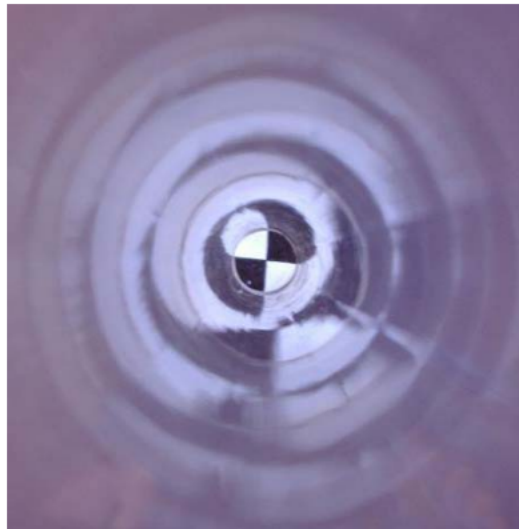


The Turbidity Tube: Simple and Accurate Measurement of Turbidity in the Field

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Introduction

Turbidity is an important water quality parameter in drinking water provision and treatment. The equipment typically used to measure turbidity can be quite expensive, and often provides results which are more precise and accurate than necessary. This high cost is a barrier to many projects in the developing world. In this paper, we will present the turbidity tube as an alternative device to measure turbidity. A turbidity tube can be purchased commercially, or can be constructed at an extremely low cost using a wide range of locally available materials. It is particularly well-suited to situations when decisions can be made based on approximate turbidity (rounded to the nearest 5 NTU). We give a brief discussion of what turbidity is, how a turbidity tube is constructed, and how to use it properly.

Background

Turbidity is a measure of the cloudiness of water. The higher the turbidity, the harder it is to see through the water. Turbidity measurements are reported in nephelometric turbidity units (NTU) or Jackson turbidity units (JTU). Different units are used depending on which method is chosen to measure turbidity. The two units are roughly equivalent and can be used interchangeably for field purposes. The NTU will be used for the remainder of this paper.

With the naked eye, an average person can begin to see turbidity levels starting at around 5 NTU and greater. Lakes that are considered relatively clear in the United States can have a turbidity up to 25 NTU (Nathanson, 2003). If water appears muddy, its turbidity has reached at least 100 NTU. At 2,000 NTU, water is completely opaque (Joyce, 1996). Figure 1 shows turbidities of <10 NTU, 200 NTU and 1,500 NTU.

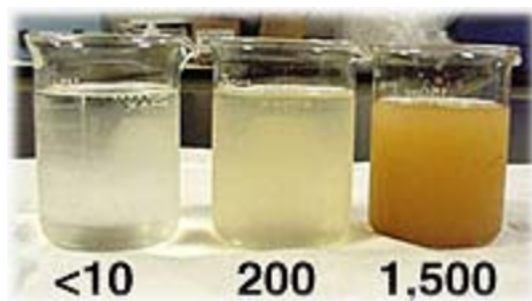


Figure 1: Sample Turbidities (Howard, 2001)

Turbidity consists of a number of substances. Mud, silt, sand, small pieces of dead plants, bacteria, aquatic organisms, algae, and chemical precipitates all contribute to turbidity.¹ Erosion, waste discharge, and urban runoff can add suspended solids to a body of water. Agricultural runoff, in addition to directly increasing suspended solids, can also contribute to the growth of algae. After a storm or flooding, turbidity in surface water generally increases rapidly due to the increase in runoff.

Turbidity is a key indicator used in assessing the suitability of water for human consumption. The material suspended in turbid water can contain a large number of pathogens. High turbidity can also have a variety of negative effects on various methods of water use and treatment (see *Turbidity*

¹ The type of particles present in water can often be estimated by inspection. Organic particles such as algae give a greenish-brown color to water. Colloidal particles look like a very fine suspension (Oxfam, 2001).

Standards for Various Purposes on page 3.) Pipes carrying turbid water can become clogged with sediment. Turbidity can also stimulate the growth of bacteria (WHO, 2004). Along with E. coli, pH, and chlorine residual, turbidity is one of the key parameters of microbial water quality (WHO, 2004). It is also used to measure the effectiveness of water filtration.

Measurement

Several methods are available to test turbidity in water. These are summarized in Table 1.

