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ABSTRACT

This water conservation education program for high schools consists of both stand-alone activities and teacher support materials. Lessons are divided into six broad categories: (1) The Water Cycle; (2) Water and Society; (3) Keeping Water Pure; (4) Visualizing Volumes; (5) The Economics of Water Use; and (6) Domestic Water Conservation. The seventh section, "Auditing Your School," entails a comprehensive water audit of the school building itself. Additional activity ideas, articles and readings, a collection of dilemmas for class discussion and independent research, recommended films, a bibliography of water in literature, a reference guide, and a glossary are also included. (WRM)

Water Wisdom

23 Stand-Alone Activities on Water Supply and Water Conservation for High School Students

Massachusetts Water Resources Authority

23 Stand-Alone Activities
on Water Supply
and Water Conservation
for High School Students

Water Wisdom

2nd Edition

Massachusetts
100 First Avenu
Charlestown, MA
(617) 241-4662

Curriculum developed in conjunction with:
The Writing Company and Maplewood Educational Consultants
Watertown, MA

Preface

The MWRA's school education project is an important component of the Authority's ongoing demand management water conservation programs. *Water Wisdom* is the third piece of the MWRA's school materials, completing the sequence begun with *Water Wizards* for elementary classes and continued with *Water Watchers* for middle school students.

Demand management is a critical element of the MWRA's plan to meet the long-range water needs of the metropolitan Boston area. By increasing efficiency and minimizing waste, we will avoid – perhaps forever – the need to develop expensive new water supplies. Leak detection and other engineering improvements are one approach; educating consumers is another. These school programs aim to ensure that all citizens served by the MWRA have a clear understanding of where their water comes from, where it goes, and how they can use the system most responsibly. We believe that *Water Wisdom* will help to bring some of this valuable information into high school classrooms.

Acknowledgements

Many dedicated teachers and support persons have helped to bring this program to life. We would like to thank Dr. Kenneth Mirvis and Cathryn Delude of The Writing Company and Drs. Darrel and Ardith Hoff of Maplewood Educational Consultants for translating our ideas and needs into classroom materials. Our teacher panel laid the foundation for how the program should be structured, then reviewed and tested the activities. Thanks to David Donovan of Milton High School, Susan Majors of Weston High School, Manny Rainha of Northeast Metropolitan Regional Vocational School, James Romano of Stoneham High School, and Beverly Smith of Brookline High School. We pilot tested the materials at Stoneham High School and South Boston High School; thanks especially to Dick Glennon and Tom Lydon. Finally, thanks to Mike Prendergast for the illustrations, to Margery Stegman of Schenkel Communications Design for the design, and to Colette Phillips of APR Company for organizing our teacher training program.

WATER WISDOM
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    Science

11. **Contamination of an Aquifer** An activity/demonstration in which students first build then contaminate a model aquifer in order to observe the environmental impact.
    Science, Geography

12. **Dispersion of Pollutants** Using ordinary coffee filters and food dye, students observe the unpredictable ways in which soluble materials move in underground rock and soil.
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13. **Cryptosporidium: Mystery Spore** Cryptosporidium, a parasitic protozoan, is immune to common disinfection methods – chlorination. The disease it causes is unpleasant to healthy individuals, but potentially deadly to immuno-suppressed individuals. In this activity, students grapple with how society should address this dilemma.
    Science, Health, Social Studies

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    A School-Wide Activity

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1. **Water in Literature** An annotated bibliography of stories, poems and novels.
2. **Murky Water Problems** A series of water-related dilemmas to trigger discussion, debate, group process, research paper ideas, and/or problem solving skills.
3. **Glossary**
4. **Resource List and Bibliography**

Introduction to *Water Wisdom*

Imagine living in a city without an adequate water supply! What would life be like? Without enough to drink, people would become sick and many would die. You would not be able to cook, bathe or clean. A single small fire could set the city aflame and the fire would be impossible to extinguish. Industries, many of which depend on water for their manufacturing processes, could no longer operate. The city would crumble.

Simply stated, a reliable supply of clean, healthful water is one of the fundamental cornerstones of cultural health and vitality. Without it, a population simply cannot survive.

The ability of a society to provide adequate supplies of fresh water is complicated by two issues: water is a limited resource and it is vulnerable to many types of pollution. Only so much water flows across each river bed, and each reservoir holds only so many gallons. In eastern Massachusetts, we polluted our nearby water sources by the 1800s, and ultimately decided to develop sources of fresh water to our west: first Lake Cochituate in Framingham, and later the Wachusett Reservoir in Clinton and the Quabbin Reservoir near Belchertown.

