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Voluntary Estuary Monitoring Manual

Chapter 15: Turbidity and Total Solids

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Natural runoff, water turbulence from storms, and wave action can cause turbidity of the water. Sediment can also be disturbed by bottom-feeding animals, adding to the water's turbidity. Although we often think that clean water is clear, even unpolluted water can have suspended particles that may lessen its clarity but do not diminish its quality. Many human activities contribute to increased turbidity, as discussed in this chapter.

Photos (l to r): G. Carver, K. Register, R. Ohrel, K. Register

Overview

Measures of turbidity indicate how cloudy or muddy the water is or, alternatively, the degree of its clarity or translucence. Several types of material cause water turbidity:

- suspended soil particles (including clay, silt, and sand);
- tiny floating organisms (e.g., phytoplankton, zooplankton, and bacterioplankton); and
- small fragments of dead plants.

Natural runoff, water turbulence from storms, and wave action can cause turbidity of the water. Sediment can also be disturbed by bottom-feeding animals, adding to the water's turbidity. Although we often think that clean water is clear, even unpolluted water can have suspended particles that may lessen its clarity but do not diminish its quality. Human activities, however, exacerbate the clouding. Sediment runoff from agricultural fields, logging activities, wash from construction sites and urban areas, and shoreline erosion from heavy boat traffic and jet skis, among other problems, all contribute to high turbidity. Excessive algal growth due to the additions of nutrients into an estuary can also affect water turbidity. High levels of turbidity over long periods of time can greatly diminish the health and productivity of the estuarine ecosystem.

This chapter explains the role of turbidity in the estuarine ecosystem and describes some common steps for monitoring it. The measurement of total solids—particles suspended and dissolved in the water—is also discussed.

Why Measure Turbidity and Total Solids?

Land use decisions throughout an estuary's watershed impact water quality. Here, extensive erosion near a highway adds to the sediment entering a nearby estuary (photo by R. Ohrel).

Turbidity is a measure of water clarity: how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, and other substances. They are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand).

Total solids refer to the matter that is suspended or dissolved in water. When a water sample is evaporated, there is often a residue left in the vessel—these are the total solids. The solids in water have different attributes and sizes. The suspended particles in water can be retained on a filter with a 2 µm or smaller pore size, while dissolved solids are small enough to pass through a filter of that size.

Turbidity and total solids can be useful indicators of the effects of runoff from construction, agricultural practices, logging activity, discharges, and other sources. Regular monitoring can help detect trends that might indicate increasing (or decreasing) erosion in the estuary's watershed.

Sources of turbidity in estuary waters include:

- soil erosion from construction, forestry, or agricultural sites;
- waste discharge;
- urban runoff;
- eroding stream banks;
- stirred-up bottom sediments from flooding, dredging, boating and jet-skiing activities, or bottom-feeding animals; and
- excessive algal growth.

Turbidity and total solids often increase sharply during and immediately following a rainfall, especially in developed watersheds, which typically have relatively high proportions of impervious surfaces such as rooftops, parking lots, and roads. The flow of stormwater runoff from impervious surfaces rapidly increases stream velocity, which increases the erosion rates of streambanks and channels. Turbidity can also rise sharply during dry weather if earth-disturbing activities are occurring without erosion control practices in place.

Sedimentation, where solids settle out of the water column onto the estuary bottom, is a priority concern in many estuaries, making turbidity monitoring an important part of most volunteer estuary water quality monitoring programs. As one example, a study of Weeks Bay, Alabama, found that its watershed contributed about 22,500 tons of sediment per year to the bay as a result of agricultural field runoff (Baldwin County, 1993).

The Role of Turbidity and Total Solids in the Estuarine Ecosystem

Highly turbid water full of suspended material has many effects on the estuarine environment. If an estuary is excessively turbid over long periods, its health and productivity can be greatly diminished.

As discussed in Chapter 9, dissolved oxygen is a critical factor controlling biological activity. Highly turbid water can influence the amount of dissolved oxygen in three ways. First, turbid waters interfere with light penetration in the water, thereby reducing the amount of light reaching the bottom, making it less suitable for plant growth. Because there are fewer aquatic plants—and therefore less photosynthesis taking place—less dissolved oxygen is produced. Dissolved oxygen concentrations are also influenced by high turbidity and its relationship to water temperature. Suspended particles absorb heat, which causes water temperature to increase. Because warm water holds less dissolved oxygen than cold water, this temperature increase causes a reduction in dissolved oxygen concentrations. High turbidity may also be caused by high levels of dead organic matter, called **detritus**. Detritus can include leaves, twigs and other plant and animal wastes. As these materials are decomposed by bacteria, oxygen can be depleted.