Table 1: Turbidity Measurement Methods

Method	Advantages	Disadvantages
Jackson Candle Turbidimeter - Water poured into tube. - Reading taken when candle burning under tube can no longer be seen.	(Historical method.)	No longer a standard method. Can't measure < 25 JTU (25 NTU).
Turbidimeter (Nephelometer) - Beam of light passed through water sample. - Amount of light scattered at a 90° angle measured.	Extremely accurate. Some are portable. Can measure very low turbidity.	Expensive. Easily damaged. Requires power source. Requires calibration.
Secchi Disk - Black and white disk lowered into water. - Maximum distance at which disk can be seen recorded.	Low cost. Portable. No consumables. Easy to learn.	Less accurate. Can't be used in shallow water or swift currents. Not applicable to small sample size.
Turbidity Tube (Transparency Tube) - Combination of Jackson candle and Secchi disk methods.	Low cost. Portable. No consumables. Easy to learn. Suitable for all water sources.	Less accurate. Can't measure < 5 NTU.

Of the available approaches to turbidity testing, a turbidity tube is the most appropriate method to test small community water supplies when funds are limited. The turbidity tube is inexpensive, easy to use, and does not need to be restocked with batteries or testing supplies. A turbidity tube can be understood intuitively, even by non-engineers. Moreover, the use of a turbidity tube conveys more information about what is being measured than does looking at a read-out on a digital screen. This provides an opportunity to educate community members about many water quality issues, including source protection and treatment options. Turbidity tubes are also very portable and are designed for use in the field. This is an added benefit; turbidity is more accurately measured on-site as it can change rapidly during transport or storage (WHO, 2004).

Because of its many advantages, a turbidity tube can be employed in a wide range of settings. Several international NGO's, including Oxfam and Doctors Without Borders, use turbidity tubes as part of their water quality testing kits for emergency situations. Many countries, including Australia, Canada, and the United States,² have networks of thousands of volunteers who use the tubes to monitor the quality of rivers, lakes, and streams.

² For comparison and in-depth statistical analysis of results obtained using turbidity tubes, total suspended solids filtration, and Secchi disks to monitor water quality in California waterways, see:

Dahlgren, Randy et al. (2004). *Transparency Tube Provides Reliable Water-Quality Measurements*. California Agriculture: July-September, pages 149-153.

Turbidity Standards for Various Purposes in Water Supply and Treatment

Drinking Water

Standard:

- Drinking water should have a turbidity of ≤ 5 NTU (Davis, 2002).

Reason:

- Turbidity becomes visible at approximately 5 NTU, and water with any visible turbidity may be rejected in favor of a clearer, possibly more contaminated source.

Chlorination

Standard:

- The World Health Organization recommends that ideally, a median turbidity value of less than 0.1 NTU should be maintained for effective disinfection (WHO, 2004).
- If water is to be chlorinated, it should have a turbidity of ≤ 5 NTU. Chlorination is even more effective at less than 1 NTU (Robens, 1996).³
- Chlorination will still be relatively effective up to 20 NTU, but this should only be done until measures can be taken to reduce the turbidity (Davis, 2002).

Reason:

- Disinfection by-products are formed when chlorine reacts with the organic matter present in turbid water. These by-products can have adverse impacts on early pregnancies and can be carcinogenic (Laurent, 2005).
- The organic matter often found in turbidity can exert a chlorine demand.
- Pathogens located inside of larger particles can be shielded from chlorine.

UV Treatment

Standard:

- If pathogens are to be destroyed through UV irradiation, whether from the sun or a lamp, turbidity must be <30 NTU (Laurent, 2005).

Reason:

- UV rays cannot reach pathogens that are far from the surface if water is turbid. Less than 1% of UV light can penetrate further than 2 cm from the surface of water with a turbidity of more than 200 NTU (Joyce, 1996).

Slow Sand Filtration

Standard:

- Water entering a slow sand filter should have a turbidity of ≤ 20 NTU (Davis, 2002).
- A turbidity of up to 200 NTU can only be tolerated for a few days (Davis, 2002).

Reason:

- Particles in turbid water will clog the filter medium.

³ Sphere standards also indicate that water to be chlorinated for disaster relief must have a turbidity of less than 5 NTU (Sphere, 2004).

Thermal Disinfection

Standard:

- None

Reason:

- Turbidity does not affect pathogen destruction by heat. This is true whether boiling or pasteurization is used and regardless of the source of the heat (solar or burning fuel) (Laurent, 2005).
- Solar disinfection can still be used to disinfect highly turbid water if the method of pathogen destruction is heat (Joyce, 1996).

