Water, water everywhere,

but is it safe to drink?



An Inquiry-based unit investigating the journey of your drinking water from source to tap

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National Science Foundation WHERE DISCOVERIES BEGIN

Learning Goals

- Different sources of drinking water will contain different contaminants, based on surrounding land uses (guided inquiry activity 1)
- As concentration of disinfectant increases, time needed decreases (lab & guided inquiry activity 2)
- Different water treatment methods can have very different outcomes (lab & guided inquiry activity 3)
- Water treatment must be tailored to the source water (guided inquiry activity 3)
- Experimental design (lab)
- Interpreting data, tables, graphs, diagrams (all 3 guided inquiry activities)
- Observation and analysis of results (lab)

Resources

- Water purification background information
 - Background slides from 2013 WaterWorks teacher workshop, available at: http://faculty.washington.edu/doddm/Personal/WaterWorks_files/WPbackgroundINFO.ppt
 - o <u>http://www.waterbornepathogens.org/</u>
 - o <u>http://ga.water.usgs.gov/edu/waterquality.html</u>
 - o http://www.sodis.ch/methode/forschung/mikrobio/index_EN
- Sentry (great place for looking up ANY public water system on the EPA website) <u>https://fortress.wa.gov/doh/eh/portal/odw/si/Disclaimer.aspx?Page=/portal/odw/si/singlesyste</u> <u>mviews/geninfosinglesys.aspx</u>
- Guided inquiry instructions: <u>http://www.pogil.org/resources/implementation/hspi-implementation-guide</u>

High School Washington State Standards: INQ A, INQB, APPB, APPE, LS2C, ESE1, ESE2

Materials

screendoor screen UV bulb (Steripen) (optional) Safety glasses Fresh chlorine bleach Hot plate	Three square feet of
UV bulb (Steripen) (optional) Safety glasses Fresh chlorine bleach Hot plate	screendoor screen
Safety glasses Fresh chlorine bleach Hot plate	UV bulb (Steripen) (optional)
Fresh chlorine bleach Hot plate	Safety glasses
Hot plate	Fresh chlorine bleach
50 ml arringe	Hot plate
50 mL symge	50 mL syringe

3 Syringe filters (one of each 0.2 um, 1.2 um, 5.0 um) Four 100 mL sterilized beakers 2 Potable Aqua Iodine tablets 2 Potable Aqua ClO₂ tablets Incubator Refrigerator Two 10 mL graduated cylinder

- Per class: ~ 50 nutrient agar plates (or other rich agar) ~ 50 transfer pipette 50 starile bestarie
- ~ 50 sterile bacteria spreaders

Timing

This unit is meant to take 3 days of classroom instruction (about 2+ hours total). We would recommend you start Day 1 on a Friday, allow the lab to run over the weekend, plate results on Monday and analyze on Tuesday. You may also want to extend Day 1 over two days, allowing lab groups to share and critique their designs before implementation.

DAY 1 (Friday)

Pre-assessment: Ask students to spend 3 minutes writing everything they know about water purification. Collect their papers. On the final day, you will be giving them back to the students.



Display the image from: <u>http://www.culture24.org.uk/science-and-nature/animals/art28614</u> of King Cholera dispensing water to children. Caption: Death comes through the water for the people of 19th century London. Courtesy Kew Bridge Steam Museum. For more information, refer to the work of Dr. John Snow.

- Ask students to describe what they see.
- Point out that some microbes in water can kill you quickly.

• Display water from a variety of sources (the tap, after being filtered, a stream or pond, the toilet, smelly water, colored water, etc.)

• Would you drink (this) water? Why or why not? Do you think there are microorganisms present in this water? What would you need to do to this water to make it drinkable?

Begin Water Purification Lab: Today, students should write the lab, and plate their pre-treated water. Groups 1, 2, 5, and 6 should set up their water samples so they have time to sit for 3 days (over the weekend). Groups 3 and 4 may begin their treatment and plating their post-treated water for as many as they have time to do. They may finish this process on day 2 (Monday).

Teacher lab instructions

- Student prerequisite: Students should be able to maintain sterile techniques while transfer using a pipette and using a sterile bacteria spreader. Two great resources for this:
 - o <u>http://www.invitrogen.com/site/us/en/home/References/gibco-cell-culture-basics/aseptic-technique.html</u>
 - o <u>http://www.youtube.com/watch?v=jr4-ye50Za4</u>
- Dirty water can be taken from many sources such as ponds, lakes, rivers, etc. NOT sewer water.
- If you are not able to make your own nutrient agar plates, you may purchase them: <u>http://www.flinnsci.com/store/Scripts/prodView.asp?idproduct=18504</u> Or you may use rich agar from <u>http://www.amazon.com/EZ-BioResearch-Pre-poured-Plates-plates/dp/B004MKHNJK</u>
- Sunlight: a piece of screendoor screen would work to cover one of the bottles.
- UV Steripen is available at <u>http://www.rei.com/product/784449/steripen-safe-water-purifier-system</u> This could be used as a teacher demo of how to design a lab, decide on conditions, plate pre and post treated water. CAUTION: no direct skin exposure and all should wear plastic safety glasses while using the UV steripen.
- Chlorine bleach: provide a 1:10 dilution of newly purchased bleach for student use. Or, you may use calcium hypochlorite if you don't have fresh bleach. (Flinn catalogue # C0348) 0.75 g Ca(OCl)₂: 100 mL water to roughly equal the 1:10 dilution needed for students.