The water provided to us by the Wachusett and Quabbin reservoir system is purified by nature, and it is some of the cleanest water available in the U.S. But building Quabbin required the flooding of four towns, forcing 2,500 people to give up their homes, businesses and churches. We could simply never undertake another such project today. We must make very careful use of the water we have available.

Our present water supply system was designed to be capable of safely providing 300 million gallons of water each day. While that is a tremendous amount of water, we used more than that for 20 years. As recently as 1987, we used an average of 336 million gallons each day. With greater Boston growing and prospering, we faced some very hard decisions: either use less water or develop a new water supply.

Studies have shown that developing a new water supply would be extremely difficult. Clearly, we could not afford to displace people as we did when Quabbin was built. Some people have suggested diverting the Connecticut River into Quabbin in order to increase the flow into the reservoir. But such an action would have questionable environmental impact and would be politically unacceptable to many of the people of Connecticut and western Massachusetts who currently use the Connecticut River for their water supply.

Other research showed that with modest residential and commercial conservation measures, coupled with an aggressive leak detection/leak repair program, we could bring our daily consumption well within the 300 million gallon per day limit. Water conservation, therefore, has become an extremely important effort that each of us in eastern Massachusetts must continue to make. Water conservation cannot happen by throwing a switch. It requires persistent, conscious work on the part of consumers, continuous investments in pipes and hardware, and very efficient fixtures, such as low-flow toilets and showerheads. Water conservation is everyone's responsibility!

We at the Massachusetts Water Resources Authority are responsible for supplying your fresh water. We want to know that we will always be able to do our job. That is why we have assembled this *Water Wisdom* program for our region's high school students. It contains lessons in such areas as water conservation, our water system, and water in nature. It provides worksheets that will help you examine water use patterns in your home and school. It recommends ways you might be able to save water, both individually and as part of a larger community.

We hope you will enjoy and learn from these activities, and that they give you a new sense of appreciation for the value – and vulnerability – of water. Most of all, we hope they motivate you to take the necessary steps to use less water now and in the future.

About *Water Wisdom*

Structure of the Program

Water Wisdom, the MWRA's water conservation education program for high schools, consists of stand-alone activities and teacher support materials. We have designed most of these activities so they can be completed in one class period; some of them extend into a second period, and the school water audit is an extended activity that we recommend doing as an extracurricular/ interdisciplinary project. In addition, we have worked to make these activities relevant to a wide range of disciplines and age groups. We sincerely believe that water conservation is an interdisciplinary issue and the responsibility of every person.

The lessons themselves are divided into six broad categories: The Water Cycle, Water and Society, Keeping Water Pure, Visualizing Volumes, The Economics of Water Use, and Domestic Water Conservation. The seventh section, Auditing Your School, entails a comprehensive water audit of the school building itself. From that effort, we hope the students will be able to make recommendations to the maintenance staff, the student body, and/or the school committee that will lead to substantially less water use each year. In addition, the program contains additional activity ideas, articles and readings, a collection of "dilemmas" for class discussion and independent research, recommended films, a bibliography of water in literature, a reference guide, and a glossary.

We hope you will use these activities as triggers for your own creativity and good ideas. We have tried to create a flexible program that you can fit into your teaching style and schedule, and that will reinforce the concepts you already teach. Lastly, some of these activities (such as #4 part 2, #7, #14, #15, #16, and #17) are well suited to unusual situations, such as those that might be encountered by substitute teachers.

Regardless of how you use *Water Wisdom*, we trust it will make your job a little easier and that it will play a role in protecting our water supply.

Goals and Objectives of Water Wisdom

- To promote water conservation among students, families, teachers and school officials.
- To enhance student understanding of water and our water supply.
- To promote an appreciation of water as a critical, yet vulnerable, natural resource.
- To provide teachers with useful, relevant materials and teaching aids.

Part I: The Water Cycle

#1 The Hydrologic Cycle
Teacher's Notes

Purpose

To provide a background on the hydrologic (water) cycle.

Activity in brief

Nature provides a continuous regeneration of our fresh water supplies by means of the *hydrologic cycle* or the *water cycle*. Understanding the cycle is an important precursor to other water-related studies. This activity illustrates the hydrologic cycle by means of lecture and discussion.

Key words and concepts

Hydrologic cycle
Transpiration
Evaporation
Condensation
Precipitation
Infiltration
Percolation
Runoff
Aquifers
Water table

Materials

Transparencies of "Hydrologic Cycle" (at end of this activity)
Transparency of "Hydrologic Cycle Vocabulary List" (at end of this activity)
Copies of the two "Hydrologic Cycle" illustrations for each student
Article Reprint: *Conservation and the Water Cycle* (attached)

Time required

One or two class periods.