Ceramic Filters

Standard:

- Water treated by ceramic filters should have a maximum pre-treatment turbidity of 15-20 NTU (Laurent, 2005).

Reason:

- High turbidity will clog filters more quickly.

Turbidity Removal

In general, surface water will need pre-treatment to reduce turbidity before it is disinfected (Wisner, 2002). Treatment methods which reduce turbidity include sedimentation, roughing filters, rapid and slow sand filters, chemical coagulation and flocculation, and ceramic filters. Some of these treatments themselves have pre-treatment turbidity limits. Water can be stored before disinfection to allow some sedimentation. Storage provides an additional benefit, in that it creates a buffer which allows users to avoid using surface water directly after it rains, when turbidity can be particularly high (Davis, 2002). The design and implementation of turbidity removal technologies are beyond the scope of this paper.

Turbidity Tube Construction - an Overview

There are many ways to build a turbidity tube. In this section, we will look at the key components of a tube and then discuss possible substitutions for these different components. This section is very broad to allow flexibility in design and material use. A detailed set of instructions for a specific turbidity tube design can be found on page 9 (*Procedure for Turbidity Tube Construction*).

How a Turbidity Tube Works

The turbidity tube uses the correlation between visibility and turbidity to approximate a turbidity level. A marker is placed at the bottom of the turbidity tube until it can no longer be seen from above due to the “cloudiness” of the water. This height from which the marker can no longer be seen correlates to a known turbidity value. Although this correlation is less accurate than what would be obtained from other methods, it is almost certainly accurate enough for most applications in the developing world. Generally, the cost savings of using a turbidity tube outweigh this loss of accuracy.

Key Components

A turbidity tube is made up of four key components (see Figure 2):

1. A Clear Tube
2. A Tube Cap
3. A Viewing Disc
4. A Measuring Device

(1) Clear Tube: The clear tube will hold the water sample being tested. The tube must be clear to allow for maximum light reflectance off of the marker being viewed. Even a light colored or white plastic tube will not let in enough light for the tube to work properly. A clear plastic tube will provide the most durability and reduce the chances of damage during transport, but a glass tube can be used if handled with caution.

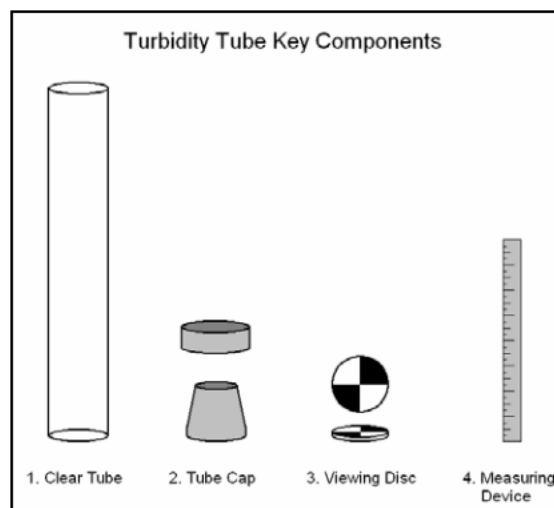


Figure 2: Key Turbidity Tube Components

Possible Clear Tube Materials: Fluorescent light sleeve, graduated cylinder, etc.

(2) Tube Cap: The tube cap prevents the water sample from leaving the clear tube. A seal to the end of the tube can be used, but a removable tube cap is preferred for cleaning of the tube and view disk. Make sure that whatever cap is used prevents leakage (a good seal is more important than removability). The size of your cap will depend on the size of your tube.

Possible Tube Caps: Rubber stopper, PVC pipe cap, Gatorade lid with rubber washer, chair leg end cap, etc.

(3) Viewing Disc: The viewing disk will be submerged in the water sample. A clear pattern must be visible on the disk as well. Generally, it is best to use a white background that is colored with a black checker pattern like the one shown in Figure 2 (this is the pattern typically found on a Secchi disk⁴ as well). The contrast makes the viewing disk very clear, which improves the accuracy of the reading. A white plastic disk patterned with black permanent marker works extremely well. The disk should be sized to fit inside the plastic tube. If necessary, the disk can be made of a porous material such as wood or cardboard, but it must be sealed by lamination or with varnish.

Possible Viewing Discs: Yogurt container lid cut into a circle, white poker chip, etc.

Possible Marking Device: Black permanent marker, black paint, etc.