Some of the physical effects of excessive suspended materials include:

- clogged fish gills that inhibit the exchange of oxygen and carbon dioxide;
- reduced resistance to disease in fish;
- reduced growth rates;
- altered egg and larval development;
- fouled filter-feeding systems of animals; and
- hindered ability of aquatic predators from spotting and tracking down their prey.

Suspended materials such as sand, soil, or silt tend to settle out faster in brackish water than in fresh water. These particles settle to the estuary bottom, where they smother fish eggs and bottom-dwelling animals, and alter the habitat needed by estuary plants and animals. For example, oysters require a hard surface on which to attach and grow. Increased sedimentation in an estuary can cover the available hard surfaces such as rocks and older oyster beds, leaving oysters without the habitat that is critical to their survival. Another problem with sedimentation in an estuary is that the newly settled particles may not be the same size as the estuary's natural bottom sediment, causing shifts from fine to coarser sediments (or vice versa). This change in sediment size can greatly affect the plants and animals that have adapted to the estuary's benthic environment.

Higher concentrations of suspended solids can serve as carriers of toxins, which readily cling to suspended particles. This is particularly a concern where pesticides are being used on irrigated crops. Where solids are high, pesticide concentrations may increase well beyond those of the original application as the irrigation water travels down irrigation ditches and ultimately into estuaries. ■

Sampling Considerations

It should be remembered that turbidity is not a measurement of the amount of suspended solids present or the rate of sedimentation of an estuary—it measures only the amount of light that is scattered or absorbed by suspended particles. Some laboratories also measure "total solids" in a waterbody, which is related to turbidity. Measurement of total solids is a more direct measure of the amount of material suspended and dissolved in water.

Chapter 6 summarized several factors that should be considered when determining monitoring sites, where to monitor, and when to monitor. In addition to the considerations in Chapter 6, a few additional ones specific to monitoring turbidity are presented here.

When to Sample

In setting up a turbidity monitoring plan, the program manager should ensure that the effort will continue for several years. Since the workings of an estuary are complex, a mere year or two of turbidity data is insufficient to capture the variability of the system. In fact, a few years of unusual data may be quite misleading and tell a story very different than reality. On the other hand, volunteers can detect some sources of erosion and turbidity in just one or two monitoring sessions.

Volunteers should sample water for turbidity on a weekly or biweekly basis, year-round. The key to effective turbidity monitoring is to sample at a sufficiently frequent interval and

As stormwater enters an estuary, it often creates a plume of highly turbid water. In this photo, a plume of stormwater delivers large amounts of dissolved and suspended materials to an estuary (photo by G. Carver).

at enough representative sites so that the data will account for most of the inherent variability within the system.

Since turbidity often increases sharply during and immediately following a rainfall, volunteers may be asked to take additional turbidity readings shortly after the storm (as soon as it is safe to do so). Stormwater, as it enters an estuary, often creates a plume of highly turbid water. This is because the stormwater is carrying high levels of suspended solids due to erosion as well as sediment from roads and parking lots in the watershed. The extent of the plume can usually be seen from above, as the color of water in the plume is different from the water in the estuary's main body. Some volunteer monitoring programs include "stormwater plume tracking" as part of their turbidity data collection to assess the spatial extent of stormwater discharges (see box, this page).

Where to Sample

If the monitoring program is designed to pinpoint trouble spots in the estuary, the manager should select monitoring sites throughout the estuary, as well as cluster sites near suspected sources of turbid water into the estuary. Such sites might include an area near a discharge pipe or a river that flows into the estuary. Since rivers may have multiple trouble spots, your monitoring efforts may require several monitoring sites in the rivers and tributaries.

Stormwater Plume Tracking

As part of a turbidity monitoring program, volunteers can conduct "plume tracking" to assess the spatial extent of stormwater discharges. By monitoring for runoff characteristics (i.e., high turbidity, low salinity, etc.) near the mouth of a freshwater input to the estuary, volunteers can assess how far the stormwater plume emanating from the stream or river extends into the estuary.