Procedure

1. Begin by discussing what we mean by a "cycle." A cycle is usually thought of as some repeating phenomena, such as the cycle of the seasons or life cycles. Have the students list different examples of cycles or discuss why a bicycle is called a bicycle.

2. Place the "Hydrologic Cycle Vocabulary List" transparency on the overhead projector and ask your students to define as many words as they can.

3. Place transparency "A" of the "Hydrologic Cycle" on the overhead projector and ask your students where they think each of the words from the vocabulary list belongs. Provide students with copies of the same drawing and have them label their drawings with the appropriate words.

4. After students have labeled their drawings, place transparency "B" of the "Hydrologic Cycle" on the projector which shows the acceptable answers. Compare student answers with the accepted answers.

5. Draw attention to the general pattern of water movement. Generally water is evaporated from the ground and from open bodies of water. Water is transpired from green growing plants. Water condenses to form clouds. Water falls to the earth by precipitation. Some of this water runs off across open areas to streams, rivers and lakes. Water percolates downward into the water table. Water also infiltrates laterally in soil and rock. Transparency B shows some of the possible routes that water moves through the cycle, but there may be other routes. It is important to have students recognize that water moves in a cyclic fashion and that many factors influence its movement in the cycle.

7. Discuss ways the hydrologic cycle is affected by different factors. For example,

   a. How does the hydrologic cycle change during winter months?
   b. How does removal of forests affect the hydrologic cycle?
   c. How does the construction of roads, parking lots and streets affect the hydrologic cycle?
   d. How might global warming patterns affect the hydrologic cycle?
   e. How do pollutants get into the hydrologic cycle?
   f. What are some of the ways that water is purified during the hydrologic cycle?

Additional Teacher Information

We recommend that you read *Conservation and the Water Cycle* (attached). It contains useful information about water use and the quantity of water that moves in the water cycle each day. The current estimate of water use in the United States for industrial, agricultural and personal use combined is about 2,000 gallons (7,500 liters) per person per day.

Water (H_2O) is the only substance that exists simultaneously and abundantly as a solid (ice), liquid (water), and gas (water vapor) over large areas of the Earth's surface and atmosphere. No other planet in the solar system has the conditions allowing such large amounts of water to exist in all three states. The Earth and its atmosphere contain about 940 million cubic kilometers (230 million cubic miles) of water. To help visualize this volume, imagine a huge ice cube 610 miles on a side. If one edge of the base of the cube were sitting in Boston, the base of the cube would extend west as far as Columbus, Ohio, as far south as North Carolina and up into the air 610 miles. Even though this sounds like a lot of water, this represents only *one hundredth of one percent of the total volume of the Earth.*

Here is another way to look at the Earth's total water supply. An estimated five billion people live on the Earth. If each person received his or her fair share of the total global water supply, each person's share would be only .046 cubic mile, a cube of water just slightly larger than 1900 feet on each edge. Picture a large square field or parking lot 1900 feet square, with an ice cube about two and a half times taller than the Prudential Building. This is your personal water cube. While this seems like a lot, consider that only about .3% of your share of this global water cube is fresh and accessible. Your total *fresh water* supply would be in a cube only 270 feet on a side. But you do not have all that water available at all times. Some is in the form of water vapor in the air or falling as precipitation. Some is in streams or aquifers. Much of this fresh water is being shared by all the plants and animals in the world. Water is a precious resource and we need to understand how it moves through nature and why we need to conserve our available fresh water supplies.

Additional Activity Ideas

1. SEAWATER AND SALT (Demonstration)
   Fill three glasses with clean drinking water. Have a student sample the first glass. To the second, add a pinch of salt. Have the student sample the water in this second glass. To the third glass, add a teaspoon of salt and stir it until the salt dissolves. Have the student sample a small sip of this solution. Most students will find this water extremely salty and unfit to drink. This third solution closely represents the salinity of ordinary sea water.

   Scientists estimate that the oceans contain as much as 50 million billion (50 quadrillion) tons of dissolved solids. If all the dissolved salts in the oceans could be removed and spread over the Earth's land surface, it would form a layer approximately 500 feet thick.

   Even "fresh" water contains some dissolved salts. But, for comparison, when one cubic foot of sea water is evaporated, it yields about 2.2 pounds of salt. When evaporated, one cubic foot of fresh reservoir or lake water yields only about one-sixth of an ounce. Stress the value of our existing fresh water supplies.

2. FRESH WATER FROM SEA WATER (Laboratory Demonstration)
   Set up a simple distillation experiment. Distill simulated "sea water." Discuss whether distillation is an efficient way to obtain fresh water from ocean water in the Boston area (and compare the Boston area to a desert area). Where would we find the land to set up the distillation plant? What environmental problems would it cause? Distillation requires large

amounts of energy; it produces large quantities of solid by-product, and water would have to be pumped against gravity into a distribution system. MWRA water is delivered into the system by gravity, thus energy costs are low. Stress the point that we must learn to conserve our available fresh water supplies.

