

Water Quality – TDS (Total Dissolved Solids)

Solids are found in streams in two forms, *suspended* and *dissolved*. Suspended solids include silt, stirred-up bottom sediment, decaying plant matter, or sewage-treatment effluent. Suspended solids will not pass through a filter, whereas dissolved solids will. Total dissolved solids, or *TDS*, can be determined by using a Vernier Conductivity Probe to determine the ability of the dissolved salts and their resulting ions to conduct an electrical current. The conductivity is then converted to TDS.

The TDS concentration in a body of water is affected by many different factors. A high concentration of dissolved ions is not, by itself, an indication that a stream is polluted or unhealthy. It is normal for streams to dissolve and accumulate fairly high concentrations of ions from the minerals in the rocks and soils over which they flow. If these deposits contain salts (sodium chloride or potassium chloride) or limestone (calcium carbonate), then significant concentrations of ions will result.

TDS is sometimes used as a “watchdog” environmental test. Any change in the ionic composition between testing sites in a stream can quickly be detected using a Conductivity Probe. TDS values will change when ions are introduced to water from salts, acids, bases, hard-water minerals, or soluble gases that ionize in solution. However, the test described here will not tell you the *specific* ion responsible for the increase or decrease in TDS. It simply give a general indication of the level of dissolved solids in the stream or lake.

There are many possible human induced sources of ions that may contribute to elevated TDS readings. Fertilizers from fields and lawns can add a variety of ions to a stream. Increases in TDS can also result from runoff from roads that have been salted in the winter. Organic matter from wastewater treatment plants may contribute higher levels of nitrate or phosphate ions. Treated wastewater may also have higher TDS readings than surrounding streams if urban drinking water has been highly chlorinated. Irrigation water that is returned to a stream will often have higher concentrations of sodium or chloride ions. Acidic rainwater, with dissolved gases like CO_2 , NO_2 , or SO_2 , often yields elevated H^+ ion concentrations.

If TDS levels are high, especially due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of animals. High concentrations of dissolved solids can add a laxative effect to water or cause the water to have an unpleasant mineral taste. It is also possible for dissolved ions to affect the pH of a body of water, which in turn may influence the health of aquatic life. If high TDS readings are due to hard-water ions, then soaps may be less effective, or significant boiler plating may occur in heating pipes.

Sources of Total Dissolved Solids

- Hard-Water Ions
 - Ca^{2+}
 - Mg^{2+}
 - HCO_3^-
- Fertilizer in agricultural runoff
 - NH_4^+
 - NO_3^-
 - PO_4^{3-}
 - SO_4^{2-}
- Urban runoff
 - Na^+
 - Cl^-
- Salinity from tidal mixing, minerals, or returned irrigation water
 - Na^+
 - K^+
 - Cl^-
- Acidic rainfall
 - H^+
 - NO_3^-
 - SO_3^{2-} , SO_4^{2-}

Expected Levels

TDS values in lakes and streams are typically found to be in the range of 50 to 250 mg/L. In areas of especially hard water or high salinity, TDS values may be as high as 500 mg/L. Drinking water will tend to be 25 to 500 mg/L TDS. United States Drinking Water Standards¹ include a recommendation that TDS in drinking water should not exceed 500 mg/L TDS. Fresh distilled water, by comparison, will usually have a conductivity of 0.5 to 1.5 mg/L TDS.

Site	Season	TDS (mg/L)	Season	TDS (mg/L)
Rio Grande River, El Paso, TX	Spring	510	Fall	610
Mississippi River, Memphis, TN	Spring	133	Fall	220
Sacramento River, Keswick, CA	Spring	71	Fall	60
Ohio River, Benwood, WV	Spring	300	Fall	143
Hudson River, Poughkeepsie, NY	Spring	90	Fall	119

MATERIALS

LabPro or CBL 2 Interface	tissues or paper towels
TI Graphing Calculator	wash bottle with distilled water
DataMate program	500 mg/L TDS standard solution
Vernier Conductivity Probe	50 mg/L TDS standard solution (optional)
small paper or plastic cup (optional)	

Collection and Storage of Samples

1. This test can be conducted on site or in the lab. A 100-mL water sample is required.
2. It is important to obtain the water sample from below the surface of the water as far away from shore as is safe. If suitable areas of the stream appear to be unreachable, samplers consisting of a rod and container can be constructed for collection.
3. If the testing cannot be conducted within a few hours, place the samples in an ice chest or a refrigerator.

PROCEDURE

1. Set the switch on the Conductivity Probe box to 0-2000 μ S (2000 μ S = 1000 mg/L TDS).
2. Plug the Conductivity Probe into Channel 1 of the LabPro or CBL 2 interface. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends.

