clean, dry, scratch-free, index-marked cell with the turbidity standard selected at the NTU within the range of interest.
3. Shake and pour standard into the sample cell to the fill mark and dry the cell exterior with a lint-free cloth.
4. Follow manufacturer's instructions for readout of turbidity value and record the NTU of the standard used and the turbidity value measured in the turbidimeter calibration log.
5. Determine the required reading for the turbidity standard from the calibration curve for the instrument's range and adjust the calibration to the required NTU reading.
6. Measure sample turbidity as soon as sample is collected (see TECHNICAL NOTE).

TECHNICAL NOTE: Turbidity should be measured immediately. However, if temporary storage of samples becomes necessary, collect samples in clean amber glass bottles, keep out of sunlight, and keep chilled at or below 4°C to prevent biodegradation of solids. The holding time must not exceed 24 hours (American Society for Testing and Materials, 1990).

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<sup>5</sup>The nephelometric method using a calibrated slit turbidimeter is not described—refer to American Society for Testing and Materials (1990).

**Measurement of sample with turbidity less than 40 NTU:**

1. After instrument standardization check, empty the cell of turbidity standard and field rinse a freshly cleaned cell with the sample to be tested. Change gloves.
2. **Measurement of discrete sample** (skip to step 3 for flowthrough cell measurement):
  - a. Shake the sample vigorously to completely disperse the solids. Allow air bubbles to disappear before filling sample cell.
  - b. Pour the sample into a sample cell to the line marked (to the neck if there is no line). Do not touch cell walls with fingers.
  - c. Remove condensation from the cell with a clean, soft, lint-free cloth or tissue. If condensation continues, apply a thin coating of silicon oil on the outside of the cell about every third time the cell is wiped dry of moisture.
  - d. Orient the cell with standard in the turbidimeter. Go to step 4.
3. **If using an instrument with an internal flowthrough cell:**
  - a. Orient the cell in the cell chamber of the turbidity instrument.
  - b. Pump a steady stream of sample in-line from the sample source.
    - Use a constant flow rate through the turbidity instrument.
    - Flow to the turbidimeter must be sufficient to keep particulates suspended (1 1/2 to 2 feet per second).
  - c. Check periodically for condensation on flow cell—remove any moisture from cell using soft, lint-free wipe. If necessary, wipe cell walls with two drops of silicon oil and a lint-free wipe. If available, try a gas sweep of the flowthrough cell compartment using dry nitrogen gas.
    - **Make sure that the flow rate of the gas does not exceed the rate recommended by the manufacturer.**
    - Filter the gas to remove particulates and moisture—use a filter that includes desiccant (particulates or moisture in the gas stream can cause additional variability in the turbidity readings).
    - Eliminate air bubbles in sample before measurement using a debubbler device.

4. Determine the measured NTU value of the sample either by reading turbidity directly from the instrument scale or by using the instrument value and calibration curve, as is appropriate for the instrument being used (see TECHNICAL NOTE).
  - a. Record three to five separate readings at regularly spaced intervals.
  - b. Report the median of the last three or more sequential values that fall within  $\pm 10$  percent.

TECHNICAL NOTE: When using the 0.2-NTU scale only, you may need to subtract a correction factor from the reading to correct for stray light. The Hach Company reports the correction for the 0.2-NTU scale to be on the order of 0.04 NTU for the Hach 2100P™. The stray-light correction is determined by reading turbidity from an empty instrument (without cuvette).

**5. Quality control.**

- a. Repeat discrete sample measurement on two additional samples and check that they fall within the  $\pm 10$ -percent criterion. Report the value of the first if two samples are measured, or report the median if three or more samples are measured.
- b. Using a clean sample cell, repeat the procedure, substituting turbidity-free water to run a blank. Run the blank either before or after the sample, following manufacturer's instructions.