Sample Test and/or Discussion Questions

1. The process by which water is released from leaf surfaces is called *Transpiration.*

2. The downward movement of water into an aquifer is called *Percolation*.

3. Make a simple sketch showing the major parts of the hydrologic cycle listing the major steps in the cycle. Use arrows to indicate the direction of water movement. *(See drawings.)*

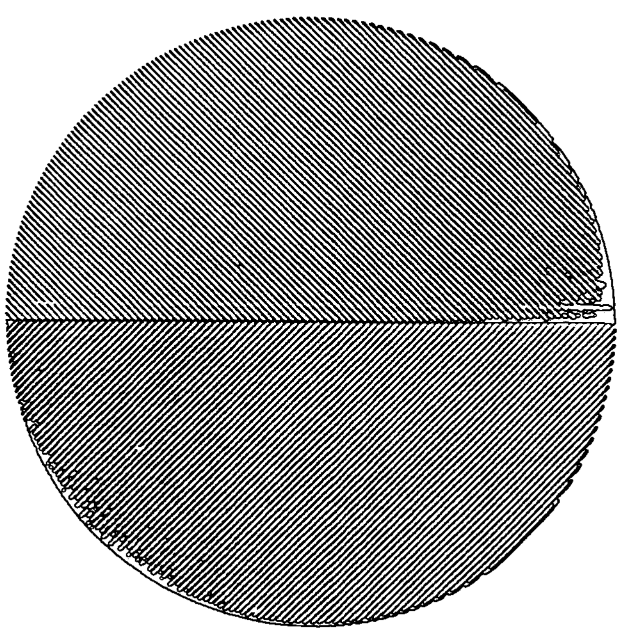
4. Choose one part of the hydrologic cycle and describe how the actions of humankind have affected it.
   Representative answers include: 1) Cutting trees increases run-off. 2) Cutting large numbers of trees reduces transpiration. 3) Impounding water in reservoirs reduces stream flow.

United States Department of Agriculture

Soil Conservation Service

Agriculture Information Bulletin No. 326

Conservation And The Water Cycle



Conservation and the Water Cycle

By the Soil Conservation Service

Water is probably the natural resource we all know best. All of us have had firsthand experience with it in its many forms—rain, hail, snow, ice, steam, fog, dew.

Yet, in spite of our daily use of it, water is probably the natural resource we least understand. How does water get into the clouds, and what happens to it when it reaches the earth? Why is there sometimes too much and other times too little? And, most important, is there enough for all the plants, and all the animals, and all the people?

Water covers nearly three-fourths of the earth; most is sea water. But sea water contains minerals and other substances, including those that make it salty, that are harmful to most land plants and animals. Still it is from the vast salty reservoirs, the seas and oceans, that most of our precipitation comes—no longer salty or mineral laden. Water moves from clouds to land and back to the ocean in a never-ending cycle. This is the water cycle, or the hydrologic cycle.

Ocean water evaporates into the atmosphere, leaving impurities behind, and moves across the earth as water vapor. Water in lakes, ponds, rivers, and streams also evaporates and joins the moisture in the atmosphere. Soil, plants, people, and animals, and even factories, automobiles, tractors, and planes, contribute moisture. A small part of this moisture, or water vapor, is visible to us as fog, mist, or clouds. Water vapor condenses and falls to earth as rain, snow, sleet, or hail, depending on region, climate, season, and topography.

Every year about 80,000 cubic miles of water evaporates from oceans and about 15,000 cubic miles from land sources. Since the amounts of water evaporated and precipitated are almost the same, about 95,000 cubic miles of water are moving between earth and sky at all times.

Storms at sea return to the oceans much of the water evaporated from the oceans, so land areas get only about 24,000 cubic miles of water as precipitation. Precipitation on the land averages 26 inches a year, but it is not evenly distributed. Some places get less than 1 inch and others more than 400 inches.

The United States gets about 30 inches a year, or about 4,300 billion gallons a day. Total streamflow from surface and underground sources is about 8.5 inches a year, or about 1,200 billion gallons a day. This is the amount available for human use—homes, industry, irrigation, recreation.

The difference between precipitation and streamflow—21.5 inches a year, or 3,100 billion gallons a day—is the amount returned to the atmosphere as vapor. It is roughly 70 percent of the total water supply. It includes the water used by plants.