(4) Measuring Device: The level of the water at the point of non-visibility needs to be measured. This can be done in two ways. The water level can be directly measured from the viewing disc to the top of the water, and a chart can be used to find the turbidity level that corresponds to the measurement. A better way is to mark the turbidity tube with the corresponding turbidity levels before testing begins so that no conversion is necessary. Your choice will depend on the availability of materials and the construction of your tube (for example, if the removal and reinsertion of your tube cap changes the height of your viewing disk, the marking will no longer be correct.)

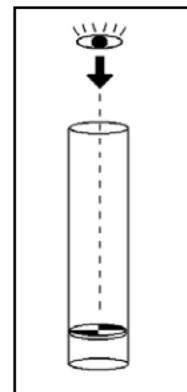
Possible Measuring Device: Ruler, tape measure, etc.

General Construction

As stated earlier, these instructions are very broad to encourage adaptations in the design. A set of specific instructions can be found on page 9 (*Procedure for Turbidity Tube Construction*). After obtaining the materials discussed above, do the following:

Step 1: Plan the Placement of Viewing Disk

You will need to be able to see the viewing disk from the top of your clear tube. The placement of the disk will depend on your tube cap. The disk can be dropped to the bottom of your tube if it is not made of a floating material. A dropped disk will need to be marked on both sides. You can also attach the disk to your tube cap with adhesive so that it will be visible when the cap is inserted. Another possibility is to mark the tube cap with a checkered pattern so that it can be treated as a viewing disk.

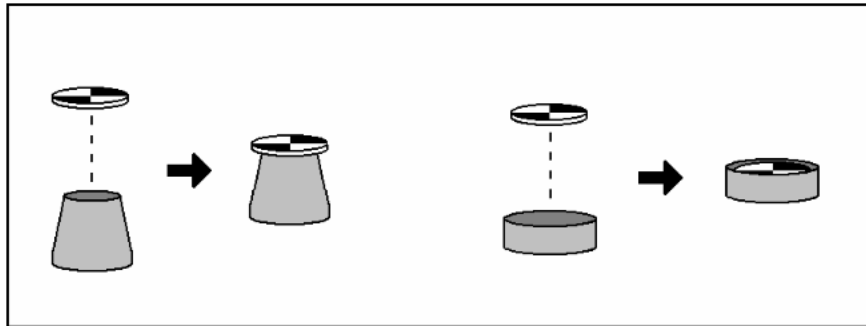


Step 1: Viewing Disk Placement

⁴ A Secchi disk is a device typically used to measure the turbidity of larger bodies of water, such as lakes. A checkered disk is lowered into the water until it can no longer be seen, and the distance of the disk below the surface is converted to an approximate turbidity. This uses the same principle as the turbidity tube, but instead of pouring the water over the disk like in a turbidity tube and measuring the height of non-visibility, the Secchi disk method lowers the disc below the surface to the depth of non-visibility.

Step 2: Combine Tube Cap and Viewing Disk

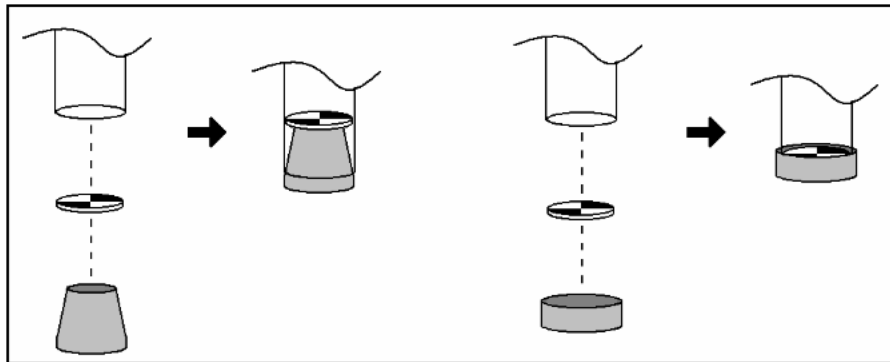
Here, you can use adhesive or sealant to bind the viewing disk to the tube cap. Make sure the disk will fit properly when the tube cap is inserted into the tube (i.e. try it before you glue it.) Again, you can also mark the checkered pattern directly on your tube cap, or a non-floating disk can be dropped from above (just make sure it is small enough as to not get stuck in the tube or the bottom.)