An effective method to monitor a stormwater plume is to divide the plume area into a grid, and conduct sampling in each of the grid areas. Sampling should extend from the area of greatest freshwater impact, across the plume, and beyond the edge of the plume. Studying the fate of stormwater and its effects on an estuary is an important component to understanding the amount of material flowing into the estuary and where stormwater material is deposited. With this monitoring, we can begin to learn what residual effects the deposited material has on the natural function of the estuary's ecosystem. By regularly monitoring storm plumes, volunteers can collect valuable information that can help detect trends.

Choosing a Sampling Method

When deciding upon the appropriate method for measuring turbidity levels in an estuary, the program manager must consider the cost of equipment, the number and location of sites to be monitored by volunteers, and the planned uses for the collected data.

There are four commonly used methods to measure turbidity in estuary waters. Turbidity meters measure turbidity, while the Secchi disk, transparency tube, and turbidity field kits measure transparency, which is an integrated measure of light scattering and absorption. Samples can also be collected by volunteers and sent to a lab for analysis. Monitors interested in submitting data to water quality agencies should consult with the agencies to determine the preferred equipment and methods.

Secchi Disk

Most volunteer water quality monitoring programs rely on the Secchi disk because it is easy to use, inexpensive, and relatively accurate. It is also easy to make (see box, page 15-5). The Secchi disk was invented by the Italian astronomer Pietro Angelo Secchi in the 1860s. This simple weighted disk is used by volunteers to measure the water depth at which the disk just disappears from view—the Secchi depth. Most programs find that the Secchi disk gives sufficiently good clarity readings.

The Secchi disk is 20 centimeters (8 inches) in diameter and divided into alternating black and white quadrants to enhance visibility and contrast (although some disks are totally white). Secchi disks cost about $25 to $50 and can be homemade.

It is lowered by hand into the water to the depth at which it vanishes from sight. The distance to vanishing is then recorded, and then the procedure is repeated so that two readings are obtained. The clearer the water, the greater the distance. If you are monitoring tributaries to the estuary, you may find a Secchi disk of limited use, however, because in many cases the river bottom will be visible and the disk will not reach a vanishing point.

Secchi readings will vary with the specific estuary, location in the estuary, and season. Water clouded with sediment after a storm or with high levels of phytoplankton during a warm spell will have low Secchi readings (poor water clarity). Low productivity winter waters or estuarine water located near the ocean will generally register higher Secchi depths. A significant change in Secchi depth may motivate a monitoring program to identify possible causes.

WARNING!
Beware of Secchi Line Shrinkage

Over time, a Secchi disk line may begin to shrink from regular water exposure and subsequent drying. This can lead to errors in Secchi depth measurements.

To minimize this problem, use a minimal-stretch nylon cord, a vinyl-coated braided metal-core clothesline, or other shrink-resistant line. But no matter what material you use, it is critical to calibrate Secchi disk lines regularly (e.g., every six months).

MAKING A SECCHI DISK

A Secchi disk is one of the simpler pieces of equipment required for water quality testing. Although many supply companies sell this item, volunteer programs on a tight budget can construct their own disks (Figure 15-1). Materials needed for this project are:

- 1/8” thick steel, 1/4” Plexiglas, or 1/4” to 1/2” marine plywood
- drill with 3/8” inch bit
- shrink-resistant rope or cord (e.g., minimal-stretch nylon, vinyl-coated braided metal-core clothesline)
- eyebolt (5/16”), approximately 3” to 4” long
- flat washers, lock washers, 2 nuts (5/16”)—2 of each
- attachable weights
- meter stick
- black and white flat enamel paint
- paintbrush
- marking pen

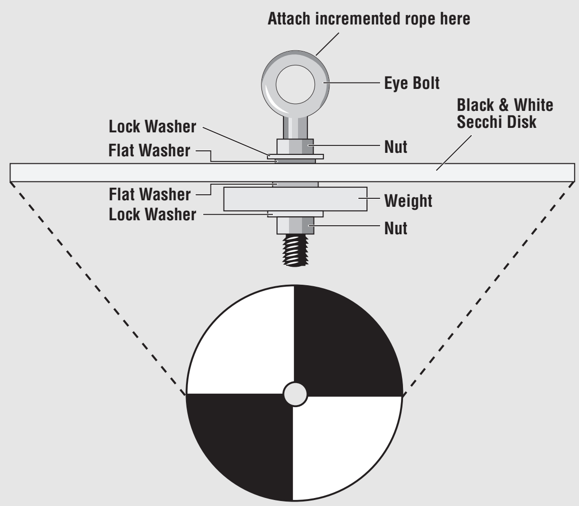

Figure 15-1. A homemade Secchi disk.

