xylem
Let's Solve Water



CastAway-CTD Lesson Plan

SonTek
a xylem brand

CastAway-CTD Lesson Plan

PART 1: INTRODUCTION TO SALINITY

Prep: 5 minutes
Activity: 45 minutes

Materials:

- Presentation slides
- Computer with projector
- Handouts – one for each student or pair

Preparation

1. Load the PowerPoint slides onto your computer. Review them and the teaching concepts.
2. Print handouts.

Warm-Up: Think-Pair-Share

3. Display the prompt for the discussion question on the board for the class to read, "Why is the ocean salty?" Invoke their senses; invite students to think about how the ocean tastes.
4. Instruct students to think about the response, then share their answer with their neighbor.
5. After a couple of minutes, facilitate a class discussion. Invite students to share with the class what they discussed with their neighbor. Use this opportunity to gauge what students already know about salinity.



ACTIVITY

CHEMISTRY OF THE OCEAN

1. Show an image of table salt and/or sea salt and solicit answers from the class, for example: What is the chemical composition of table salt?, What is the difference between table salt and sea salt?, Do you think sea salt is healthier than table salt?, Can you taste the difference between sea salt and table salt?

2. Discuss the concepts of Ions, Salts, Ionic Compounds, and Electrolyte Solutions at a level appropriate to the class (see Wikipedia pages for various definitions). For example, the ionic compound NaCl dissolves in water to form an electrolyte solution consisting of positively charged Na+ cations and negatively charged Cl- anions. A more advanced discussion may involve displaying the periodic table and topics related to atomic structure. For example, ions form because atoms lose or gain electrons in order to stabilize their electron shell and salts form because oppositely charged ions form an ionic bond.

3. Review the molecular structure of sodium chloride. Explain that a sodium atom has an extra electron in its outermost shell and wants to get rid of it. A chlorine atom is missing an electron. They bind together to create an ionic bond, making sodium chloride or table salt. Are sodium and chloride the only salts in the ocean?

4. Law of Constant Proportions: explain that the relative proportions of major ions in the ocean are constant, regardless of the total salinity. This is the Law of Constant Proportions. Even though ocean salinity may vary, the relative concentration of the major ions remains unchanged. Chloride remains the dominant ion at about 55%, followed by sodium (30.6%), sulfate (7.7%), magnesium (3.7%), calcium (1.2%), and potassium (1.1%).

5. Inputs and Outputs: Ask students, "What brings water to the ocean? What are the inputs? Where do the salts in the ocean come from?" (rivers and rain). Give students a minute to think to themselves, then share with their neighbor. After a couple of minutes, lead a discussion with the whole class.

6. Residence Time: residence time is the average time that a substance remains in a body of water before removal. Invite the class to provide examples of residence time in other systems related to everyday life.

7. Explain that rivers erode elements from the Earth's crust and deliver them to the ocean as dissolved ions. These ions accumulate over time in the ocean, giving the ocean a higher salt concentration than rivers. Rivers also deliver many other elements in addition to the major ions to the ocean. For example, elements such as phosphorus and nitrogen, key nutrients that fuel phytoplankton at the base of the ocean food chain. The key difference between major ions and the rest of the elements in the periodic table (e.g. nutrients) is chemical reactivity. Nutrients for example, get used up quickly by plants, whereas salts don't, and are left to accumulate.

8. Reactivity of elements in the ocean: Imagine a student alone in an empty room. Every 5 minutes, someone brings in a plate of chocolate chip cookies and a plate of broccoli. After an hour, do you expect there to be more cookies or broccoli left over? (Likely, broccoli). Why? Answer: because the cookies are the more desirable food, they are considered to be more "reactive" and will therefore persist in the room for a shorter period of time.

9. Hand out the periodic table of elements in the ocean (Nozaki 1997[1]). Explain that for each element, the graph shows a vertical profile of concentration vs. depth. Some elements are more abundant in surface waters and become more scarce with depth. Ask students to list the major salt ions in seawater on their worksheet and circle them on their periodic table (don't remind them what they are; they should remember at least a few after the lesson that was just taught). After they have had a chance to guess on their own, review as a class the major salt ions.