Step 2: Combining the Tube Cap and Viewing Disk

Step 3: Affix Tube Cap to Bottom of Tube

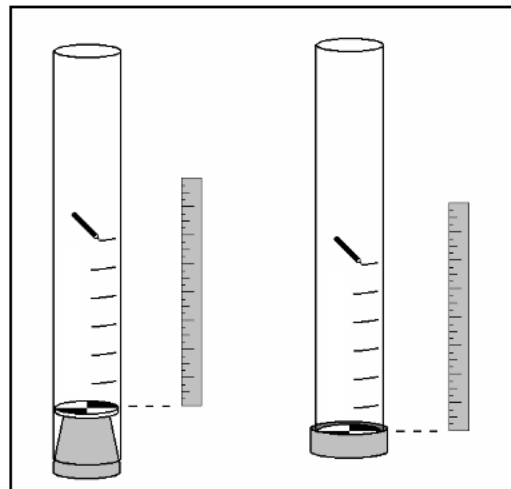
Ideally, the tube cap will be removable for cleaning, but the primary concern is that water does not escape the tube during testing. Some sort of sealant or putty can be used to seal the cap well. Make sure the disc is still clearly viewing from the top of the tube.



Step 3: Affixing the Tube Cap to the Tube Base

Step 4: Mark Tube with Measurement Increments

Ideally, the turbidity level will be marked directly onto the tube. Place the zero mark of a measuring tape or ruler *even with the viewing disk* and measure up the tube, marking the proper intervals found in Table 2 on page 14. Two rubber bands on each end of the tape will hold it in place well while you mark levels with a marker. If the tube is not easily marked, measurements in centimeters can also be taken and then used to find the corresponding turbidity in Table 2.



Step 4: Marking Measurements on the Tube

The tube should now be complete. After all components have dried, test the tube for leakage and make adjustments accordingly. If you are not able to mark the tube directly and will be measuring the depth of the disk below the surface for each reading, try to attach the measuring device to the side of the tube (again, rubber bands work well).