¹ Established by 1986 Amendments to the Safe Drinking Water Act

3. Turn on the calculator and start the DATAMATE program. Press **CLEAR** to reset the program.
4. Set up the calculator and interface for the Conductivity Probe.
 - a. Select SETUP from the main screen.
 - b. Press **ENTER** to select CH 1.
 - c. Select CONDUCTIVITY from the SELECT SENSOR menu (not required if your Conductivity Probe is auto-ID).
 - d. Select CONDUCT 1000 (MG/L) or CONDUCTIVITY (MG/L) from the CONDUCTIVITY menu.



5. You are now ready to prepare the Conductivity Probe for calibration.
 - If your instructor directs you to use the stored calibration, proceed directly to Step 6.
 - If your instructor directs you to manually enter the calibration values, select CALIBRATE then MANUAL ENTRY. Enter the intercept and slope values for the 0-1000 mg/L conductivity calibration, select OK, then proceed to Step 6.
 - If your instructor directs you to perform a new calibration for the Conductivity Probe, follow this procedure.

First Calibration Point

- a. Select CALIBRATE, then CALIBRATE NOW.
- b. Perform the first calibration point with the probe in the air (e.g., out of any solution).
- c. Wait for the readings stabilize and press **ENTER**.
- d. Type “0” as the mg/L TDS and press **ENTER**.

Second Calibration Point

- e. Place the Conductivity Probe into the 500 mg/L TDS standard solution. The hole near the tip of the probe should be covered completely.
- f. Wait for the readings to stabilize and press **ENTER**.
- g. Type “500” as the mg/L TDS and press **ENTER**.
- h. Select OK to return to the setup screen.

6. Set up the data-collection mode.
 - a. To select MODE, press **▲** once and press **ENTER**.
 - b. Select SINGLE POINT from the SELECT MODE menu.
 - c. Select OK to return to the main screen.



7. Collect TDS concentration data.
 - a. Place the tip of the electrode into a cup with sample water from the body of water you are testing. The hole near the tip of the probe should be covered completely.
 - b. When the reading has stabilized, select START to begin sampling. **Important:** Leave the probe tip submerged while data is being collected for the next 10 seconds.

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- c. After 10 seconds, the TDS value will appear on the calculator screen. Record this value on the Data & Calculations sheet (round to the nearest 1 mg/L TDS).²
- d. Press [ENTER] to return to the main screen.
- e. Select START to repeat the measurement. Record this value on the Data & Calculations sheet (round to the nearest 1 mg/L TDS).
- f. Press [ENTER] to return to the main screen.

²If your readings are less than 100 mg/L, you may choose to recalibrate the probe for a lower range setting of 0-100 mg/L for more accurate results. To do this, change the setting on the probe box to 0-200 μ S and repeat Steps 2-5. Use the stored 100-mg/L TDS calibration, or calibrate with a 50 mg/L TDS standard provided by your instructor.

DATA & CALCULATIONS

TDS: Total Dissolved Solids

Stream or lake: _____

Date: _____

Site name: _____

Time of day: _____

Student name: _____

Student name: _____

Student name: _____

Student name: _____

Reading	TDS (mg/L)
1	
2	
Average	

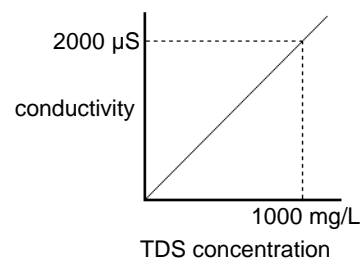
Field Observations (e.g., weather, geography, vegetation along stream) _____

Test Completed: _____ Date: _____

TEACHER INFORMATION

Water Quality - TDS

1. There is a nearly linear relationship between conductivity and total dissolved solid concentration (of dissolved ionic substances). A curve similar to the one shown here can be obtained using standard TDS solutions. In the figure shown here, the ratio of TDS concentration in mg/L to conductivity in $\mu\text{S/cm}$ is 0.5 to 1, and represents the approximate relationship between TDS concentration *as sodium chloride* and conductivity.



2. Step 5 of the student procedure provides three alternatives for loading or performing a TDS calibration:
- The easiest option is to use the TDS calibration stored in the DATAMATE program. The stored calibration measures mg/L TDS as NaCl; therefore, it is based on a sodium chloride standard, and does not take into account the variation in ion composition of different streams.
 - The stored TDS calibrations in the DATAMATE program make use of the equation, $\text{TDS} = 0.50 \times \text{Conductivity (in } \mu\text{S/cm)}$ —a relationship based on sodium chloride calibrations. Most freshwater streams, however, have higher concentrations of hard-water ions (Ca^{2+} and HCO_3^-) than salt ions (Na^+ and Cl^-). Large variations in ionic composition of streams result in the 0.50 “constant” actually ranging from 0.50 to 0.90. An average value of 0.70 is often used in freshwater studies

$$\text{TDS} = 0.70 \times \text{Conductivity (in } \mu\text{S/cm)}$$

If you are making measurements in a freshwater (non-brackish) samples, improved TDS data can usually be obtained if you use a calibration that reflects the 0.70 value. Students can use the MANUAL ENTRY option of the CALIBRATION menu to manually enter the intercept and slope values for a calibration based on the constant, 0.70. The values to be manually entered are¹

$$\text{Intercept} = 0 \quad \text{Slope} = 593$$

This calibration will give TDS readings (in mg/L TDS) over a range of 0-1400 mg/L when using the 0-2000 $\mu\text{S/cm}$ switch setting of the Conductivity Probe.²