10. Instruct students to share with a partner one thing they notice about the vertical profiles of these salt ions and write that observation on their worksheet. (Students should notice that the major ions exhibit both a high concentration AND a constant concentration over depth. Instruct students to complete the remainder of the worksheet with their partner. Lead a discussion with the class and review their answers.

11. Explain that elements that are used up easily (the cookies of the sea) are the nutrients organisms need for food and growth. They typically are less abundant at surface because organisms are using them. We call these "reactive" or "non-conservative" elements because, unlike the major ions, the concentration of these elements is controlled by chemical reactions. In contrast the concentration of the major ions is controlled only by physical processes like evaporation and precipitation. Due to low reactivity, over long periods of time, the major ions accumulate in seawater in very high concentrations, making the ocean salty.

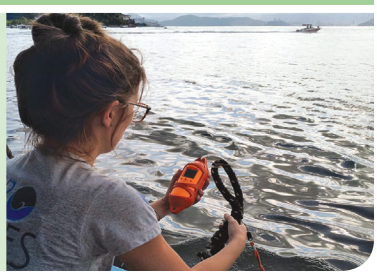
12. Residence Time: when we say that an element accumulates and remains in a seawater longer, we can say that that element has a longer residence time. (Show equation for residence time). We can calculate residence time by dividing the total amount of something in a reservoir by the rate of removal (or rate of input).

13. Hand out residence time worksheet. Run through an example with them, then instruct students to work in pairs to complete the worksheet.

Closure: Exit-Slip

Students write their answer to the below questions and submit it to the teacher on their way out the door.

1. What is the Law of Constant Proportions?
   Be sure to list the six major ions in seawater in your answer.
2. Are these ions conservative or non-conservative?
3. Why?



1. Nozaki, Y. A fresh look at element distribution in the North Pacific Ocean. EOS Trans., American Geophysical Union, 1997.

CONSERVATIVE AND NON-CONSERVATIVE ELEMENTS

INSTRUCTIONS: Use the periodic table of elements' vertical profiles to answer the questions below.

1. What six elements make up the major salt ions in seawater? Write them below and circle them on your periodic table.
   a.
   b.
   c.
   d.
   e.
   f.

2. What patterns do you observe about the vertical profiles of the major salt ions? How do they change with depth? What other patterns can you identify with other elements?

3. Take a look at nitrogen and phosphorus. Draw the vertical profile for both elements below. What pattern can you observe about these two nutrients (describe their abundance at the surface and whether that increases or decreases with depth)?

4. What processes are occurring at the ocean's surface? List two. *(hint: think of the biology)*

5. How might those processes affect the abundance of nutrients like nitrogen and phosphorus or major ions such as chloride and sodium? Do those activities appear to influence the abundance of salt ions?

RESIDENCE TIME WORKSHEET

Example: Consider a high school that has 800 students (i.e. there are 800 students in our reservoir). These students are evenly divided among the 4 grade levels (Freshman, Sophomore, Junior, and Senior). If we assume that all seniors graduate every spring, 200 students are leaving the school each year (i.e. the rate of output is 200 students per year). Let's also assume that 200 new students enter as Freshman each fall (rate of input is 200 students per year). This means that our reservoir is in a steady state.

The equations for residence time is given as:

$$\tau = \frac{\textbf{total amount in reservoir}}{\textbf{rate of input (or rate of output)}}$$

Therefore, in this example, the residence time for a high school student is:

$$\tau = \frac{\textbf{800 students}}{\textbf{200 students per year}} = \textbf{4 years}$$

INSTRUCTIONS: Work with a partner to find the residence time for the questions below:

1. A forest is planted with 2500 trees. Each year, a local logger cuts down 5 trees, but a conservation group plants 5 adult trees, so the forest is in a steady state. What is the residence time of a tree in the forest?

2. Lake Wilson has a volume of 200 million gallons. It has a rainfall rate (input) of 1 million gallons per year. What is the residence time of water in Lake Wilson?