Man can exist on a gallon or so of water a day for drinking, cooking, and washing though he seldom does or has to. In medieval times he probably used no more than 3 to 5 gallons a day. In the 19th century, especially in Western nations, he was using about 95 gallons a day. At present in the United States, man uses about 1,500 gallons a day for his needs and comforts including recreation, cooling, food production, and industrial supply.

When water hits the ground some soaks into the soil, and the rest runs off over the surface. The water that soaks into the soil sustains plant and animal life in the soil. Some seeps to underground reservoirs. Almost all of this water eventually enters the cycle once more.

Man can alter the water cycle but little, so his primary supply of water is firmly fixed. But he can manage and conserve water as it becomes available—when it falls on the land. If he fails to do so he loses the values that water has when used wisely.

Water management begins with soil management. Because our water supply comes to us as precipitation falling on the land, the fate of each drop of rain, each snowflake, each hailstone depends largely on where it falls—on the kind of soil and its cover.

A rainstorm or a heavy shower on bare soil loosens soil particles, and runoff—the water that does not soak into the soil—carries these particles away. This action, soil erosion by water, repeated many times ruins land for most uses. Erosion, furthermore, is the source of sediment that fills streams, pollutes water, kills aquatic life, and shortens the useful life of dams and reservoirs.

Falling rain erodes any raw-earth surface. Bare, plowed farmland, cleared areas going into housing developments, and highway fills and banks are especially vulnerable.

In cities and suburbs, where much of the land is paved or covered—streets, buildings, shopping centers, airport runways—rainwater runs off as as much as 10 times faster than on unpaved land. Since this water cannot soak into the soil, it flows rapidly down storm drains or through sewer systems, contributing to floods and often carrying debris and other pollutants to streams.

Grass, trees, bushes, shrubs, and even weeds help break the force of raindrops and hold the soil in place. Where cultivated crops are grown, plowing and planting on the contour, terraces, and grassed waterways to carry surplus water from the fields are some of the conservation measures that slow running water. Stubble mulching protects the soil when it has no growing cover. Small dams on upper tributaries in a watershed help control runoff and help solve problems of too much water one time and not enough another time.

Throughout the world the need for water continues to increase. Population growth brings demands for more water. Per capita use of water, especially in industrialized countries, is increasing rapidly.

It is man's management of the precipitation available to him that determines whether or not he has both the quantity and the quality of water to meet his needs.

It is man's obligation to return water to streams, lakes, and oceans as clean as possible and with the least waste.

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HYDROLOGIC CYCLE
VOCABULARY LIST