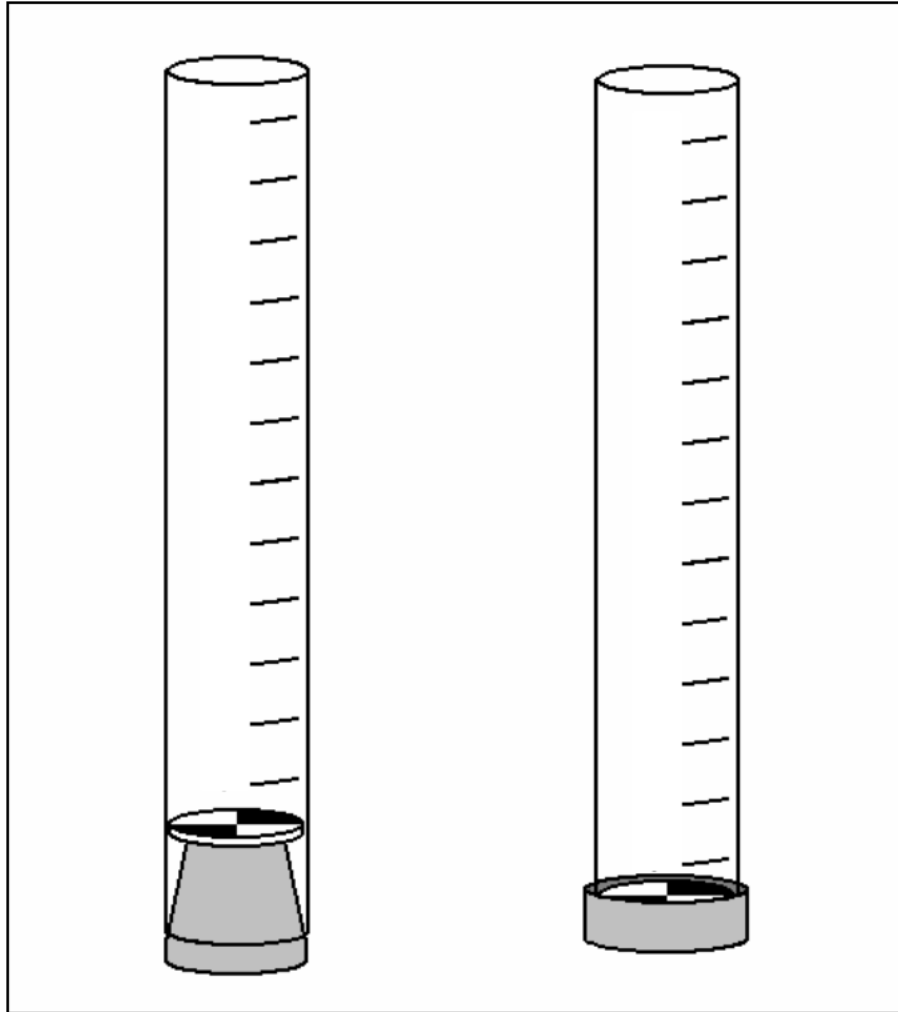


Figure 3: Completed Turbidity Tubes

Procedure for Turbidity Tube Construction

In this section, we will give specific instructions on how to build a turbidity tube. Many of the materials listed can be substituted with other materials depending on what is available to the user. For ideas about how to adapt the design, refer to the section titled *Turbidity Tube Construction- an Overview* found on page 5.

Required Materials

- Black Permanent Marker
- 4' or Longer Fluorescent Light Sleeve (available at most hardware stores)
- (2) Rubber Bands
- Rubber Stopper
- Scrap Paper or Newspaper
- Scissors
- Super-Glue
- Tape Measure
- White Plastic Milk Jug (Opaque)

Construction Procedure

Step 1: Cut a circle (a few centimeters larger than your tube diameter) out of a flat side of the milk jug. Place the circle on the ground and trace the tube mouth onto the plastic square.



Figure 4: Cut Milk Jug



Figure 5: Trace Tube Mouth

Step 2: Cut inside of the traced line such that the resulting plastic disk will fit easily into the fluorescent light sleeve. Use the black permanent marker to color the checkered pattern in Figure 6 onto the disk. This is your viewing disk



Figure 6



Figure 7: Cut Out Viewing Disk

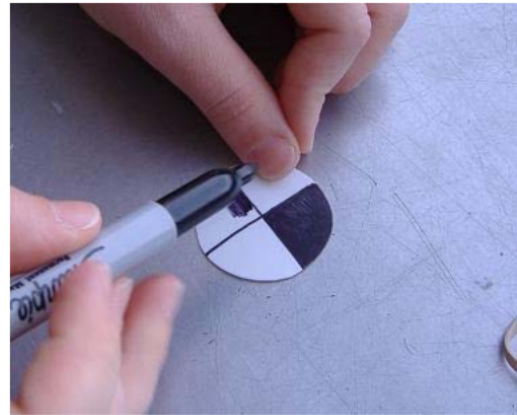


Figure 8: Color Checkered Pattern onto Disk

Step 3: Lay scrap paper down to prevent super glue from damaging any surfaces. Lay the viewing disk checked face down on the paper. Put a thin line of superglue on the rim of the rubber stopper, and quickly press the rubber stopper centered onto the back of the viewing disk until it properly adheres to the rubber stopper.

CAUTION: Superglue binds skin instantly.



Figure 9: Glue Disk onto Rubber Stopper

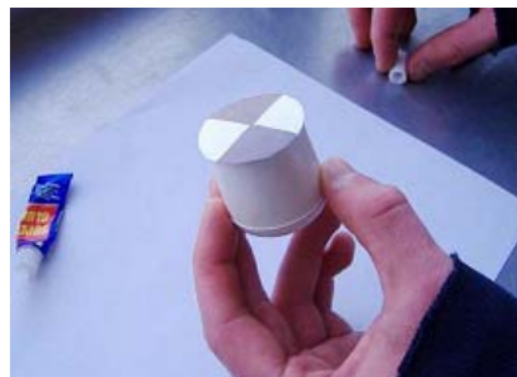


Figure 10: Glued Pieces

Step 4: Press the rubber stopper into the bottom of the fluorescent light sleeve and make sure it is inserted completely. The viewing disk may need to be scissor-trimmed to fit into the light sleeve properly.

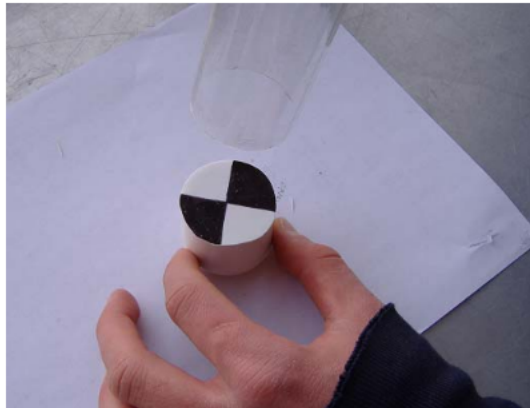


Figure 11: Insert Rubber Stopper into Tube End



Figure 12: Inserted Rubber Stopper

Step 5: Attach the tape measure to the tube using rubber bands at both ends. Align the zero-end of the tape measure with the viewing disk so that measurements increase as you move up the tube. Using Table 2 on page 14, place a short marking at each distance that corresponds to a specific turbidity level. Write the corresponding turbidity level next to each marking all the way up the tube. Example: Put a dash 6.7 centimeters from the viewing disk and write “240 NTU,” then 7.3 centimeters from the disk and write “200 NTU,” etc.