3. What is the residence time of chloride in the ocean? To calculate, you'll need to know the following:

   a. Volume of the ocean = 1.3×10^{18} m^3
   b. Total amount of chloride in the ocean = 20 g/L
   c. Average concentration of chloride in rivers = 8 mg/L
   d. Total riverine flow rate = 3.7×10^{13} m^3/year
   e. Unit conversions: 1000 L/m^3, 1000 mg/g

RESIDENCE TIME WORKSHEET (ANSWERS)

Example: Consider a high school that has 800 students (i.e. there are 800 students in our reservoir). These students are evenly divided among the 4 grade levels (Freshman, Sophomore, Junior, and Senior). If we assume that all seniors graduate every spring, 200 students are leaving the school each year (i.e. the rate of output is 200 students per year). Let's also assume that 200 new students enter as Freshman each fall (rate of input is 200 students per year). This means that our reservoir is in a steady state.

The equations for residence time is given as:

$$\tau = \frac{\textbf{total amount in reservoir}}{\textbf{rate of input (or rate of output)}}$$

Therefore, in this example, the residence time for a high school student is:

$$\tau = \frac{\textbf{800 students}}{\textbf{200 students per year}} = \textbf{4 years}$$

INSTRUCTIONS: Work with a partner to find the residence time for the questions below:

1. A forest is planted with 2500 trees. Each year, a local logger cuts down 5 trees, but a conservation group plants 5 adult trees, so the forest is in a steady state. What is the residence time of a tree in the forest?

$$\tau = \frac{2500 \text{ trees}}{5 \text{ trees per year}} = 500 \text{ years}$$

2. Lake Wilson has a volume of 200 million gallons. It has a rainfall rate (input) of 1 million gallons per year. What is the residence time of water in Lake Wilson?

$$\tau = \frac{200 \text{ million gallons}}{1 \text{ million gallons per year}} = 200 \text{ years}$$

3. What is the residence time of chloride in the ocean? To calculate, you'll need to know the following:

   a. Volume of the ocean = 1.3×10^{18} m^3
   b. Total amount of chloride in the ocean = 20 g/L
   c. Average concentration of chloride in rivers = 8 mg/L
   d. Total riverine flow rate = 3.7×10^{13} m^3/year
   e. Unit conversions: 1000 L/m^3, 1000 mg/g

$$\frac{\left(1.3 \times 10^{18} m^3\right) \times \left(20 \frac{g}{L}\right) \times \left(\frac{1000L}{1m^3}\right)}{\left(8 \frac{mg}{L}\right) \times \left(\frac{1g}{1000mg}\right) \times \left(3.7 \times 10^{13} \frac{m^3}{yr}\right) \times \left(\frac{1000L}{1m^3}\right)} = 88 \text{ million years}$$

PART 2: CLASSROOM DEMONSTRATION

Introduction

The purpose of this activity is to explore the relationship between four important properties of seawater: temperature, salinity, conductivity, and density. The CastAway-CTD measures temperature and conductivity and computes salinity and density. For the purposes of this exercise, we do not distinguish between Practical and Absolute salinity. In the demonstration and discussion, salinity is treated as grams of sea salt per kilograms of seawater. The thermodynamic relationships between these properties are well-established, but beyond the scope this demonstration. It is worth noting that some solution properties such as temperature and conductivity are more easily measured than others (i.e. salinity or more formally the "chemical composition").



Materials:

- CastAway-CTD
- Several liters of seawater (or alternatively a solution prepared from an aquarium salt mix)
- Two buckets large enough to completely immerse the CastAway-CTD with at least 30cm of water
- A means to cool one volume of seawater (e.g. a large refrigerator).
- Access to software or online website that performs seawater salinity calculations.

Setup:

For the in-class demonstration, the instructor needs two buckets of seawater at different salinities and different temperatures. It is practical to obtain a single batch of seawater, split it into two volumes and then dilute one of the volumes with roughly 1 part of deionized (distilled) water per 10 parts seawater. The higher salinity seawater needs to be chilled to a low temperature, preferably close to freezing. The two resulting solutions should exhibit an inverse relationship between salinity and conductivity, which is counterintuitive and raises questions that can be discussed in class or as homework.

Demo:

The instructor uses the CastAway-CTD to measure the temperature and conductivity of both buckets of seawater. Students can also carry out this step, but ideally, students should not be allowed to see the salinity reading of the instrument, only the temperature and conductivity. For discussion, the measured temperature and conductivity may be written on the board. The class is then encouraged to predict which bucket has more salt, or a higher salinity and which might be denser.