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Hydrologic cycle

Transpiration

Evaporation

Condensation

Precipitation

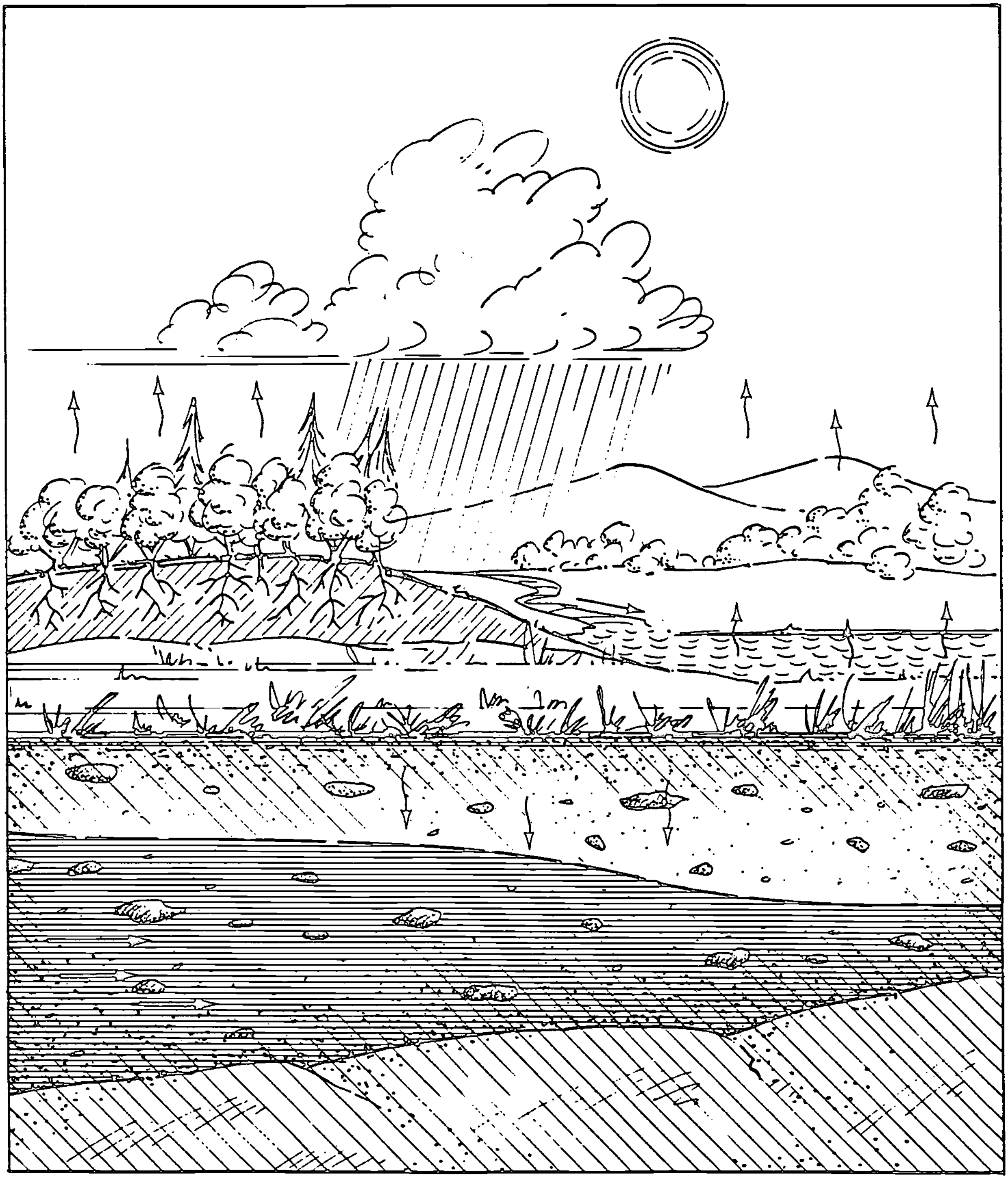
Infiltration

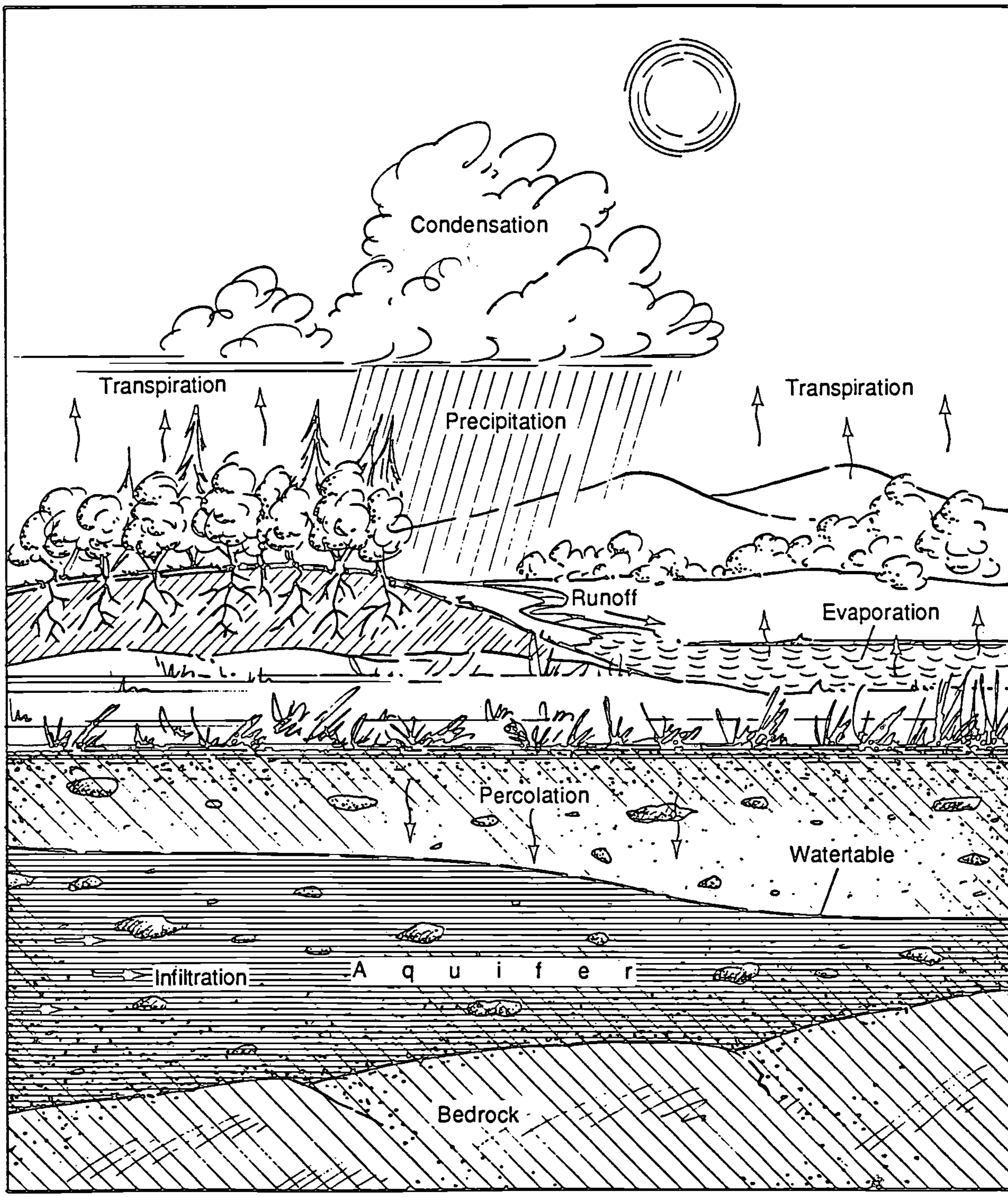
Percolation

Runoff

Aquifers

Water Table




Condensation
Transpiration
Precipitation
Transpiration
Runoff
Evaporation
Percolation
Watertable
Infiltration
A q u i f e r
Bedrock

#2 Transpiration
Teacher's Notes

Purpose

To acquaint students with transpiration, a critical step in the hydrologic cycle.

Activity in brief

In a combination indoor-outdoor laboratory experiment, students measure the amount of water transpired by a leaf on a tree during a 24-hour period.

Key words and concepts

Transpiration
Condensation

Materials

Plastic sandwich bags without recloseable tops
Twist ties
Small pebbles
Metric balances capable of measuring to a hundredth of a gram
Small graduated cylinders

Time required

One half of one class period and a second full period the next day.

Procedure

1. After introducing the hydrologic cycle, discuss the meaning of transpiration.

2. Give each student a plastic sandwich bag, a small pebble and a twist tie.

3. Have the students carefully determine the mass of their bag, pebble and twist tie to the nearest hundredth gram.

4. Have each of your students place a small pebble in the bag and tie the bag and pebble around a single leaf on a deciduous tree. The pebble weights the bag so it hangs down and the transpired water will collect in the bottom of the bag rather than running out. The bag should be secured tightly on the stem of the twig. Allow the bag to remain undisturbed for 24 hours.

5. At the beginning of the next class period, ask your students to observe the condensation of moisture on the interior of the bag. Have them remove the bags carefully so that none of the water is spilled. Use the twist tie to close the bag tightly. Weigh the bag, pebble, twist tie and water. The difference in mass is the amount of water transpired in 24 hours.

6. Have the students record the difference in weight, and remind them that one gram of water under standard temperature and pressure (STP) has a volume of one milliliter. (Even though conditions of their experiment are not at STP, this conversion is sufficiently accurate.) If enough water has been collected, you may want them to use graduated cylinders to measure the volume of the water collected.