- Syringe filters (all from Whatman): the sterile version is a little pricey. If you have an autoclave, you might consider purchasing non-sterile ones and autoclaving them. If you do not have an autoclave, here is what you want:
 - 10462200 Puradisc 30 Syringe Filter, cellulose acetate, 0.2 μm, sterile, 50/pk (~\$158 on Amazon)
 - 10462260 Puradisc 30 Syringe Filter, cellulose acetate 1.2 μm, sterile, 50/pk (~\$156 on Amazon)
 - 10462000 Puradisc 30 Syringe Filter, cellulose nitrate, 5.0 μm, sterile, 50/pk (~\$144 on Amazon)
- It would be a good idea to rinse the syringe in between treatments.
- For sterile beakers, you may cover with foil and put them in a 400°F oven for at least 4 hours.
- Iodine & ClO₂ tablets
 - The amounts have been calculated based on Potable Aqua tablet information. We advise you use this brand of tablets. Here's their website (iodine is on the left, ClO₂ is on the right): http://www.potableaqua.com/products.php
 - Add 2 Iodine tablets to 100 mL distilled water to create a stock solution. Add 1 ClO₂ tablet to 100 mL distilled water to create a stock solution.
- If you have an advanced group, you might suggest they test the synergistic effects of chlorine bleach plus sunlight.
- We would suggest students plate their pre-treated water and then keep the plates in the refrigerator until they plate their treated water. Both should then be incubated at the same time(37°C for 24 hours) and results can be easily compared on the final day.

Water Purification Lab

What if there was a shortage of drinkable (potable) water and the only water you had available was from an un-trusted source...what would you need to do to the water to be confident enough to drink it? There are a variety of methods of water purification which we can test. Each group will have one variable to test. For each variable, you must test an experimental control (no treatment) and three conditions of your variable. You will need to test the water before and after treatment. Each group will have the following materials:

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
Sunlight	Chlorine bleach	Boiling	Syringe filter	Iodine tablets	ClO ₂ tablets
*400 mL dirty	*400 mL dirty	*10 mL dirty	*400 mL dirty	*400 mL dirty	*400 mL dirty
water	water	water	water	water	water
*A piece of	* 1:10 dilute	*Hot plate	*One syringe	*20 mL Iodine	*20 mL ClO ₂
screen to cover	chlorine bleach	*250 mL beaker	*3 syringe	stock solution	stock solution
bottles	*8 agar plates	*4 centrifuge	filters of	*graduated	*graduated
*Dark drawer	*4 water bottles	tubes	differing pore	cylinder	cylinder
*8 agar plates	(you provide)	*Forceps	sizes	*8 agar plates	*8 agar plates
*4 water bottles	*Pipette &	*Timer	*Four 100 mL	*4 water bottles	*4 water bottles
(you provide)	spreader	*8 agar plates	sterilized	(you provide)	(you provide)
*Pipette &	*3 days of time	*Pipette &	beakers	*Pipette &	*Pipette &
spreader	*Hint: 2 drops,	spreader	*8 agar plates	spreader	spreader
*3 days of time	4 drops, 8	*Hint: 30 sec, 1	*Pipette &	*3 days of time	*3 days of time
	drops	min, 5 min	spreader	*Hint: 2.5mL,	*Hint: 2.5mL,
				5mL, and 10mL	5mL, and 10mL

QUESTION: How do different water treatment methods impact the number of bacteria in a 0.1 mL sample?

YOU get to design this lab. Please start by listing the following in your lab notebook.

- YOUR group's specific question:
- Independent (manipulated) variable:
- Dependent (responding) variable:
- Controlled variables (at least 3):
- What are your three conditions:
- What is your Experimental Control?

Now, explain your experimental design using words and pictures. Include all relevant numerical values.

Conduct your experiment. Collect all the data that you think are important for answering your group's question. Organize your data in a table so they make sense.

ANALYSIS:

- 1. How could you have killed the same number of bacteria but faster?
- 2. If you could, which treatment methods would you combine and why?
- 3. Why don't all people have the same quality of drinking water?

Write a conclusion for this lab.

DAY 2 (Monday)

Today you will have students plate their treated water and incubate ALL plates (the pre-treated water plates that have been in the fridge and the treated water plates) for 24 hours. Groups 3 and 4 should finish their treatments. Then, students will do the guided inquiry activities 1 & 2 (see below). If you are not familiar with how to use guided inquiry activities, please use http://www.pogil.org/resources/implementation/hspi-implementation/hspi-implementation-guide for additional information.

Guided Inquiry Activity 1 resources:

- http://superiorsites3.com/NNS01DrinkingWater.htm
- <u>http://www.groundwater.org/get-informed/groundwater/contamination.html</u>

Guided Inquiry Activity 2 resource:

• EPA CT table: <u>http://water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/upload/2001_01_12_mdbp_profile_benchpt</u> <u>4.pdf</u>

DAY 3 (Tuesday)

Today students should start with the guided inquiry activity 3 (see below). When complete, allow students time to gather their data from the incubating plates and complete the lab.

Post-assessment: Near the end of the period, return student pre-writes. In a different color writing utensil, ask students to cross out anything they no longer agree with and add what they have learned in the past couple of days. Collect after 5 minutes.

Guided Inquiry Activity 3 resources:

- <u>http://www.sodis.ch/methode/forschung/mikrobio/index_EN</u>
- http://www.cdc.gov/healthywater/drinking/travel/backcountry_water_treatment.html

How Does the Location of a Water Source Affect the Presence of Contaminants?

Why?

Most cities and bottled water suppliers draw their drinking water from rivers, lakes, and/or wells. Is it safe to drink the water directly from these sources? Are all sources of drinking water the same? What factors might influence the quality of these water sources? In this activity we will investigate possible ways that drinking water sources might become contaminated then we will consider how drinking water systems might be impacted by different types of contamination.

Use the information from Model 1 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

Model 1

Possible Contaminants in Surface Water Sources

"Surface water" is a term that refers to water that is above the ground level. Water from wells is usually classified as "groundwater."