Discussion/explanation of observations:

A typical set of conditions for this experiment are:

Bucket #1: T = 5°C; Salinity = 35; Conductivity = 3.4 S m-1

Bucket #2: T = 20°C; Salinity = 32; Conductivity = 4.7 S m-1

Q: Why is it that a sample of seawater with more salt would have a lower conductivity, when it is a well-known fact that increasing the amount of salt increases the electrolytic conductivity of a solution?

A: Because, like many physical properties, electric conductance or resistance is a function of multiple properties. In this case, both temperature and salinity affect the conductivity and temperature has the greater influence. At this point, a more advanced class (e.g. college level science, may choose to discuss thermodynamic systems, state functions, etc.).

Example questions to ask and work through with students during class.

1. In class we measured the conductivity of seawater in two buckets at different temperatures and found the following:

   Bucket #1: T = 5°C; Salinity = 35; Conductivity = 3.4 S m-1

   Bucket #2: T = 20°C; Salinity = 32; Conductivity = 4.7 S m-1

   Are the samples composed of the same seawater? Explain.

   Correct response:

   No. Bucket #2 has a lower salinity by about 3.

   Answering this question requires a calculation using any one of a variety of programs or websites where temperature and conductivity can be entered in order to compute salinity.

2. How do the densities of the two seawater samples compare?

   Correct response:

   The seawater in bucket #1 is denser.
   ρ1 = 1027.7 kg m-3
   ρ2 = 1025.7 kg m-3

Answering this question requires a calculation using any one of a variety of programs or websites where temperature and salinity can be entered in order to compute density.

Advanced questions:

3. By manipulating temperature only, can the two buckets be brought to the same density? Explain.

   Correct response:

   Yes. There are several combinations of temperature that give matching densities. However, all combinations require raising the temperature of Bucket #1, i.e. lowering the temperature of bucket #2 all the way to the freezing point only brings the density up to about 1026, therefore it is necessary to raise the temperature of bucket #1 to decrease its density.

   This question requires students to use the two salinity values computed in #1 above and adjust the input temperatures in the calculation used in #2 until the computed densities match.

4. How many grams of Calcium are in 2 kg of the water in bucket #2?

   Correct response:

   This requires combining information on the composition of sea salt (see lecture slide) and some basic unit conversions. From the slide provided in class there are 0.42 g Ca per 1 kg seawater with Salinity = 35. So:

   Grams of sea salt in 2 kg seawater with Salinity = 32:

   $$\text{grams sea salt} = 2\ \text{kg} \times 32\ \text{gkg} = 64\ \text{g}$$

   Grams of Calcium in 64 grams of sea salt:

   $$64\ \text{g sea salt} \times 0.42\ \text{g Ca}35\ \text{g sea salt} = 0.77\ \text{g Ca}$$

PART 3: FIELD WORK

Prep: 30-45 minutes
Activity: 60 minutes

Materials:

- CastAway-CTD Kit - includes:
  - ✓ CastAway-CTD in protective jacket
  - ✓ Carabiner clip
  - ✓ Maintenance kit
  - ✓ Splash-proof case with USB drive, Bluetooth modem, and 4-AA batteries
  - ✓ Magnetic stylus pen
- Windows computer with internet access (at the time this lesson plan was developed, CastAway software runs on Windows systems only)
- Worksheets for students
- Clipboards (one per group of students)
- Pens/Pencils (one per group of students)
- Optional: dive reel

NOTE:
It is highly recommended that the instructor perform at least one field test on their own before embarking on a field trip with students!

Preparation

1. **Prepare your CastAway-CTD**

   a. Review equipment and laminated printouts included in your CastAway-CTD case.



   b. Follow the prompts from the laminated sheets inside your CastAway case to install the software (you will need a Windows computer to install).

   c. Install the batteries on your CastAway-CTD 1-3 days before use. Remove batteries for storage periods of more than 3 days to avoid battery depletion. Bring one extra set of AA batteries for field work.

2. **Prepare your field trip**

   a. Identify a study site with consideration for both access and safety. In the absence of a ship, the CastAway is ideally deployed from an ocean pier with public access. A pier deployment allows the students to measure a vertical profile of water properties rather than a single measurement that would be obtained in the shallow water on the beach.

   b. Consider any regulations that may prevent use of the CastAway at the study site. For example, if you plan to visit the local pier, it would be advisable to discuss your field trip with a nearby lifeguard.

   c. Identify the weather and the time for high and low tides for the date of your field trip and plan accordingly.