7. Discuss how trees affect the temperature and humidity in a forest. If possible, measure the temperature and humidity in a heavily wooded area and compare this temperature with a nearby unwooded area, such as a parking lot.

Additional activity ideas

1. (SOCIAL STUDIES TEACHERS TAKE NOTE) Count the number of leaves on a small tree and estimate how much water that tree will transpire. Large mature trees may have upwards of 100,000 leaves, and there may be as many as 200 fully grown trees on a single acre. By some estimates, 40,000 square miles of rain forest are being cleared each year in tropical South America. A square mile contains 640 acres of land. Calculate the amount of water vapor that would be returned to the atmosphere by 40,000 acres of trees per day if the transpiration conditions were the same as those of your experiment. (To give a better understanding of this amount of water, you may wish to convert their metric measurements into gallons. One liter of waters equals 1000 ml. There are 3.74 liters in a gallon.)

   Have your students follow current events stories about efforts to save the rain forests, and have them explore other effects of deforestation on the global ecology, such as its contribution to the "greenhouse effect."

2. Conduct the experiment again using different types of leaves, or check the difference in transpiration rates in daylight hours and during hours of darkness, or on cloudy days as contrasted with cloudless days. Discuss what reasons may contribute to the difference in rates.

Sample test and/or discussion questions

1. The process by which water vapor is released from plant leaves is called *(transpiration).*

2. The removal of large forested areas is called *(deforestation).*

3. Pine trees (conifers), not deciduous trees, were planted in the watershed area surrounding Quabbin Reservoir. Do you believe the difference in transpiration rates between these two types of trees was a factor in this decision?
   On the one hand, conifers have a lower transpiration surface area than deciduous trees which makes them attractive for the watershed. On the other hand, their root systems hold large amounts of water and they continue to transpire through the entire year, thus they may not have been a good choice for the watershed's forests.