***For measurement of sample with turbidity exceeding 40 NTU:***

1. Obtain discrete sample.
2. Dilute the sample with one or more equal volumes of turbidity-free water until turbidity is less than 40 NTU after mixing and degassing.
3. For 100- and 1,000-NTU ranges only—place the cell riser into the cell holder before the sample cell. This decreases the length of the light path in order to improve the linearity of measurements. **Do not use the cell riser for the lower NTU ranges.**
4. Follow procedures for samples with turbidity less than 40 NTU.
5. Based on the dilution factor and original sample volume, compute the turbidity of the original sample (see 6.7.2, "Calibration for Turbidimeter," steps 11 and 12):
  - a. Add volume of dilution water (in mL) to sample volume (in mL).

- b. Multiply by NTU of diluted sample.
- c. Divide by the volume of sample (in mL) that was diluted.

EXAMPLE: If 5 volumes of turbidity-free water were added to 1 volume of sample, and the diluted sample showed a turbidity of 30 units, then the turbidity of the original sample is computed as 180 units.

Don't forget to adjust the turbidity value of diluted samples using the dilution factor.

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### DETERMINATION BY SUBMERSIBLE SENSOR 6.7.3.B

Determination of turbidity using a multiparameter instrument with submersible sensor-containing sonde is useful for water-quality studies in which the turbidity data will be used qualitatively and not for regulatory or compliance purposes. Turbidity sensors for these instruments utilize an LED with near infrared radiation as the light source and turbidity values normally are reported as NTU. Current instrumentation of this type is not approved by the USEPA.

Multiparameter instruments can be used with a flowthrough chamber, instead of being deployed in situ, for monitoring ground-water field measurements. If measurements will be made in a flowthrough chamber, the turbidity probe is part of the sonde bundle that includes other field-measurement sensors (for example, pH, conductivity, temperature, and dissolved oxygen) and a separate or parallel setup for turbidity measurement (fig. 6.7-2) is not needed.

Multiparameter instruments with internal batteries and memory can be used in surface-water studies that require long-term deployment. Guidelines for long-term instrument deployment falls under the topic of continuous monitors, and is beyond the scope of this chapter—refer to manufacturer's instructions and recommendations and to guidance documents for continuous monitors.

***The following procedures apply to in situ determination and to determination of turbidity in a flowthrough chamber:***

1. Calibrate the instrument in the laboratory or office before leaving for the field site (see 6.7.2).
2. At the field site, follow procedures for selection of surface-water and ground-water sampling locations and for in situ (Procedure A) or flowthrough-chamber (Procedure B) field measurements, as described in NFM 6.0.

**Procedure A: In situ measurement**—Immerse the sonde with turbidity and other field-measurement sensors in the water body.

**Procedure B: Flowthrough chamber**—Secure chamber cover over sonde/probe to form an air-tight and water-tight seal. Discharge first sample aliquot to waste, then open connection to flowthrough chamber and pump sample from water source to flowthrough chamber according to instructions in NFM 6.0.3.

3. Activate instrument to display turbidity values in real time.
4. Agitate the turbidity-containing sonde to remove bubbles from the optical surface: move sonde up and down or in a circular pattern and (or) activate wiper mechanism if available.
5. Monitor turbidity readings as described for other field measurements in NFM 6.0.
  - Allow at least 2 minutes before recording the required number of sequential readings.
  - Stability is reached if values for three (for in situ procedure) to five (for flowthrough-chamber procedure) or more sequential readings, spaced at regular time increments, are within 10 percent.
6. Record turbidity readings on field form and in field notes. Log the reading into instrument memory, if applicable.
7. **Surface-water sites**—Repeat steps 2–5 for in situ measurements (Procedure A) at each vertical to be measured.
8. Before leaving the field site, clean the sonde with a thorough rinse of deionized water and replace sonde in the storage vessel.
9. **Quality control.** Check instrument performance periodically by placing a check standard in the instrument storage vessel and comparing standard value with the reading displayed.

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### ABSORPTOMETRIC DETERMINATION 6.7.3.C

The absorptometric method described below uses a field spectrophotometer to provide a relative measure of the sample turbidity. The spectrophotometer shoots a beam of light through the sample at a specific wavelength and measures the amount of transmitted light absorbed by solids present in the sample compared to how much of the transmitted light is absorbed by a Formazin standard.