- 1. Is the water shown in the diagram an example of surface water, groundwater, or some other type of water?
- 2. Circle the section(s) of the river where sediments (gravel, sand, silt) are entering the water.
- 3. List two different contaminants that might enter the river from farmlands.



http://superiorsites3.com/NNS01DrinkingWater.htm

4. List two unique contaminants that might be present in river water if it were taken from the four labeled points on the river.

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Point A	Point B	Point C	Point D

5. Imagine that you are in charge of the Drinking Water Treatment Facility for the city shown in Model 1. You have inlet pipes that draw river water from points **A**, **B**, **C**, and **D**. Which location would you choose to use as your water source? Justify your answer in complete sentences. Include one piece of evidence that supports your choice and one piece of evidence that argues against your choice.



Model 2

Possible Contaminants in Groundwater Sources



http://mail.groundwater.org/gi/images/contamination_diagram.jpg

Use the information from Models 1 and 2 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

- 6. Carefully observe Model 2. <u>Draw a heavy line along the boundary</u> between the surface of the ground and the underground areas. Highlight or lightly shade all of the underground areas depicted in the diagram. Draw hatch marks (///) on top of all the areas where groundwater is shown.
- 7. Circle the well that is drawing water from underground. This is the source of water for the Drinking Water Treatment Facility. Find the building that represents this facility. What is the label written on the diagram next to this facility?
- 8. Carefully observe the differences and similarities between Model 1 and Model 2. Identify two contaminant sources included in Model 2 but missing in Model 1. List them here. Might these contaminants also be a problem for water taken from rivers or lakes? Explain your answer.
- 9. Write one complete sentence that describes the relationship between the location of a water source and the type(s) of treatment needed to produce safe drinking water from that source's water.

Extension Questions

- 10. Using Models 1 and 2, identify 3 5 possible sources of bacterial contamination that might enter either surface water or groundwater sources.
- 11. When providing safe drinking water, one must consider the cost of installing the pipes, pumps, and storage tanks for the treated drinking water as well as the costs of building and operating the Drinking Water Treatment Facility. Describe how these additional costs might influence your choice of the water intake point along the river shore. *Hints: Where do most of the people live along the river in Model 1? Where do most of the people live in the location depicted in Model 2?*

Guided Inquiry Activity 1 KEY

How Does the Location of a Water Source Affect the Presence of Contaminants? (~25 minutes)

Learning Goal: Different sources of drinking water will contain different contaminants, based on surrounding land uses. Why?

Most cities and bottled water suppliers draw their drinking water from rivers, lakes, and/or wells. Is it safe to drink the water directly from these sources? Are all sources of drinking water the same? What factors might influence the quality of these water sources? In this activity we will investigate possible ways that drinking water sources might become contaminated then we will consider how drinking water systems might be impacted by different types of contamination.

Use the information from Model 1 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

Model 1

Possible Contaminants in Surface Water Sources

"Surface water" is a term that refers to water that is above the ground level. Water from wells is usually classified as "groundwater."

- Is the water shown in the diagram an example of surface water, groundwater, or some other type of water? *Surface*
- 2. Circle the section(s) of the river where sediments (gravel, sand, silt) are entering the water.
- 3. List two different contaminants that might enter the river from farmlands. *Livestock waste, Fertilizer*



reprinted with permission from *Is Our Water Safe to Drink?* by J. Gordon Millichap, MD http://superiorsites3.com/NNS01DrinkineWater.htm 4. List two unique contaminants that might be present in river water if it were taken from the four labeled points on the river.

Point A	Point B	Point C	Point D	
Silt Mining Pollutants Septic	Pesticides s Landfill Industrial	Livestock. Industrial Fertilizer Runoff	Pesticide Industrial Urban Sewage Oil	

5. Imagine that you are in charge of the Drinking Water Treatment Facility for the city shown in Model 1. You have inlet pipes that draw river water from points **A**, **B**, **C**, and **D**. Which location would you choose to use as your water source? Justify your answer in complete sentences. Include one piece of evidence that supports your choice and one piece of evidence that argues against your choice.

If you draw water from point A, you would be dealing with 3 contaminants. If you draw from points B-D, you are dealing with those 3 initial contaminants as well as more contaminants. This is not only potentially harmful, but it can be costly to remove.

Model 2

Possible Contaminants in Groundwater Sources



http://mail.groundwater.org/gi/images/contamination_diagram.jpg

Use the information from Models 1 and 2 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

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- 6. Carefully observe Model 2. <u>Draw a heavy line along the boundary</u> between the surface of the ground and the underground areas. Highlight or lightly shade all of the underground areas depicted in the diagram. Draw hatch marks (///) on top of all the areas where groundwater is shown.
- 7. Circle the well that is drawing water from underground. This is the source of water for the Drinking Water Treatment Facility. Find the building that represents this facility. What is the label written on the diagram next to this facility? Municipal Water Supply Plant
- Carefully observe the differences and similarities between Model 1 and Model 2. Identify two contaminant sources included in Model 2 but missing in Model 1. List them here. Might these contaminants also be a problem for water taken from rivers or lakes? Explain your answer.
 Acid Rain and hazardous waste dumpsite are missing from Model 1. Yes, acid rain will fall into rivers and lakes; hazardous waste can leach into the groundwater that feeds rivers and lakes.
- 9. Write one complete sentence that describes the relationship between the location of a water source and the type(s) of treatment needed to produce safe drinking water from that source's water. *Treatment of a water source needs to be tailored for the contaminants from that point of entry as well as other contaminants upstream from that water source, acid rain, and underground contaminants in a well.*

Extension Questions



10. Using Models 1 and 2, identify 3 – 5 possible sources of bacterial contamination that might enter either surface water or groundwater sources.