Cut the steel, Plexiglas, or plywood into a circle with a 20-centimeter (8”) diameter. Section the disk into four quarters and paint two opposing quarters white and the other two black. Paint the other side of the disk totally white.

After the paint has dried, drill a hole in the center of the disk. Put a nut onto the eyebolt followed by a lock washer and flat washer. Insert the eyebolt assembly through the hole in the disk with the white and black side facing the eye of the bolt. Place another flat washer on top of the assembly along with a sufficient number of weights (dependent on the disk material used). Add another lock washer and nut to finish the assembly.

Attach a 6-meter length of shrink-free cord or rope through the eyebolt and fasten securely. Place the meter stick alongside the rope and disk and mark the rope in 5- or 10-centimeter increments with an indelible marker or waterproof ink measuring from the top of the disk. A different color marker used at each full meter increment will facilitate reading Secchi measurements.

A volunteer uses a Secchi disk from the shady side of a dock (photo by K. Register).

Turbidity Meter

The most accurate means of assessing turbidity is with a turbidity meter, called a nephelometer. A turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample. It measures turbidity in nephelometric turbidity units or NTUs. Meters can measure turbidity over a wide range, from 0 to 1,000 NTUs. Measurements can jump into hundreds of NTUs during runoff events. Therefore, the turbidity meter to be used should be reliable over the range in which you will be working. Meters of this quality cost about $800. Many meters in this price range are designed for field or lab use.

Although turbidity meters can be used in the field, volunteers might want to collect samples and take them to a central point for turbidity measurements. This is because of the expense of the meter (most programs can afford only one and would have to pass it along from site to site, complicating logistics and increasing the risk of damage to the meter) and because the meter includes glass cells that must remain optically clear and free of scratches. At a reasonable cost, volunteers can also take turbidity samples to a lab for meter analysis.

Transparency Tube

The transparency tube (sometimes called a “turbidity tube”) is a clear, narrow plastic tube marked in units (usually centimeters) with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears. Volunteers then record the depth at which the pattern disappeared. Volunteer groups using transparency tubes have found tube readings to relate fairly well to lab measurements of turbidity and total suspended solids, although the transparency tube is not as precise or accurate as a meter. Also, readings in transparency tubes can be rendered inaccurate in cases of highly colored waters. A transparency reading taken from one tube cannot be compared with a reading taken from another tube of a different manufacturer, especially if the tube is homemade. Transparency tubes can be purchased from scientific supply houses for about $35 to $60.

Turbidity Field Kits

With these kits, turbidity is measured by using a standardized turbidity reagent to match the turbidity of a water sample. Drops of the turbidity reagent are added to a test tube of turbidity-free water until the water in the test tube becomes as blurred or cloudy as the water sample from the estuary, which is in an identical test tube. These field kits cost about $40.

Laboratory Analysis

Analysis of turbidity or of total solids by a professional laboratory is by far the most accurate means of obtaining this data. Most laboratories institute strict quality assurance and quality control methods to ensure consistently reliable results. A college or professional lab may offer its services free of charge to a volunteer program.

If the program decides to use lab analysis, it must ensure that its volunteers adhere to strict guidelines while collecting samples. Sloppy field collection techniques will result in poor data. ■

How to Measure Turbidity

General procedures for measuring turbidity are presented in this section for guidance only; they do not apply to all sampling methods. **Monitors should consult with the instructions that come with their sampling and analyzing instruments. Those who are interested in submitting data to water quality agencies should also consult with the agencies to determine acceptable equipment, methods, quality control measures, and data quality objectives (see Chapter 5).**

Reminder!

To ensure consistently high quality data, appropriate quality control measures are necessary. See "Quality Control and Assessment" in Chapter 5 for details.

Before proceeding to the monitoring site and collecting samples, volunteers should review the topics addressed in Chapter 7. It is critical to confirm the monitoring site, date, and time; have the necessary monitoring equipment and personal gear; and understand all safety considerations. Once at the monitoring site, volunteers should record general site observations, as discussed in Chapter 7.

STEP 1: *Check equipment.*

In addition to the standard sampling equipment and apparel listed in Chapter 7, the volunteer should bring the following items to the site for each sampling session:

- turbidity meter, turbidity standards, lint-free cloth to wipe the cells of the meter; or
- Secchi disk with weight attached and on a calibrated line; or
- transparency tube; or
- turbidity test kit.

