Parts Per Million

Adapted from: "Reaching Your Limits" in Project WET: Curriculum & Activity Guide. Bozeman: The Watercourse and the Council for Environmental Education, 1995.

Grade Level: basic

Duration: 30 minutes

Setting: classroom or laboratory

Summary: Students observe demonstrations about how much one part per million (ppm) is.

Objectives: Students will examine water quality standards, concentrations, dilution, and understand the concept of parts per million and milligrams per liter.

Related Module Resources:

- PA Code Chapter 16. Water Quality Toxics Management Strategy – Statement of Policy
- PA Code Chapter 93. Water Quality Standards
- PA Code Chapter 96. Water Quality Standards Implementation
- National Primary Drinking Water Standards
- National Secondary Drinking Water Standards
- The ABC's of Environmental Regulation

Vocabulary: MCL, MCLG, ppm (parts per million), dilution

Materials (Included in Module):

- blue or green food coloring [Main Box]
- 6 plastic cups coloring [Main Box]
- wet erase marker coloring [Main Box]
- 1 part per thousand (ppt) visual aid sheet and overhead
- 1 part per million (ppm) visual aid sheet (50,000 circles)
- Water Quality Standards:
  -"Drinking Water Facts: Water Quality Standards"
  -"Pennsylvania Department of Environmental Protection Division of Drinking Water Management Maximum Contaminant Levels (MCLs)"
  -"National Recommended Water Quality Criteria: 2002"
  -"Table 1: Water Quality Criteria for Toxic Substances"

Additional Materials (NOT Included in Module):

- One 10ml graduate cylinder
- One 100ml or 250 ml beaker
- Overhead projector

ACADEMIC STANDARDS

ENVIRONMENT & ECOLOGY

7th Grade

4.1.7.C. Explain the effects of water on the life of organisms in a watershed.
- Explain how water is necessary for all life.

4.3.7.A. Identify environmental health issues.
- Identify various examples of long-term pollution and explain their effects on environmental health.
- Identify diseases that have been associated with poor environmental quality.

4.9.7.A. Explain the role of environmental laws and regulations.
- Identify and explain environmental laws and regulations (e. g., Clean Air Act, Clean Water Act, Recycling and Waste Reduction Act, Act 26 on Agricultural Education).
- Explain the role of local and state agencies in enforcing environmental laws and regulations (e. g., Department of Environmental Protection, Department of Agriculture, Game Commission).

10th Grade

4.3.10.A. Describe environmental health issues.
- Identify the effects on human health of air, water and soil pollution and the possible economic costs to society.

4.9.10.B. Explain why environmental laws and regulations are developed and enacted.
- Analyze the roles that local, state and federal governments play in the development and enforcement of environmental laws.
- Identify local and state environmental regulations and their impact on environmental health.

12th Grade

4.9.12.A. Analyze environmental laws and regulations as they relate to environmental issues
- Research and describe the effects of an environmental law or regulation and how it has impacted the environment.

SCIENCE & TECHNOLOGY

7th Grade

3.1.7.D. Explain scale as a way of relating concepts and ideas to one another by some measure.
- Apply various applications of size and dimensions of scale to scientific, mathematical and technological applications

10th Grade

3.1.10.D. Apply scale as a way of relating concepts and ideas to one another by some measure.
- Convert one scale to another.

BACKGROUND:

There are many organizations and citizen monitoring groups like Creek Connections that monitor water quality. In addition, federal government agencies such as the U.S. Environmental Protection Agency (EPA) and many state protection agencies, such as the Pennsylvania Department of Environmental Protection (DEP) monitor water quality to maintain safe drinking water. Water quality is also important for healthy ecosystems so that fish, frogs and blue herons can

thrive. Often water quality is measured by the presence or absence of chemicals in the water.

Animals and plants that live in aquatic ecosystems can only survive under certain chemical conditions. In other words, they have a range of tolerance when they are healthiest. Changes above or below the tolerance levels can cause the plants and animals to relocate or simply die out. Also, humans have ranges of tolerance for this same water that we might have to drink, swim in, or fish in. With this in mind, standards have been developed to identify water bodies that have improper chemical levels or contain dangerous levels of toxins.