Septic tank, livestock waste, urban wastes, manure

11. When providing safe drinking water, one must consider the cost of installing the pipes, pumps, and storage tanks for the treated drinking water as well as the costs of building and operating the Drinking Water Treatment Facility. Describe how these additional costs might influence your choice of the water intake point along the river shore. *Hints: Where do most of the people live along the river in Model 1? Where do most of the people live in the location depicted in Model 2?*

In model 1, most of the people live downstream from the contaminants. This would require extensive and costly treatment of all the contaminants. The Drinking Water Treatment Facility would be best upstream from all contaminants. In model 2, most people live upstream from the facility. The water supply plant still has to account for and treat urban runoff as it could be present in the groundwater flow as contamination migrates towards the well.

Assessment Questions for Activity #1

- 1. Explain the difference between surface water and groundwater.
- 2. List three different contaminants that might commonly be found in river water. (Base your answer on the diagrams you have interpreted, not on your outside knowledge.)

- **3.** Imagine a river system that starts as a mountain stream and heads down to the ocean. Where would you be most likely to find the most different types of contaminants present in the river water?
 - a. In the mountains where lots of sediments enter.
 - b. Midway along the length of the river, where many farms are located.
 - c. At the mouth of the river, where it meets the ocean.

Write one sentence to support your answer to #3.

KEY: Assessment Questions for Activity #1

1. Explain the difference between surface water and groundwater.

Surface water refers to water from streams, rivers, lakes, and other places above the ground level; groundwater refers to water that has seeped from the surface to underground areas.

2. List three different contaminants that might commonly be found in river water. (Base your answer on the diagrams you have interpreted, not on your outside knowledge.)

May include any answers labeled in Model 1.

- 3. Imagine a river system that starts as a mountain stream and heads down to the ocean. Where would you be most likely to find the most different types of contaminants present in the river water?
- a. In the mountains where lots of sediments enter.
- b. Midway along the length of the river, where many farms are located.
- c. At the mouth of the river, where it meets the ocean.

Write one sentence to support your answer to #3.

c, The farther the water travels along the river, the more contaminants are added. Since contaminants added in the upstream sections of the river are still there when more contaminants are added from the middle and lower sections of the river, by the time the water has reached the ocean it may have lots of different types of contaminants in it.

How can you ensure that your drinking water will not contain harmful microorganisms?

Disinfecting Drinking Water Sources

Why?

There are many microorganisms (protozoa, bacteria, viruses) that can make us sick if we consume them in our drinking water. Obviously, Drinking Water Treatment Facilities are in the business of *treating* water from surface or underground sources to ensure that their consumers are not infected and sickened by these microorganisms. In this activity we will investigate some of the basic concepts of disinfection. We will also compare the effectiveness of a variety of treatment processes to determine the best treatment process(es) for specific types of microorganisms.

Use the information from Model 1 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

Model 1 How well one disinfectant works to kill one type of protozoan (*Giardia*)

CT Values for Inactivation of Giardia Cysts by Chlorine Dioxide, pH 6.0-9.0

	Temperature (°C)																								
% Inactivated	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
90	21.0	17.9	14.9	11.8	8.7	8.5	8.3	8.1	7.9	7.7	7.4	7.1	6.9	6.6	6.3	6.0	5.8	5.5	5.3	5.0	4.7	4.5	4.2	4.0	3.7
99	42.0	35.8	29.5	23.3	17.0	16.6	16.2	15.8	15.4	15.0	14.6	14.2	13.8	13.4	13.0	12.4	11.8	11.2	10.6	10.0	9.5	8.9	8.4	7.8	7.3
99.9	63.0	53.8	44.5	35.3	26.0	25.4	24.8	24.2	23.6	23.0	22.2	21.4	20.6	19.8	19.0	18.2	17.4	16.6	15.8	15.0	14.2	13.4	12.6	11.8	11.0

1. Model 1 presents experimental data related to one particular microorganism. What is the name of this microorganism ?

- 2. Model 1 presents experimental data related to one particular chemical disinfectant. What is the name of this disinfectant ?
- 3. What is the temperature range over which experimental data were collected?
- 4. The experimental results are valid for which range of pH conditions? Circle your answer.

pH1-pH6 $pH6-pH9$ $pH9-pH14$ all $pHva$	values from $1 - 1$	4
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5. One measure of how well a particular disinfectant kills off microorganisms is called "% Inactivation." Write one sentence that describes what it must mean to "inactivate" a microorganism.

- 6. Imagine that your water sample includes 100 of the microorganisms before it is treated with disinfectant. How many of the organisms will survive in the sample if the disinfectant efficiency is 99% inactivation?
- 7. Model 1 introduces a term called "**CT** value." This is a calculated value not a characteristic that is directly measured experimentally. This value represents two different variables.

C = concentration of disinfectant (reported in mg/L)

 \mathbf{T} = time of exposure to disinfectant (reported in minutes)

The unit of the CT value is (mg/L)•min

Using your knowledge of algebra, what mathematical operation must be used to calculate the CT value?

Circle your answer(s) and explain your reasoning.

 $C + T \qquad C - T \qquad C \times T \qquad C \bullet T \qquad C \div T \qquad C / T$

Use the numerical data in Model 1 to answer questions # 8 - 10.

- 8. What is the CT value required to inactivate 90% of *Giardia* cysts if the water sample temperature is 10°C?
- 9. As the temperature of the water sample increases, what happens to the CT value required to inactivate 90% of *Giardia* cysts? Circle your answer.

CT increases as temperature increases

CT decreases as temperature increases

CT does not respond to temperature changes

Relationship cannot be determined

10. You are the manager of a Drinking Water Treatment Facility. Unfortunately, the source water entering your facility contains *Giardia* cysts. You are responsible to design a treatment process that will inactivate 99% of *Giardia* cysts in the incoming water supply. What is the CT value required to inactivate 99% of *Giardia* cysts if the water sample temperature is 20°C?

If you use a chlorine dioxide disinfectant with a concentration (C) of 2mg/L, how many minutes (T) will you need to expose the sample of water to the disinfectant before the water will be safe to drink?