STEP 2: *Monitor turbidity.*

The following section describes four ways to analyze a water sample for turbidity. If analyzing turbidity by Secchi disk, follow Procedure A. If using a turbidity meter, use Procedure B. If using a transparency tube, follow Procedure C. If using a turbidity field test kit, follow Procedure D.

Using a transparency tube is an easy way to measure the water transparency. It is especially useful in water that is too shallow for a Secchi disk (photo by K. Register).

Procedure A—Measuring water clarity with a Secchi disk

The key to consistent results is to train volunteers to follow standard sampling procedures and, if possible, have the same individual take the reading at the same site throughout the season. If the conditions vary from this ideal situation, record any differences on the data sheet. The line attached to the Secchi disk must be marked according to units designated by the volunteer program. Many programs require volunteers to measure to the nearest 1/10 meter. Meter intervals can be marked with waterproof ink or tagged (e.g., with duct tape) for ease of use. Do not wear sunglasses while viewing the Secchi disk in the water.

The optimal conditions for recording Secchi disk readings are:

- clear sky;
- sun directly overhead (but disk should be in shade or shadow); and
- measurements made from the protected side of a boat or dock with minimal waves or ripples.

Steps for using a Secchi disk are as follows:

- Check to make sure that the Secchi disk is securely attached to the measured line.
- Tie a wrist loop at the end of the rope so that the rope end does not accidentally drop into the water when the disk is lowered.

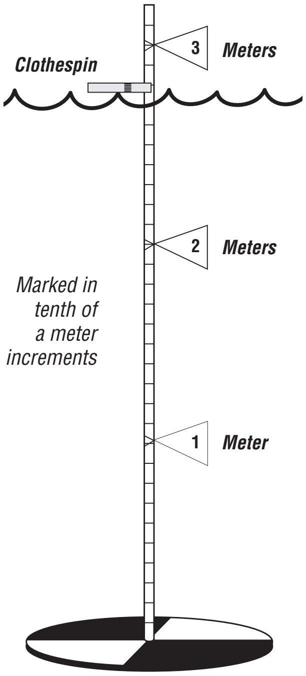

Figure 15-2. Using a Secchi disk to measure transparency. The disk is lowered until it is no longer visible. That point is the Secchi disk depth *(redrawn from USEPA, 1997).*

- Lean over the shady side of the boat or dock and lower the Secchi disk by hand into the water, keeping your back toward the sun to block glare. Make sure the disk hangs horizontally when suspended.
- Lower the disk until it disappears from view. Lower it one third of a meter and then slowly raise the disk until it just reappears. Move the disk up and down until the exact vanishing point is found. This is called the limit of visibility.
- Attach a clothespin to the line at the point where the line enters the water or, if that is not possible, note carefully where the line meets the water's surface (Figure 15-2). Raise the Secchi disk and record the depth measurement on your data sheet.
- Repeat the procedure and write the second measurement on your data sheet, as well as the average of the two depths.
- If the disk hits the bottom before dropping out of sight, note this observation and record the bottom depth.

Procedure B—Measuring water turbidity with a turbidity meter

- Prepare the sample containers.

  If factory-sealed, disposable Whirl-pak bags are used to sample, no preparation is needed. Reused sample containers (and all glassware used in this procedure) must be cleaned before the first run and after each sampling run. Follow the procedures described in Chapter 7.

- Collect the sample.

  Refer to Chapter 7 for details on how to collect water samples using screw-cap bottles or Whirl-pak bags.

- Analyze the sample.

  While monitors should consult with the instructions that come with their turbidity meter, the following procedure applies to field or lab use of most turbidity meters:

  (a) Prepare the turbidity meter for use according to the manufacturer's instructions.
  (b) Use the turbidity standards provided with the meter to calibrate it. Make sure it is reading accurately in the range in which you will be working.
  (c) Shake the sample vigorously and wait until the bubbles have disappeared. You might want to tap the sides of the bottle gently to accelerate the process.
  (d) Use a lint-free cloth to wipe the outside of the tube into which the sample will be poured. Be sure not to handle the tube below the line where the light will pass when the tube is placed in the meter. NOTE: If the tube becomes scratched, it will have to be replaced. The scratches on the glass can affect the meter's readings.
  (e) Pour the sample water into the tube. Wipe off any drops on the outside of the tube.
  (f) Set the meter for the appropriate turbidity range. Place the tube in the meter and read the turbidity measurement directly from the meter display.
  (g) Record the result on the field or lab sheet.
  (h) Repeat steps c-g for each sample.