Water quality standards are important for a number of reasons. The levels of numerous water quality parameters affect how healthy and safe water is for humans to drink and for aquatic life to live in. The EPA has passed federal regulations regarding the maximum and recommended contaminant levels of numerous chemicals, compounds, metals and solids in drinking water and surface water throughout the US. These standards are part of the Clean Water Act, the Safe Drinking Water Act and the Water Pollution Prevention Act. All states must uphold these minimum standards; however, state agencies, such as the Pennsylvania Department of Environmental Protection, that wish to implement more stringent regulations are able to do so. State standards may not be less rigorous than the national standards.

The safety of our drinking water is maintained by the drinking water standards established by the EPA, DEP, and other state agencies. These standards list specific, enforceable **Maximum Contaminant Levels (MCLs)** for each drinking water quality parameter. [See "Drinking Water Facts Water Quality Standards" (federal drinking water standards) and "Pennsylvania Department of Environmental Protection Division of Drinking Water Management Maximum Contaminant Levels (MCLs)" (state drinking water standards) at the end of this section.] MCLs are the maximum level of a given contaminant allowed by law in drinking water. In addition to MCLs, the EPA and some states have set **Maximum Contaminant Level Goals (MCLGs)**. Although MCLGs are not enforceable, they are target levels of contaminants at which humans experience no adverse effects. MCLs are set to be as close to MCLGs as possible. A feasible MCL is based upon the practicality of establishing and maintaining a specific level of contaminant. Treatment technology and the cost of removing a contaminant may determine the feasibility of maintaining a contaminant level. Although MCLs may not always meet the optimal MCLGs, MCLs are established so that humans are receiving a safe dose of the contaminant.

Contaminant levels that are significantly higher than the MCL are known to cause cancer, kidney effects, and other serious health problems in humans. For example, the MCL for nitrate in drinking water is 10 mg/L in both the national and Pennsylvania regulations. Nitrate levels above 10 mg/L are known to cause methemoglobulinemia, or blue baby syndrome in infants. High contaminant levels also adversely affect aquatic life. MCLs are enforceable standards, not mere recommendations, and are enforced by the EPA and

DEP Office of Water Supply Management (or equivalent state agency). Municipalities should strive to maintain these levels in the interest of public health.

In addition to establishing MCLs and MCLGs, the EPA and state environmental agencies divide drinking water standards into two categories: primary and secondary. Contaminants regulated by primary standards pose severe health risks to humans and aquatic life if MCLs are exceeded. Secondary standards are "non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color)" (EPA). Although not enforced by the EPA, state agencies may elect to make them enforceable at the state level.

Although no enforceable regulations exist for surface water contaminants at the national level, the EPA has established National Recommended Water Quality Criteria for surface water. The DEP, however, has used these recommendations to establish enforceable Water Quality Criteria for Toxic Substances in surface water in Pennsylvania. These criteria establish maximum levels of contaminants to avoid public health issues derived from human consumption of fish and aquatic life, as well as to avoid adversely affecting aquatic life and biodiversity. At the state level, Water Quality Criteria for Toxic Substances are enforced by the DEP Office of Water Management (or equivalent state agency). [See both the National Recommended Water Quality Criteria: 2002 (national recommendations) and PA Code 16 Table 1:Water Quality Criteria for Toxic Substances (state regulations) at the end of this section.]

Most contaminant levels that are governed by Primary and Secondary Drinking Water Standards are listed as mg/L (milligrams per liter). [Surface Water Criteria levels are listed as ug/L (micrograms per liter; one microgram equals 0.001 mg).] Mg/L reflects the concentration of the contaminant dissolved in water, i.e., X milligrams of contaminant dissolved in one liter of water. Using the nitrate example from above, the PA state and national MCL for nitrate is 10 mg/L. That is to say, the maximum amount of nitrate allowed in each liter of water is 10 mg. Most water quality parameters are measured in mg/L.