ACTIVITY
FIELD WORK



1. Prepare your students for field work. Open up Google maps to Google Earth view and zoom to your study site.
2. Explain that in the field, as a class, you'll be collecting salinity measurements using the CastAway-CTD. Optionally, the instructor may wish to obtain a water quality test kit from any number of online distributors. Note that such test kits are typically specific to water type (e.g. coastal seawater, drinking water, etc.) and should be used accordingly. Break the class into groups of 2-5 people.
3. Get students into their groups in the classroom. Looking at Google Earth display of the study site, ask each group to make a list of natural or built systems near your study site that might affect the flow of water into your study site (is there a river that flows into it? Is there a storm drain outflow pipe?)
4. Take your students to your study site. Review the safety parameters and the activity. Break the students into the groups assigned in the classroom. Each group should have a worksheet, a clipboard, and a pen/pencil. While one group is taking a measurement with the CastAway (instructions below), the other groups should fill out their worksheets. Try to obtain field guides with information about local plants and marine life so your students can accurately ID them (worksheet question #3).
5. Taking a measurement with the CastAway-CTD: first, make sure the CastAway is securely tied to the rope



and that the other end of the rope is tied securely to the boat, pier, or other solid object in case you lose your grip (using a bowline, or other secure knot type). Turn on your CastAway and wait for GPS to register (it



can take 3-6 minutes before GPS turns on). Keep in mind that the CastAway will need to be at least elbow deep in order to take a measurement. Follow the instructions on the laminated sheets included in your CastAway kit to take a measurement.



6. When finished, press any button to turn the screen on and select the "X"(end) button on the lower right.



7. Scroll through the profile screens to see immediate results.

NOTE:
It is recommended that students spend some time learning how to use the castaway system in the classroom before performing field data collection.

- Allow each group of students to complete a measurement.
- Once every group has completed a measurement, gather your students and return to the classroom.

FIELD GUIDE & WORKSHEET

Your Group's Name: _____

Name of Study Site: _____

Time/Date of Field Work: _____

General Description of Study Site: _____

_____

_____

1. Are there any water inputs that flow into your study site (rivers, creeks, storm drains, channels that bring runoff from the street)?

2. Describe the built environment around your study site (i.e. are there houses, industry, roads, farms, etc)?

3. Identify the plants and animals you see at your study site. How might they depend on the salinity (or freshness) of your study site for survival?

4. When was the date of the last rain? How might rain affect the salinity of your study site?

5. Would you expect the surface water of your study site to have higher or lower salinity than the deepest part of your study site?

6. List two other questions you would like to find out about salinity at your site or your study site generally.

   a._____

   b._____

PART 4: ANALYSIS

Prep: 15 minutes
Activity: 60 minutes

Materials:

- CastAway Data pre-loaded onto your computer
- Internet access
- Projector
- Salinity Worksheet

Preparation:

1. Load CastAway data from field work onto computer.
2. Open web browser to https://www.nodc.noaa.gov/.

Warm-Up:

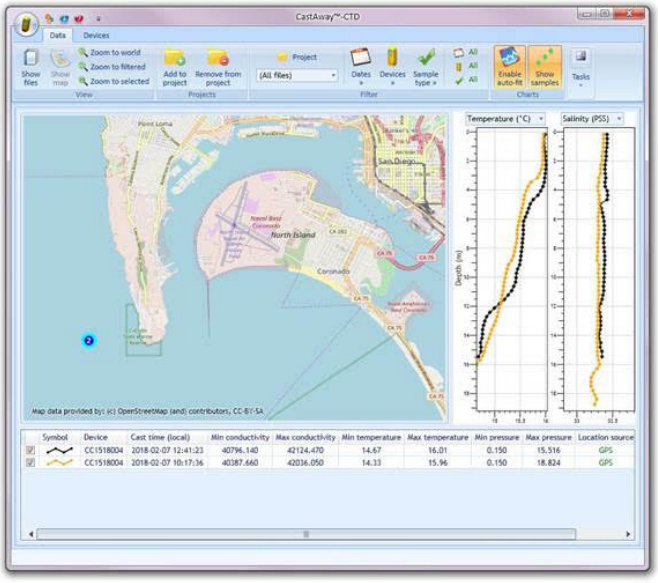
1. Think-Pair-Share: Display the prompt on the board, "What were your key observations from our field work last class?" (the idea is to jog their memory of the experience).
2. Instruct students to think about their answer for a minute, then share with their neighbor.