Procedure C—Measuring water clarity with a transparency tube

Readings in transparency tubes can be rendered inaccurate in cases of highly colored waters. A transparency reading taken from one tube cannot be compared with a reading taken from another tube of a different manufacturer, especially if the tube is homemade.

- Collect the sample in a bottle or bucket at mid-depth if possible. Avoid stagnant water and sample as far from the shoreline as is safe. Avoid collecting sediment from the bottom.

- Prepare the transparency tube by placing it on a white surface.
- Look vertically down the tube to see the black and white pattern on the bottom. Take readings in open but shaded conditions. Avoid direct sunlight by turning your back to the sun.
- Stir or swish the water in the bucket or bottle until it is homogeneous, taking care not to produce air bubbles (these will scatter light and affect the measurement).
- Slowly pour the water sample into the tube, stopping intermittently to see if the black and white pattern has disappeared. To avoid introducing air bubbles, pour the water against the inside wall of the tube.
- When you can no longer see the pattern, look at the ruler on the side of the tube, and record the number of units on your data sheet. This is the depth of the water column in the tube when the pattern just disappears.

NOTE: Some transparency tubes have a water-release valve at the bottom of the tube. With these tubes, you are required to fill the tube entirely, then open the valve while you look down the tube. As soon as you see the black and white pattern appear, close the valve, and record the depth at which you first saw the pattern.

Procedure D—Measuring water clarity with a turbidity field kit

While monitors should consult with the instructions that come with their kits, the following procedure applies to most turbidity field kits:

- The kits come with two tubes, each with a black and white pattern on the bottom. Fill one of the two turbidity tubes to the line indicated with the water to be tested. This is usually 50 ml. If you cannot see the black and white pattern on the bottom of the tube when you look down through the column, pour out half of the water until 25 ml remains in the test tube (or pour out the amount stated in your kit's instructions).
- Fill the second turbidity tube with turbidity-free water that is equal to the amount of the sample (50 or 25 ml). Distilled or tap water can be used.
- Place the tubes next to each other, and look down the tubes to note the difference in clarity. If there is a difference in clarity, go on to the next step.
- Shake the bottle of standard turbidity reagent, and add the reagent to the "clear water" tube according to the kit's instructions. Keep track of how much reagent is being added. Stir the contents of both tubes to equally distribute turbid particles. After each addition of reagent, compare the turbidity of the tubes.
- Continue to add the reagent and stir both tubes until the turbidity of both test tubes is the same.
- Record the total amount of turbidity reagent added.

STEP 3: *Clean up and send off data.*

Volunteers should thoroughly clean all equipment and transport the samples to the designated lab, if necessary. Samples submitted to a lab for analysis must be processed within 24 hours of collection. Keep samples in the dark and on ice or refrigerated.

Make sure that the data sheet is complete, legible, and accurate, and that it accounts for all samples. Volunteers should make a copy of the completed data sheet before sending it to the designated person or agency in case the original data sheet becomes lost.

How to Measure Total Solids

The measurement of total solids cannot be done in the field. Samples must be collected using clean glass, plastic bottles, or Whirl-pak bags and taken to a laboratory where the test can be run. Total solids are measured by weighing the amount of solids present in a known volume of sample. This is done by weighing an empty beaker, filling it with a known volume, evaporating the water in an oven and completely drying the residue, and then weighing the beaker with the residue. The total solids concentration is equal to the difference between the weight of the beaker with the residue and the weight of the beaker without it.

Total solids are measured in milligrams per liter (mg/l). Since the residue is so light in weight, the lab will need a balance that is sensitive to weights in the range of 0.0001 gram. Balances of this type are called analytical or Mettler balances, and they are expensive (around $3,000). The technique requires that the beakers be kept in a desiccator, which is a sealed glass vessel containing material that absorbs moisture and ensures that the weighing is not biased by water condensing on the beaker. Some desiccants change color to indicate moisture content.

Volunteers can collect samples for total solids analysis using the instructions in Chapter 7. If you are sending your samples to a lab for analysis, they must be tested within 24 hours of collection. Keep samples in the dark and on ice or refrigerated. Learn from the lab what volume of water needs to be collected. For some tests, 50 ml are needed, while other tests require 100 ml or more. ■

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U.S. Geological Survey, Florida Bay: http://coastal.er.usgs.gov/flbay/ref.html