Show the setup of your calculations. Include the correct unit in your final answer.

STOP

If your facility can only expose water to disinfectant for 2 minutes, what concentration of disinfectant must you use? Show the setup of your calculations. Include the correct unit in your final answer.

- Based on your answers to #10, circle the true statement:
 To inactivate the same % of microorganisms in water samples of the same temperature,
- a. as the concentration of disinfectant increases, the time the sample must be exposed also increases.
- b. as the concentration of disinfectant increases, the time the sample must be exposed decreases.
- c. There is no way to define a relationship between concentration of disinfectant and exposure time.

Extension Questions

- 12. You are managing a water treatment facility along the Clearwater River that successfully inactivates 99% of the microorganisms entering the plant. Your standard process includes exposing the river water to a 0.5 mg/L concentration of chlorine for 30 minutes. Calculate the CT value for your treatment process. Show the setup.
- 13. As the manager of the Clearwater River Treatment Facility (see #12), you have a new challenge. Your town is sponsoring a concert that will double the population for a week. As a result, your facility will need to process twice as much water each day. Describe in 2-3 sentences how you will alter your treatment process to accommodate the additional demand for safe drinking water.

How can you ensure that your drinking water will not contain harmful microorganisms?

Disinfecting Drinking Water Sources (~20 minutes)

Why?

There are many microorganisms (protozoa, bacteria, viruses) that can make us sick if we consume them in our drinking water. Obviously, Drinking Water Treatment Facilities are in the business of *treating* water from surface or underground sources to ensure that their consumers are not infected and sickened by these microorganisms. In this activity we will investigate some of the basic concepts of disinfection. We will also compare the effectiveness of a variety of treatment processes to determine the best treatment process(es) for specific types of microorganisms.

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99	42.0	35.8	29 .5	23.3	17.0	16.6	16.2	15.8	15.4	15.0	14.6	14.2	13.8	13.4	13.0	12.4	11.8	11.2	10.6	10.0	9.5	8.9	8.4	7.8	7.3
99.9	63.0	53.8	44.5	35.3	26.0	25.4	24.8	24.2	23.6	23.0	22.2	21.4	20.6	19.8	19.0	18.2	17.4	16.6	15.8	15.0	14.2	13.4	12.6	11.8	11.0

1. Model 1 presents experimental data related to one particular microorganism. What is the name of this microorganism ?

Giardia

2. Model 1 presents experimental data related to one particular chemical disinfectant. What is the name of this disinfectant ?

Chlorine Dioxide

- 3. What is the temperature range over which experimental data were collected? 1-25 *C
- 4. The experimental results are valid for which range of pH conditions? Circle your answer.

pH 1 – pH 6 pH 6 – pH 9 pH 9 – pH 14 all pH values from 1 –	14
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pH 6 – pH 9

 One measure of how well a particular disinfectant kills off microorganisms is called "% Inactivation." Write one sentence that describes what it must mean to "inactivate" a microorganism. To inactivate an organism means to make them unable to reproduce; therefore, they cannot infect.

- 6. Imagine that your water sample includes 100 of the microorganisms before it is treated with disinfectant. How many of the organisms will survive in the sample if the disinfectant efficiency is 99% inactivation? One organism
- 7. Model 1 introduces a term called "**CT** value." This is a calculated value not a characteristic that is directly measured experimentally. This value represents two different variables.
 - C = concentration of disinfectant (reported in mg/L)

 \mathbf{T} = time of exposure to disinfectant (reported in minutes)

The unit of the CT value is (mg/L)•min

Using your knowledge of algebra, what mathematical operation must be used to calculate the CT value?

Circle your answer(s) and explain your reasoning.

C + TC - T $C \times T$ $C \cdot T$ $C \cdot T$ C/T $C \times T$ and/or $C \cdot T$ $C \cdot T$ STOP

Use the numerical data in Model 1 to answer questions # 8 - 10.

- What is the CT value required to inactivate 90% of *Giardia* cysts if the water sample temperature is 10°C?
 CT =7.7
- 9. As the temperature of the water sample increases, what happens to the CT value required to inactivate 90% of *Giardia* cysts? Circle your answer.

CT increases as temperature increases

CT decreases as temperature increases

CT does not respond to temperature changes

Relationship cannot be determined

CT decreases as temperature increases

10. You are the manager of a Drinking Water Treatment Facility. Unfortunately, the source water entering your facility contains *Giardia* cysts. You are responsible to design a treatment process that will inactivate 99% of *Giardia* cysts in the incoming water supply. What is the CT value required to inactivate 99% of *Giardia* cysts if the water sample temperature is 20°C?

If you use a chlorine dioxide disinfectant with a concentration (C) of 2mg/L, how many minutes (T) will you need to expose the sample of water to the disinfectant before the water will be safe to drink?

Show the setup of your calculations. Include the correct unit in your final answer. $C \times T = CT$

 $2mg/L \times Min = 10 mg/L \cdot min$ $10mg/L \cdot min \div 2 mg/L = 5 minutes$ T = 5mins If your facility can only expose water to disinfectant for 2 minutes, what concentration of disinfectant must you use? Show the setup of your calculations. Include the correct unit in your final answer.

 $C \times T = CT$ $C \times 2 \min = 10 mg/L \cdot \min$ C = 5 mg/L

- 11. Based on your answers to #10, circle the true statement:To inactivate the same % of microorganisms in water samples of the same temperature,
- a. as the concentration of disinfectant increases, the time the sample must be exposed also increases.



- b. as the concentration of disinfectant increases, the time the sample must be exposed decreases.
- c. There is no way to define a relationship between concentration of disinfectant and exposure time.

b. as the concentration of disinfectant increases, the time the sample must be exposed decreases

Extension Questions

12. You are managing a water treatment facility along the Clearwater River that successfully inactivates 99% of the microorganisms entering the plant. Your standard process includes exposing the river water to a 0.5 mg/L concentration of chlorine for 30 minutes. Calculate the CT value for your treatment process. Show the setup.