Figure 13: Rubber-band Tape Measure to Tube

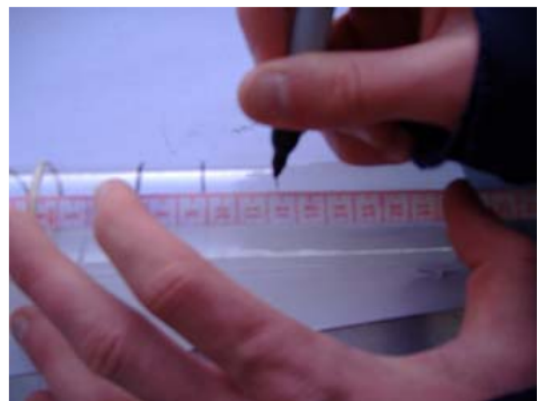


Figure 14: Mark Values at Specified Lengths from Table 2 (page 14)

Step 6: Trim the top of the tube to about 5 centimeters above the 5 NTU mark (the 5 NTU mark is located at about 85 centimeters from the viewing disk).



Figure 15: Trim Top of Tube

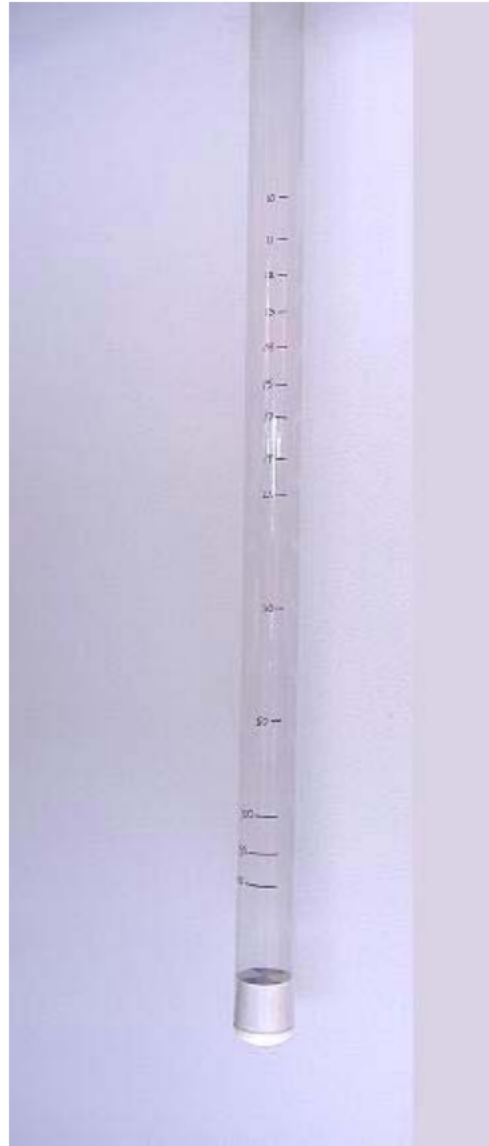


Figure 16: Completed Turbidity Tube

The tube is now complete. It can be cleaned by removing the stopper. If the permanent marker rubs off at some point, simply redraw the pattern.

Using a Turbidity Tube

Before You Begin:

- Be sure to use a clean bucket or other container to collect water samples
- Measurements should be taken in daylight, but not direct sunlight. Cast a shadow on the tube by placing yourself between the sun and the tube.
- Do not wear sunglasses when reading the tube.
- If possible, work with a partner to help verify measurements and disk visibility.