- ▶ **This method is not approved by the USEPA.** It is a useful method, for example, if the purpose for the turbidity determination is as an indicator of ambient or “stabilized” conditions during well development or purging.
- ▶ Spectrophotometric measurement of turbidity yields readings in FTU. **Do not enter absorptometrically derived turbidity values into the data base.**
- ▶ **Turbidity values below 50 FTU—the range of most surface water and ground water—are inaccurate using this method** and the procedure is recommended only as a relative measure of sequential turbidity values.

The absorptometric method for a Hach DR/2000™ portable spectrophotometer is described below, because this is the instrument that currently is in use for most USGS field work. **Check operating instructions if using an instrument of different make, model, or manufacturer—the position on the dial for wavelength of turbidity may vary for different instruments.**

1. Enter the stored program number for turbidity and rotate the wavelength dial until the display indicates the wavelength value in nanometers (nm) for the instrument in use—450 nm for a Hach DR/2000™, for example.
2. Put on gloves. Measure standards on the instrument that bracket the range anticipated in the sample solution. This step checks the accuracy of the calibration scales. **Change gloves with each change in standard and sample.**
3. Pour 25 mL of deionized water into a clean sample cell for the blank. Hold the cell by the rim—do not touch the cell wall.
4. Place blank sample into cell holder, close the light shield, and press zero. The display should show “wait” and then “0. FTU turbidity.”

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5. Shake environmental sample vigorously to suspend all solids and allow air bubbles to dissipate.
6. Pour 25 mL of sample into another clean sample cell, holding cell by the rim (top lip).
7. Carefully place sample into cell holder.
  - a. Close the light shield. Press read/enter.
  - b. The display first will show "wait" and then show the turbidity value in FTU.
  - c. Record the FTU reading.

## TROUBLESHOOTING 6.7.4

Consult instrument manufacturer for additional guidance if troubleshooting suggestions shown on table 6.7-3 do not remedy the problem encountered.

Table 6.7-3. Troubleshooting guide for field turbidity measurement

Symptom	Possible cause and corrective action
Erratic readings	<ul style="list-style-type: none"> <li>• Check voltage of the batteries: replace weak batteries with new batteries.</li> <li>• Condensation on cell wall: see fourth symptom.</li> <li>• Bubbles in sampling system or on optical surface of probe-based system: tap sample line to flowthrough cell or chamber systems to dislodge bubbles; adjust debubbler apparatus; remove bubbles on probe-based system by agitating the unit repeatedly or activating wiper mechanism.</li> </ul>
Unusually high or low turbidity	<ul style="list-style-type: none"> <li>• Bubbles in sampling system or on optical surface of probe-based system: see corrective action for erratic readings (first symptom).</li> </ul>
Readings first appear stable, then begin to increase inexplicably	<ul style="list-style-type: none"> <li>• Check for moisture on cell wall: see fourth symptom.</li> </ul>
Moisture or condensation on wall of cell	<ul style="list-style-type: none"> <li>• Wipe cell dry.<sup>1</sup></li> <li>• Apply a thin veneer of silicon oil.<sup>2</sup></li> <li>• Add gas sweep to system.</li> </ul>
Blank samples or reference material standards do not read accurately	<ul style="list-style-type: none"> <li>• Check that the cells are oriented as instructed.</li> <li>• Check accuracy against that of another instrument.</li> </ul>

<sup>1</sup> Use soft, lint-free cloth.

<sup>2</sup> Check with instrument manufacturer before applying silicon oil.

## 6.7.5 REPORTING

ASTM and USEPA guidelines for reporting turbidity measurements are tabled below.

- ▶ **Record only NTU** (not FTU) values in the data base.
- ▶ Remember to multiply sample readings by the appropriate dilution factor to obtain a final turbidity value.

Table 6.7-4. Guidelines for reporting nephelometric turbidity measurements (from USEPA, 1990)

NTU	Record to nearest
0-1	0.05
1-10	0.1
10-40	1
40-100	5
100-400	10
400-1,000	50
>1,000	100