Another popular way of recording the concentration of chemicals in the water is called **parts per million (ppm).** *Surprise, milligrams per liter (mg/L) is the same amount as ppm!* When dealing with substances that have the same density as water, the two are the same amount. Just like mg/L, parts per million is a ratio. Using the nitrate example again, 10 mg/L is equivalent to 10 ppm, meaning that there are 10 units of nitrate in every million units tested. This is the same as 10 particles nitrate within one million particles. In fractional form, it would look like this:

$$\frac{10}{1{,}000{,}000}$$

To indicate even smaller concentrations, scientists use parts per billion (ppb) and parts per trillion (ppt). 1 ppm equals 1,000 ppb and 1,000,000 ppt. 1 ug/L = 1ppb or 1,000 ppt. Recall that Water Quality Criteria for Toxic Substances are measured in ug/L, or

ppb. One part per billion is more diluted than one part per million. **Dilution** means to decrease the concentration of a mixture (chemical perhaps) by adding more water – reducing the strength or visual evidence (e.g., color) of the mixture.

Although these amounts may seem like extremely small concentrations, the toxicity of many chemicals can cause health or habitat problems even at these low amounts. People can smell petroleum products in water at concentrations as low as 10 parts per billion. A total phosphorus level of just 0.1 ppm (0.1 mg/L) can cause excessive algae growth to occur in a pond or lake. A total residual chlorine level of 0.06 mg/L (0.06 ppm) is toxic to striped bass larva. Most Water Quality Criteria for Toxic Substances are listed as ug/L (or ppb), reflecting the high toxicity of contaminants such as arsenic and PCBs, even when they are greatly diluted.

Many of the chemicals tested in a basic water chemistry monitoring program (total dissolved solids, dissolved oxygen, nitrates, phosphates, alkalinity, sulfates, iron) are either measured in parts per million (ppm) or milligrams per liter (mg/L). The preference between ppm and mg/L is usually left up to the water testing agency or scientist. We encourage using mg/L for Creek Connections sampling.

OVERVIEW: Students observe a dilution demonstration to understand the concept of parts per million. Students may also observe a paper visual aid demonstration to reinforce the concept. Parts per million could be reviewed with Creek Connections sampling as a context. Students will also see that mg/L is interchangeable with ppm.

PROCEDURE – *Part A – Dilution Demonstration*

Teacher Preparation:

1. Locate the stack of 6 plastic cups, food coloring, and wet erase marker in the module. Also locate a 10 ml graduated cylinder and a 100 ml beaker in your classroom.

2. Fill the beaker with 100 ml of water and add several drops of food coloring.

3. Fill each of the six cups with 90 ml of clean, clear water.

4. Make copies of one or more of the water quality standard guides for your students.

Student Activity:

1. Stimulate a class discussion about when the units parts per million (ppm) are used. Remind students that seemingly miniscule concentrations of contaminants can severely compromise the safety of our drinking and surface water. Explain that the EPA and DEP have established and enforce safe levels of contaminants in our drinking and surface water. Ask students if they are having trouble imagining the quantity 1 ppt or 1 ppm. Explain that you are going to do a demonstration to help them get a better grasp on the concept.

2. Show students a cup of water. Ask how they know the water is safe to drink. Have students list things they would like to know about the water before they drink it. Why would they drink water from a faucet, but probably not from a mountain stream?

3. Show students the beaker of colored water. Tell students that this represents a chemical or pollutant. Ask them if they would like to drink it.

4. Show the students the six water-filled cups. Explain that each cup contains 90 ml of clean, uncontaminated water. Take 10 ml of the chemical/pollutant colored water and pour it into one of the cups containing 90 ml of clear water. Calculate the concentration *(1 part per 10*). Use a wet erase marker to write the concentration on the side of the cup. Would they drink it?

5. Take 10 ml of this diluted solution and put it in 90 ml of clear water. What is the concentration of the chemical/pollutant? *(1 part per 100).* Use a wet erase marker to write the concentration on the side of the cup. Is a shade of color even detectable? Would they drink the water now?

6. Dilute the chemical/pollutant one more time, 10ml to 90 ml of clear water. What is the concentration now? *(1 part per 1,000).* Use a wet erase marker to write the concentration on the side of the cup. Tell them this measurement is known as parts per thousand (ppt). Any color shade?