0.5 mg/LX 30 min = 15 mg/L min

13. As the manager of the Clearwater River Treatment Facility (see #12), you have a new challenge. Your town is sponsoring a concert that will double the population for a week. As a result, your facility will need to process twice as much water each day. Describe in 2-3 sentences how you will alter your treatment process to accommodate the additional demand for safe drinking water.

We will need to double the concentration to 1 mg/L if the water will only have half as much time:

1 mg/LX 15 min = 15 mg/L min

Assessment Questions for Activity #2

- 1. What is the meaning of the term 90% Inactivation?
 - a. Microorganisms are killed off 90% of the time when the treatment plant is operating.
 - b. Each microorganism sustains damage to 90% of if its cell wall.
 - c. The treatment facility is operating only 90% of the time.
 - d. 90% of the microorganism in a sample of water are killed off.
 - e. None of the above

- 2. When environmental engineers calculate the CT value to determine the efficiency of a disinfection process, the variables in the C•T equation represent:
 - a. C = concentration of disinfectant and T = time of exposure
 - b. C = chlorine and T = temperature of water
 - c. C =concentration of disinfectant and T = temperature of water
- 3. Describe how the CT value changes as the temperature of water changes.

Assessment Questions for Activity #2

- 1. What is the meaning of the term 90% Inactivation?
 - a. Microorganisms are killed off 90% of the time when the treatment plant is operating.
 - b. Each microorganism sustains damage to 90% of if its cell wall.
 - c. The treatment facility is operating only 90% of the time.
 - d. 90% of the microorganism in a sample of water are killed off.
 - e. None of the above
- 2. When environmental engineers calculate the CT value to determine the efficiency of a disinfection process, the variables in the C•T equation represent:
 - a. C = concentration of disinfectant and T = time of exposure
 - b. C = chlorine and T = temperature of water
 - c. C = concentration of disinfectant and T = temperature of water
- 3. Describe how the CT value changes as the temperature of water changes. *The CT values decreases as the water temperature increases.*

How can you match water treatment processes to the microorganisms present in specific water sources?

Optimizing Drinking Water Treatment Facilities

Why?

Any water source, whether surface water or groundwater, may be contaminated with microorganisms that can cause human illnesses. It is prohibitively expensive and energy intensive for any one Drinking Water Treatment Facility to incorporate all of the available treatments to ensure protection against all microorganisms. In this activity, you will evaluate the effectiveness of different treatment processes to inactivate different types of microorganisms (protozoans, bacteria, and viruses). Then you will use all of your knowledge of disinfection techniques to design a cost-effective treatment facility to protect against a specific set of microorganisms present in one water source.

Model 1

Relative Effectiveness of Three Water Disinfectant Processes



Figures from Crittenden et al. (MWH), 2005

Use the information from Model 1 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

- 1. What range of CT values does Model 1 include? (Recall that the unit for CT values is (mg/L)•minutes)
- 2. What three disinfection processes does Model 1 include?
- 3. What % Inactivation of microorganisms do the data represent? Circle your answer.

90%	99%	99.9%	99.99%	cannot be	determined	from	the c	data
2070	///0	////0	///////////////////////////////////////	eannot be	acterimited	110111	une (aucu

- 4. List three types of viruses included in the experimental data presented in Model 1. *Hint: Look carefully at the names of all the organisms.*
- 5. List one different type of bacterium included in the data in Model 1.
- 6. *C. Parrum* infection causes nasty diarrhea. If you want to use Free Chlorine (such as bleach) as your disinfectant, approximately what CT value must be used to inactivate 99% of the *C. parrum* bacteria in a water sample?
- 7. Poliovirus infection can cause permanent paralysis or death. If you want to use Free Chlorine (such as bleach) as your disinfectant, approximately what CT value must be used to inactivate 99% of the poliovirus particles in a water sample?
- 8. Discuss the meaning of the two CT values you identified in questions #6 and #7. Is Free Chlorine equally effective as a disinfectant for *C. parvum* and poliovirus?

Explain your answer, citing evidence from Model 1.

STOP

9. *M. fortuitum* can cause lung, heart, and nervous system infections. Which would be a better disinfectant to inactivate 99% of the *M. fortuitum* in a water sample – Free Chlorine or Chlorine Dioxide? Explain your answer.

Read This!

UV light is considered a disinfectant, even though it is not a chemical. We cannot determine a concentration for light, so instead of a CT value we use a calculated value called IT. The I represents the amount of irradiation and the T still represents the exposure time. You will see this value included on some tables of disinfectant data.

- 10. Considering only the three disinfectants included in Model 1, which disinfectant is best for inactivating adenovirus? Explain your answer.
- Circle the ending which makes the following statement true. Disinfectants can be weak or strong for a particular microorganism. For a weak disinfectant,
- a. you need a low CT value to ensure 99% inactivation of a specific type of microorganism.
- b. you need a higher CT value to ensure 99% inactivation of a specific type of microorganism.
- c. you cannot determine the CT value needed to ensure 99% inactivation of a specific type microorganism.