- A third option has students perform a two-point calibration. To obtain a standard that reflects the unique ionic composition of your particular stream, you can collect a 1-liter water sample, and determine the TDS concentration of 500 mL of the sample using Method 2 of Test 12: *TDS by Evaporation*. After finding its concentration, you can now use the remaining 500 mL of the water sample as a standard solution. For the first calibration point, simply hold the probe in the air (out of solution), and enter a value of “0” (mg/L TDS). For the second calibration point, place the Conductivity Probe into the water sample, and enter the value you obtained using Method 2 (e.g., 142 mg/L TDS).

¹These calibration values were obtained by multiplying the calibration for the 0-2000 $\mu\text{S/cm}$ conductivity calibration by the constant, 0.70: Intercept = $0 \times 0.70 = 0$, Slope = $847.2 \times 0.70 = 593$.

²If you are using the low-range switch setting (0-200 $\mu\text{S/cm}$) for samples with low TDS values, you can manually enter a calibration corresponding to the 0.70 constant: Intercept value = 0, Slope = 46.0

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3. If you choose to calibrate the Conductivity Probe, you will want accurate standard solutions. The 1000 $\mu\text{S}/\text{cm}$ Standard that shipped with the Conductivity Probe will last a long time if you take care not to contaminate it with a wet or dirty probe. This is a good concentration to calibrate your Conductivity Probe in the middle range (0 to 2000 μS). Vernier sells three Conductivity Standards, one appropriate for each range of the Conductivity Probe. They come in 500 mL bottles for \$12 each. Order codes are:

- Low Conductivity Standard 150 $\mu\text{S}/\text{cm}$CON-LST
- Medium Conductivity Standard 1413 $\mu\text{S}/\text{cm}$ CON-MST
- High Conductivity Standard 12,880 $\mu\text{S}/\text{cm}$ CON-HST

To prepare your own standard solutions using solid NaCl, use a container with accurate volume markings (e.g., volumetric flask) and add the amount of solid shown in the first column of Table 2. This standard can be used to calibrate Conductivity Probe for Test 12, using the amount shown in mg/L as TDS (second column).

Table 2		
Add this amount of NaCl to make 1 liter of solution	TDS and Conductivity values equivalent to the NaCl concentration in the first column	
	Total dissolved solids (TDS)	Conductivity
0.0474 g (47.4 mg/L)	50 mg/L as TDS	100 $\mu\text{S}/\text{cm}$
0.491 g (491 mg/L)	500 mg/L as TDS	1000 $\mu\text{S}/\text{cm}$
1.005 g (1005 mg/L)	1000 mg/L as TDS	2000 $\mu\text{S}/\text{cm}$
5.566 g (5566 mg/L)	5000 mg/L as TDS	10,000 $\mu\text{S}/\text{cm}$

4. Flinn Scientific (P.O. Box 21, Batavia, IL 60510, Tel: 800-452-1261, www.flinnsci.com) sells a set of four standard solutions in 500-mL bottles. The concentrations correspond to the four solutions shown in Table 2. Here is the ordering information:
- Conductivity Calibration Kit with four 500-mL bottles (50 mg/L, 500 mg/L, 1000 mg/L, and 5000 mg/L TDS, order code AP 9111)
5. Your Vernier Conductivity Probe is automatically temperature compensated between temperatures of 5 and 35°C. Readings are automatically referenced to a conductivity value at 25°C. The Conductivity Probe will, therefore, give the same conductivity reading in a solution that is at 15°C as it would if the same solution were warmed to 25°C. This means you can calibrate your probe in the lab, and then use these stored calibrations to take readings in colder (or warmer) water in a lake or stream. If the probe was not temperature compensated, you would notice a change in the conductivity reading as temperature changed, even though the actual ion concentration did not change.
6. The SINGLE POINT data-collection mode was designed to make measurements easier and more accurate. When SINGLE POINT mode is used, the interface takes readings for 10 seconds. These readings are averaged and this average value is displayed on the calculator. This method has several advantages over other data-collection modes: (1) It eliminates the need for students to choose one value over another if that value is fluctuating; (2) If the readings are fluctuating a little, an average of the values is desirable; (3) It requires the students to hold the sensor in the water longer that they might tend to otherwise.