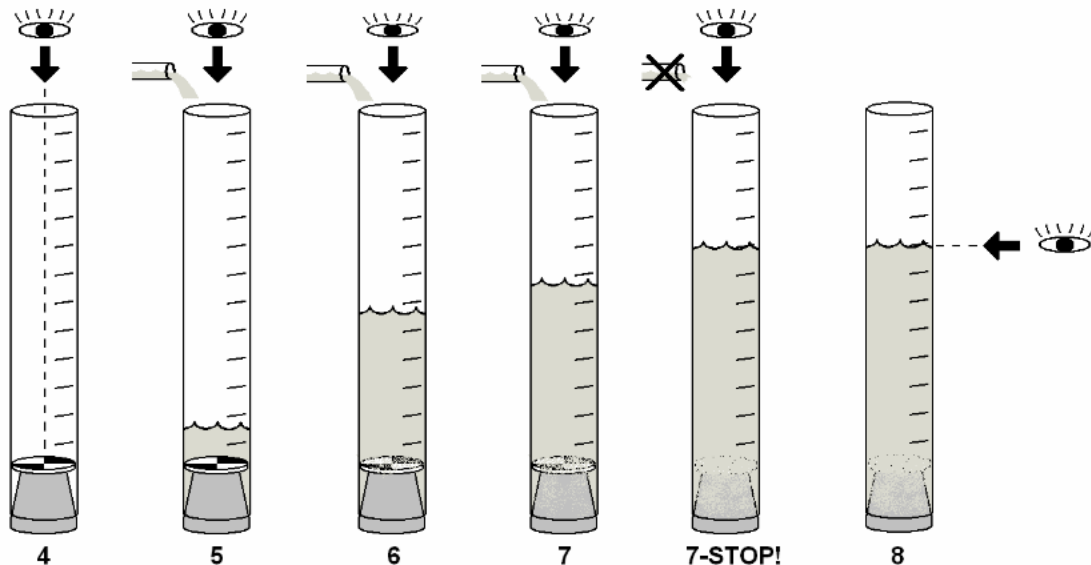
When Measuring, Remember:

- Highly colored water will register as having a higher turbidity than it actually does.
- The turbidity scale is logarithmic, so it cannot be linearly interpolated.

Measuring Procedure:

1. Dip the container into the water. Be careful not to include sediment from the bottom of the body of water.
2. Rinse the tube with the water that is going to be tested and pour it out.
3. Stir or swirl the water sample in the container vigorously until it is homogenous, introducing as little air as possible.
4. Place your head 10 to 20 centimeters directly over the tube so that you can see the viewing disk while the sample is being poured into the tube.
5. Slowly pour water into the tube. Try not to form bubbles as you pour. *If bubbles do form:* Stop pouring and allow any bubbles to rise and the surface of the water to become still.
6. Keep slowly adding water until the pattern on the disc becomes hard to see.
7. Watch the viewing disk closely and add water even more slowly. Stop pouring as soon as the pattern on the disk can no longer be seen. *If you can still see the viewing disk pattern when the tube is full:* Record the turbidity value as less than the final measuring mark. (Example: If your tube is full and your highest mark is 5 NTU, write down that the turbidity is “<5 NTU”.)

Read the turbidity from the scale on the side of the tube. *Remember:* If your turbidity tube does not have turbidity values marked on the tube side, simply measure the water level with a ruler or tape measure and find the corresponding turbidity value in Table 2 (see page 14).



Length-to-Turbidity Conversion Chart

Table 2 provides the turbidity values (in NTU) that correspond to different lengths measured above the viewing disk. These values can be used to mark the turbidity tube directly or to convert measured values to turbidity units.

Table 2: Length-to-Turbidity Conversion⁵

Centimeters	NTU
6.7	240
7.3*	200*
8.9	150
11.5	100
17.9	50
20.4	40
25.5	30
33.1	21
35.6	19
38.2	17
40.7	15
43.3	14
45.8	13
48.3	12
50.9	11
53.4	10
85.4*	5*

*Interpolated/Extrapolated Values (see explanation below).

The relationship between the depth of the viewing disc and the turbidity is exponential. Plotting the non-highlighted values in Table 2 and using a computer to give the best fit line yields the following equation:

$$\text{Depth in Centimeters} = 244.13 * (\text{Turbidity in NTU})^{-0.662}$$

An R² Value of 0.996 was calculated for the above equation. We then used the equation to calculate the depths for our desired values of 5 NTU and 200 NTU. These values were mentioned in this paper, so we felt they should be included. If another turbidity value is important to the user, the corresponding depth can be found using the above equation.

⁵ (UW Extension, 2003). Several tables of slightly different conversions are currently in use. This table was chosen from among the alternatives because of the reliability of the source and because the values were more conservative than in other tables.

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*All figures (except Figure 1) and photographs created by authors.