Model 2 Relative Effectiveness of Seven Water Disinfectant Processes

Treatment		<u>Microorganisms</u>									
Process	Viruses	Bacteria	Protozoans								
Free chlorine	Very effective	Very effective	Less effective								
Chlorine dioxide	Effective	Very effective	Effective								
lodine	Effective	Effective	Not effective								
UV light	Effective	Very effective	Very effective								
Natural sunlight	Effective	Effective	Less effective								
Boiling	Very effective	Very effective	Very effective								
Membrane Filtration	Variably effective	Very effective	Very effective								

For more details see: http://www.sodis.ch/methode/forschung/mikrobio/index_EN and http://www.cdc.gov/healthywater/drinking/travel/backcountry_water_treatment.html

Use the information from Model 2 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

12. Which three of the disinfectants in Model 1 are chemical disinfectants? Which four are physical disinfectants? Chemical disinfectants:

Physical disinfectants:

13. You are part of an environmental engineering consulting team. You have been hired by the town of Springfield to design a Drinking Water Treatment Facility. The town draws its water from the Muddybanks River. Microbiological testing has documented the presence of the following pathogens in the river water. Please recommend the most cost effective series of disinfectant processes that will ensure the health of townspeople who drink the treated water. You may assume that the fewer the processes included, the lower the cost of the facility. **However, the facility does not have the capacity to boil the water it treats, due to energy costs.**

Use information from **Model 1** to fill in the table below.

Name of microorganism	Type of microorganism	Name of recommended disinfection
E. coli	bacterium	
Hepatitis A	virus	
Giardia	protozoan	

- 14. Circle the one most valid statement, based on your overall understanding of water contaminants, disinfection processes, and the relative effectiveness of particular disinfectants for specific microorganisms. The statement must be supportable based on evidence from the Models you have analyzed.
 - a. If one city has a Drinking Water Treatment Facility that effectively provides safe drinking water for its residents, you can use the same design for any city's drinking water supply.
 - b. The water treatment processes used in a Drinking Water Treatment Facility must be carefully tailored to the characteristics of the water source that feeds the facility.
 - c. Since viruses are so tiny compared to bacteria and protozoans, you can simply use a treatment process that inactivates viruses. The bacteria and protozoa will automatically be inactivated, too.
 - d. Larger cities will always have better quality drinking water than smaller towns or individual homeowner well systems.

Extension Questions

15. What would be the most difficult combination of three microorganisms to effectively inactivate in a Drinking Water Treatment Facility? Justify your answer by citing specific evidence from Models 1 and 2.

How can you match water treatment processes to the microorganisms present in specific water sources? (~35 min)

Optimizing Drinking Water Treatment Facilities

Learning goal: Different microorganisms require different disinfection processes.

Why?

Any water source, whether surface water or groundwater, may be contaminated with microorganisms that can cause human illnesses. It is prohibitively expensive and energy intensive for any one Drinking Water Treatment Facility to incorporate all of the available treatments to ensure protection against all microorganisms. In this activity, you will evaluate the effectiveness of different treatment processes to inactivate different types of microorganisms (protozoans, bacteria, and viruses). Then you will use all of your knowledge of disinfection techniques to design a cost-effective treatment facility to protect against a specific set of microorganisms present in one water source.

Model 1

Relative Effectiveness of Three Water Disinfectant Processes



Figures from Crittenden et al. (MWH), 2005

Use the information from Model 1 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

- What range of CT values does Model 1 include? (Recall that the unit for CT values is (mg/L)•minutes) 0.01-10,000 mg/L•min
- 2. What three disinfection processes does Model 1 include? *Free Chlorine, Chlorine Dioxide, UV Light*
- 3. What % Inactivation of microorganisms do the data represent? Circle your answer.

90%	99%	99.9%	99.99%	cannot be determined from the data
2070	///	· · · · · · ·		earniet se determined from the data

99%

4. List three types of viruses included in the experimental data presented in Model 1. *Hint: Look carefully at the names of all the organisms*.

Adenovirus, Hepatitis A, Calicivirus, Reovirus, Rotavirus, Poliovirus

- 5. List one different type of bacterium included in the data in Model 1. *E. coli, Legionella, M. fortuitum,*
- 6. C. Parrum infection causes nasty diarrhea. If you want to use Free Chlorine (such as bleach) as your disinfectant, approximately what CT value must be used to inactivate 99% of the C. parrum bacteria in a water sample? CT= 5,000
- Poliovirus infection can cause permanent paralysis or death. If you want to use Free Chlorine (such as bleach) as your disinfectant, approximately what CT value must be used to inactivate 99% of the poliovirus particles in a water sample? 10-20
- 8. Discuss the meaning of the two CT values you identified in questions #6 and #7. Is Free Chlorine equally effective as a disinfectant for *C. parvum* and poliovirus?

Explain your answer, citing evidence from Model 1.

Free Chlorine is more effective as a disinfectant for poliovirus with a CT value of 10-20 whereas C. parvum requires a CT of 5,000.

STOP

9. *M. fortuitum* can cause lung, heart, and nervous system infections. Which would be a better disinfectant to inactivate 99% of the *M. fortuitum* in a water sample – Free Chlorine or Chlorine Dioxide? Explain your answer.

Chlorine dioxide would be more effective at inactivating M. fortuitum because it requires a CT of 1-11, but free chlorine requires a CT of 100-1000.

Read This!

UV light is considered a disinfectant, even though it is not a chemical. We cannot determine a concentration for light, so instead of a CT value we use a calculated value called IT. The I represents the amount of irradiation and the T still represents the exposure time. You will see this value included on some tables of disinfectant data.

10. Considering only the three disinfectants included in Model 1, which disinfectant is best for inactivating adenovirus? Explain your answer.

Free Chlorine is best at inactivating Adenovirus with a CT of 0.01-0.15

11. Circle the ending which makes the following statement true. Disinfectants can be weak or strong for a particular microorganism.

For a weak disinfectant,

- a. you need a low CT value to ensure 99% inactivation of a specific type of microorganism.
- b. you need a higher CT value to ensure 99% inactivation of a specific type of microorganism.
- c. you cannot determine the CT value needed to ensure 99% inactivation of a specific type microorganism.

b. you need a higher CT value to ensure 99% inactivation of a specific type of microorganism.