7. Repeat three more times until you reach parts per million (ppm). Use a wet erase marker to write the concentrations on the side of the cups. Would they drink the water with the chemical/pollutant now, at 1ppm? Parts per million (ppm) is often used to describe the concentration of chemical parameters in waterways. Remember, milligrams per liter (mg/L) is used interchangeably with ppm.

8. Distribute and have students review the water quality sheet(s) you have photocopied for them, "Drinking Water Facts: Water Quality Standards" and/or "Pennsylvania Department of Environmental Protection Division of Drinking Water Management Maximum Contaminant Levels (MCLs)". These indicate how much (usually in mg/L) of a contaminant is allowed in our drinking water. Have students notice that in some cases, there is to be less than 1 mg/L of contaminant in the water.

9. Remind students that although dilution is a method of reducing the concentration of a chemical/pollutant within a sample, to ensure water is safe to drink, other forms of treatment are necessary.

PROCEDURE – *Part B – Paper Visual Aid Demonstration*

Teacher Preparation:

1. Find the visual aid sheets with many circles on them at the end of this activity. There is a visual aid sheet (both paper and overhead transparency versions) with 1,000 circles on it that can allow you to demonstrate parts per thousand (ppt). There is also a visual aid sheet (paper version only) with approximately 50,000 circles on it (very small circles).

2. If you plan to use the overhead transparency of the parts per thousand demonstration, procure and set up an overhead projector. Also locate the wet erase marker in the module.

3. Make 20 copies of the 50,000 circles sheet (which will give you one million circles, thus allowing you to demonstrate parts per million (ppm)). Tape these sheets on the chalkboard.

4. Make copies of one or more of the water quality standard guides for your students.

Student Activity:

1. Stimulate a class discussion about when the units parts per million (ppm) are used. Remind students that seemingly miniscule concentrations of contaminants can severely compromise the safety of our drinking and surface water. Explain that the EPA and DEP have established and enforce safe levels of contaminants in our drinking and surface water. Ask students if they are having trouble imagining the quantity 1 ppt or1 ppm. Explain that you are going to do a demonstration to help them get a better grasp on the concept.

2. To demonstrate to the class how much 1 ppt is, use a colored pen to color in one circle on the 1,000 circle paper or overhead transparency.

3. To demonstrate to the class how much 1 ppm is, use a colored pen to color in **one** circle of the 1,000,000 circles (20 sheets). Remember, milligrams per liter (mg/L) is used interchangeably with ppm.

4. Distribute and have students review the water quality sheet(s) you have photocopied for them, "Drinking Water Facts: Water Quality Standards" and/or "Pennsylvania Department of Environmental Protection Division of Drinking Water Management Maximum Contaminant Levels (MCLs)". These indicate how much (usually in mg/L) of a contaminant is allowed in our drinking water. Have students notice that in some cases, there is to be less than 1 mg/L of contaminant in the water.

DISCUSSION:

Has your concept of parts per million changed? Does it seem bigger or smaller than they imagined? *Answers will vary.*

Did you know that such small amounts are detectable? *Answers will vary.*

Are any contaminants are allowed in our drinking water? *Yes, but maximum allowable levels of these contaminants have been established by the EPA and DEP.*

Who enforces our drinking and surface water standards at the national and state levels? *The EPA (national) and DEP (state).*

Are state water quality standards allowed to be different from the national standards? If so, are they allowed to be more or less stringent? *Yes, state standards may differ from national standards, but state standards must be as or more stringent (not less) than the national standards.*

Refer to one or more of the water quality standard sheets. What are some of the illnesses associated with levels of specific contaminants that exceed the MCLs? *See water quality sheets for answers.*

EVALUATION:

- Explain the concept of parts per million.
- Why are mg/L and ppm the same?
- Have students conduct the demonstration as a peer presentation.

EXTENSIONS AND MODIFICATIONS:

- Have the students explain how to make a solution with 1 part per billion of the pollutant chemical.
- Continue the demonstration until ppb is reached.
- Have students research the environmental standards for the amounts certain pollutants are allowed to be in drinking water (most are in the ppm and ppb ranges).

NOTES (TEACHERS, PLEASE WRITE ANY SUGGESTIONS YOU HAVE FOR TEACHERS USING THIS ACTIVITY IN THE FUTURE):