Sampling in Ocean Salt Water or Tidal Estuaries

Salt-water samples may exceed the high range of the Conductivity Probe, 0 to 20,000 $\mu\text{S}/\text{cm}$ (0 to 10,000 mg/L TDS). Seawater from the mid-Atlantic ocean has a conductivity value of 53,000 $\mu\text{S}/\text{cm}$ (or a TDS concentration of about 26,500 mg/L). Samples in this range will need to be diluted in order for them to be measured using the high range. For example, you can take a sample of ocean water, and dilute it to $\frac{1}{4}$ of its original concentration by adding 100 mL of the salt-water sample to 300 mL of distilled water. This diluted sample can then be measured using the Conductivity Probe at the high-range setting. If the TDS value for the diluted sample is measured to be 6,600 mg/L, then this answer is multiplied by a factor of 4 to obtain the TDS value of the original sample: $4 \times 6,600 = 26,400$ mg/L TDS.

How the Conductivity Probe Works

The Vernier Conductivity Probe measures the ability of a solution to conduct an electric current between two electrodes. In solution, the current flows by ion transport; therefore, an increasing concentration of ions in the solution will result in higher conductivity values.

The Conductivity Probe is actually measuring *conductance*, defined as the reciprocal of resistance. When resistance is measured in ohms, conductance is measured using the SI unit, *siemens* (formerly known as a *mho*). Aqueous samples are commonly measured in microsiemens, or μS .

Even though the Conductivity Probe is measuring conductance, we are often interested in finding the *conductivity* of a solution. Conductivity, C , is found using the following formula

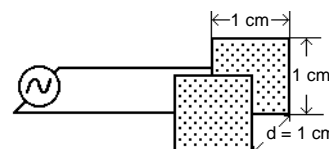
$$C = G \cdot k_c$$

where G is the conductance, and k_c is the cell constant. The cell constant is determined for a probe using the following formula

$$k_c = d/A$$

where d is the distance between the two electrodes, and A is the area of the electrode surface. For example, the cell in the figure shown here has a cell constant of

$$k_c = d/A = 1.0 \text{ cm} / 1.0 \text{ cm}^2 = 1.0 \text{ cm}^{-1}$$



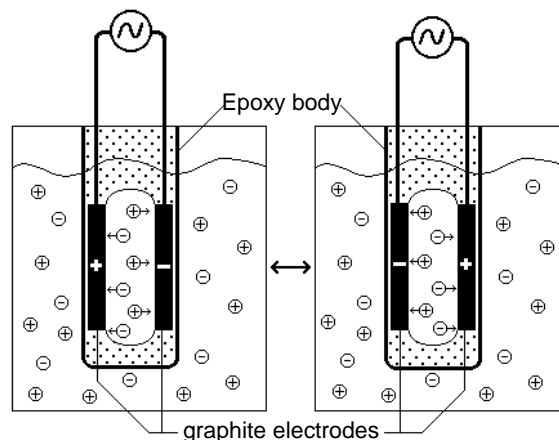
The conductivity value is found by multiplying conductance and the cell constant. Since the Vernier Conductivity Probe also has a cell constant of 1.0 cm^{-1} , its conductivity and conductance have the same numerical value. For a solution with a conductance value of 1000 μS , the conductivity, C , would be

$$C = G \cdot k_c = (1000 \mu\text{S}) \times (1.0 \text{ cm}^{-1}) = 1000 \mu\text{S}/\text{cm}$$

A potential difference is applied to the two probe electrodes in the Conductivity Probe. The resulting current is proportional to the conductivity or TDS value of the solution. This current is converted into a voltage to be read by Logger *Pro*.

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Alternating current is supplied to prevent the complete ion migration to the two electrodes. As shown in the figure below, with each cycle of the alternating current, the polarity of the electrodes is reversed, which in turn reverses the direction of ion flow. This very important feature of the Conductivity Probe prevents most electrolysis and polarization from occurring at the electrodes. Thus, the solutions that are being measured for conductivity are not fouled. It also greatly reduces redox products from forming on the relatively inert graphite electrodes.



The Vernier Conductivity Probe has three sensitivity range settings.

- 0 to 200 $\mu\text{S}/\text{cm}$ (0 to 100 mg/L TDS)
- 0 to 2000 $\mu\text{S}/\text{cm}$ (0 to 1000 mg/L TDS)
- 0 to 20,000 $\mu\text{S}/\text{cm}$ (0 to 10,000 mg/L TDS)

These ranges are selected using a toggle switch on the end of the amplifier box attached to the probe. It is very important to consider this setting when loading or performing a calibration; no single calibration can be used for all three settings.