Lead a class discussion, making sure to mention average salinity measured, major inputs into your study site, and any notable events; perhaps bring to the attention of your students when the last rain was if you haven't already.

ACTIVITY
DATA

1. Display your CastAway data from your field work and project for the whole class to see (follow instructions on the laminated sheets included in your CastAway case).
2. Review with students what your general findings are from field work. Have students discuss how the property profiles change with depth – are they constant, or is there a slope? Estimate simple statistics on the profiles, including depth-average values, maxima, minima, etc.
3. Instruct your students to use an online resource to locate real-time salinity data near where you took your measurements. An example of this can be found at www.nodc.noaa.gov. The NODC pulls live data from buoys, shore stations, ships, profilers, and moored sensors that monitor ocean salinity around the globe.
4. Locate at least two platforms that have data for salinity at various depths (try to find one in the Pacific ocean and one in the Atlantic ocean, each with data for salinity at over 1000 m deep).
5. Hand out the worksheet and instruct students to complete it in small groups.
6. Graph salinity vs. depth at a location you chose.



SonTek CastAway-CTD Software



NODC Website

NOTE:
It is highly recommended that the instructor familiarize themselves with how to obtain data from the NODC website before presenting it to the classroom.

SALINITY WORKSHEET

Using data from www.nodc.noaa.gov, complete the questions below.

1. Station #1: Select one station, buoy, or float in the Pacific Ocean. Write the name of your station (buoy or float) below:

_____

➲ Select three different depth measurements collected at your station and write them below. What is the salinity at each depth?

Depth (in meters)	Salinity
_____	_____
_____	_____
_____	_____

2. Station #2: Select a similar station, buoy, or float in the Atlantic Ocean. Write the name of your station (buoy or float) below:

_____

➲ Select three different depth measurements (that are roughly the same depths as the depths you chose for your Pacific Ocean station) collected at your station and write them below. What is the salinity at each depth?

Depth (in meters)	Salinity
_____	_____
_____	_____
_____	_____

3. In general, is salinity higher or lower in the Pacific Ocean versus the Atlantic (feel free to look at other buoys in each ocean region to get a more general sense)?

_____

4. Does salinity increase or decrease with depth? Why do you think this is?

_____

_____

_____

5. How do the measurements at these stations compare to the salinity of your study site?

_____

_____

_____



SonTek would like to sincerely thank the Scripps Institution of Oceanography for its partnership in the development of this curriculum intended for use by high school and university instructors who wish to answer the question "why is the ocean salty" and provide a structured method for using the CastAway-CTD to collect salinity data.

For more information please visit sontek.com/castaway-ctd or contact one of our Application experts at inquiry@sontek.com - we are always here to help!

About Our Contributing Authors



Dr. Todd Martz

Associate Professor of Marine Chemistry in the Geosciences Research Division at Scripps Institution of Oceanography, UC San Diego.

Dr. Martz's research focuses on exploring new methods and technologies for measuring dissolved carbon dioxide in the ocean and adapting these techniques for use on autonomous instrumentation, such as oceanic floats and moorings. His research focuses on observing both short and long term variability of ocean chemistry in order to characterize a variety of biogeochemical processes, such as production and respiration in the open and coastal ocean.



Shannon Waters

Healthy Beaches Manager, Surfrider Foundation

As a graduate student at Scripps Institution of Oceanography, Shannon became interested in the ways that recreational technology can be used to engage audiences in marine chemistry. For her final capstone project, she developed high school educational materials on the subjects of climate change, ocean warming, and ocean acidification. She was hired by Surfrider Foundation in 2016 to lead the development of the Smartfin Program, a citizen science initiative that invites surfers to collect data for oceanographic research. Shannon has recently transitioned into a new role at Surfrider, where she manages the Beach Cleanup Program and advocates for policy measures that address the global plastic pollution problem.

SonTek | 9940 Summers Ridge Rd | San Diego, CA 92121-3091

Tel +1 858.546.8327 | sontek.com

© 2018 SonTek Reserved

xylem
Let's Solve Water