Model 2

Relative Effectiveness of Seven Water Disinfectant Processes

<u>Treatment</u>	<u>Microorganisms</u>				
<u>Process</u>	Viruses	Bacteria	Protozoans		
Free chlorine	Very effective	Very effective	Less effective		
Chlorine dioxide	Effective	Very effective	Effective		
lodine	Effective	Effective	Not effective		
UV light	Effective	Very effective	Very effective		
Natural sunlight	Effective	Effective	Less effective		
Boiling	Very effective	Very effective	Very effective		
Membrane Filtration	Variably effective	Very effective	Very effective		

For more details see: <u>http://www.sodis.ch/methode/forschung/mikrobio/index_EN</u> and <u>http://www.cdc.gov/healthywater/drinking/travel/backcountry_water_treatment.html</u>

Use the information from Model 2 to answer the following questions. Be sure you have reached a consensus with your group before you write down any answers.

12. Which three of the disinfectants in Model 1 are chemical disinfectants? Which four are physical disinfectants? Chemical disinfectants:

Free Chlorine, Chlorine Dioxide, Iodine

Physical disinfectants:

UV Light, natural sunlight, boiling, membrane filtration

13. You are part of an environmental engineering consulting team. You have been hired by the town of Springfield to design a Drinking Water Treatment Facility. The town draws its water from the Muddybanks River. Microbiological testing has documented the presence of the following pathogens in the river water. Please recommend the most cost effective series of disinfectant processes that will ensure the health of townspeople who drink the treated water. You may assume that the fewer the processes included, the lower the cost of the facility. **However, the facility does not have the capacity to boil the water it treats, due to energy costs.**

Use information from Model 1 to fill in the table below.

Name of	Type of	Name of recommended disinfection	
microorganism	microorganism	treatment process	
E. coli	bacterium	Free chlorine then UV light	
Hepatitis A	virus	Free Chlorine then UV l ight	
Giardia	protozoan	UV Light	

14. Circle the one most valid statement, based on your overall understanding of water contaminants, disinfection processes, and the relative effectiveness of particular disinfectants for specific microorganisms. The statement must be supportable based on evidence from the Models you have analyzed.

- a. If one city has a Drinking Water Treatment Facility that effectively provides safe drinking water for its residents, you can use the same design for any city's drinking water supply.
- b. The water treatment processes used in a Drinking Water Treatment Facility must be carefully tailored to the characteristics of the water source that feeds the facility.
- c. Since viruses are so tiny compared to bacteria and protozoans, you can simply use a treatment process that inactivates viruses. The bacteria and protozoa will automatically be inactivated, too.
- d. Larger cities will always have better quality drinking water than smaller towns or individual homeowner well systems.

b. The water treatment processes used in a Drinking Water Treatment Facility must be carefully tailored to the characteristics of the water source that feeds the facility.

Extension Questions

15. What would be the most difficult combination of three microorganisms to effectively inactivate in a Drinking Water Treatment Facility? Justify your answer by citing specific evidence from Models 1 and 2.

Answers may vary C. parvum, Legionella, and Giardia would be the most difficult to treat as a higher CT is required with both free chlorine and chlorine dioxide. Free Chlorine is less effective at treating protozoans. UV light is very effective at treating both bacteria and protozoans with lower CT values.

Assessment Questions for Activity #3

1. Circle the most valid statement based on your overall understanding of water contaminants and disinfection processes.

a. *C. parvum* is a difficult microorganism to treat because it requires a higher CT value to achieve 99% inactivation with free chlorine and chlorine dioxide.

b. *C. parvum* is a difficult microorganism to treat because it requires a lower CT value to achieve 99% inactivation with free chlorine and chlorine dioxide.

c. *C. parvum* has the same CT value as all other microorganisms in the presence of free chlorine and chlorine dioxide.

2. What are the most effective physical treatment processes to disinfect microorganisms?

3. Consider how clean your water is and how accessible clean water is around the world. Write a 3-5 sentence explanation of why water borne pathogens are more prevalent in third world countries.

Assessment Questions for Activity #3 Answers

1. Circle the most valid statement based on your overall understanding of water contaminants and disinfection processes.

a. *C. parvum* is a difficult microorganism to treat because it requires a higher CT value to achieve 99% inactivation with free chlorine and chlorine dioxide.

b. *C. parvum* is a difficult microorganism to treat because it requires a lower CT value to achieve 99% inactivation with free chlorine and chlorine dioxide.

c. *C. parvum* has the same CT value as all other microorganisms in the presence of free chlorine and chlorine dioxide.

a. C. parvum is a difficult microorganism to treat because it requires a higher CT value to achieve 99% inactivation with free chlorine and chlorine dioxide.

2. What are the most effective physical treatment processes to disinfect microorganisms?

Boiling and UV light

3. Consider how clean your water is and how accessible clean water is around the world. Write a 3-5 sentence explanation of why water borne pathogens are more prevalent in third world countries.

Answers will vary

Extension

Possible Extension/Enrichment Projects

Exploring the Water Treatments Used for Each Student's Home Drinking Water

Using the Washington State Department of Health website Sentry database, students:

a. identify the source of their home drinking water

b. identify the contaminants present in the source water

c. list the treatment processes used on their drinking water

d. identify the exceedances for the past year (times when contaminant levels exceeded allowable levels

e. report to the class on their findings

Exploring the Availability of Safe Drinking Water to People Around the World

Students :

a. choose one "developed" and one "undeveloped" country from around the world

b. predict the % of people in that country who have access to treated drinking water

c. compare their predictions to the WHO website data at this

site:http://gamapserver.who.int/gho/interactive_charts/mdg7/atlas.html?indicator=i0&date=2011



Alternately, students can work in small groups to color in a map of the world to show their predictions of the % of people in different regions who have access to treated drinking water. If they use this color key, they can directly compare to the WHO website.

	Percentage of population with access
Color	to improved drinking water sources
Dark orange	<50% of population
Pale orange	50 - 74%
Pale blue	75 - 90%
Dark blue	>90%
white	No data available