#2 Transpiration
Student Activity

Background

The *hydrologic cycle* is the name given to the process by which water cycles through the environment. Water falls to the Earth by precipitation (rain, snow, sleet and hail). It moves down into the rock and soil by percolation and infiltration to recharge our aquifers. It runs off the surface of our land through streams and rivers. Water from large bodies of water is returned to the atmosphere by evaporation. But large amounts of water are also returned to the atmosphere by a process called *transpiration*. Transpiration is the process by which green growing plants release the water from their leaf surfaces into the air. In order to sustain a healthy water cycle, each part of the cycle must continue to operate. If we remove large amounts of forested areas, the orderly return of water to the atmosphere by transpiration may suffer. Today, large areas of tropical rain forests are being cleared of timber. This *deforestation* may have serious long-term environmental effects. While it may not disturb the total global recycling of water, it will affect how rainfall is distributed. Certain regions in North Africa which were deforested had a steady decrease in rainfall while desert/arid lands increased.

Procedure

1. You will be given a small plastic bag, a twist tie and a small clean pebble. Place all three items on a metric balance and determine their total mass to the nearest hundredth of a gram. Record their total mass on your data sheet.

2. Following your teacher's instructions, place the pebble in the bag and place the bag over the leaf of a tree or shrub. Tightly fasten the bag to the stem with the twist tie. Allow the bag to remain in place and undisturbed for 24 hours.

3. At the beginning of the class period on the following day, examine the bag and record your observations on your data sheet.

4. Carefully remove the bag and fasten the top of the bag tightly with the twist tie. Return to your classroom and carefully weigh the bag, pebble, twist tie and water. Record the total weight on your data sheet.

5. Subtract the weight of the bag, pebble and twist tie that you determined yesterday from today's weight. Record this amount on your data sheet. A gram of water has a volume of 1 milliliter under normal conditions. Record (in milliliters) the volume of the water you collected.

6. You can estimate the number of leaves on a deciduous tree without too much trouble. Count the number of branches and the number of leaves on one or two branches. You then have enough information to make a reasonable estimate of the total number of leaves.

   Estimate the number of leaves on a mature tree. Multiply this number by the volume of water you collected in 24 hours. Record this value on your data sheet. This number represents the amount of water transpired by a single tree under conditions similar to yours.

7. There are roughly 200 trees per acre in a mature deciduous forest. Calculate the total amount of water that an acre of mature deciduous trees will transpire in 24 hours. Convert your answer in milliliters into gallons. (There are 3,740 ml in a gallon.)

8. Assuming the rain forests in South America transpire at the rate you determined, calculate the amount of water 40,000 acres of rain forest transpire per day. (40,000 acres is the amount of rain forest currently being cleared each year.) The Massachusetts Water Resources Authority is currently supplying 325 million gallons of water each day. Compare this amount to the amount of water 40,000 acres of forest would transpire in a day.

#2 Transpiration
Data Sheet

Name________________________________ Class/Section__________________________

Date________________________________

1. The mass of my bag, pebble and twist tie to the nearest .01 gram was ________________.

2. After allowing the leaf to transpire for 24 hours, I observed the following:
____.

3. After weighing the water, pebble, bag and twist tie, on the second day, I found the total mass to be __________. (Record to the nearest .01 g.) This amount equals __________ml.

4. I estimate that there are about ________________leaves on a mature deciduous tree.

5. A mature deciduous tree would transpire how many milliliters of water if it were growing under the same conditons as the tree used in this experiment? (Show calculations.)
_____________ml.

6. There may be as many as 200 deciduous trees growing on an acre of land. Calculate how much water an acre of mature deciduous trees would transpire in 24 hours.
_____________ml.

7. How many gallons of water would this equal? (There are 3,740 ml per gallon.) Show your calculations.
_____________gal.

8. Assume that tropical rain forests transpire at the same rate as the tree in your experiment. If 40,000 acres of rain forest are cleared each year, how much water would 40,000 acres of rain forest transpire in one day? Show your calculations.
_____________gal.

9. If the MWRA supplies 250 million gallons of water each day to people in the Greater Boston area, would 40,000 acres of trees transpire as much water per day as we use?

#3 What is an Aquifer?
Teacher's Notes

Purpose

To demonstrate how water is stored in underground formations called *aquifers* and what is meant by the term *water table*. The activity demonstrates how different soil and rock in an aquifer yield water at different rates depending on the particle size of the material.

Activity in brief

Through teacher laboratory demonstration, students learn two properties of aquifers--*water-holding capacity* and *percolation*. Students will have a clearer understanding of the need to situate reservoirs near aquifers to allow ready transport of precipitation through rock and soil in order to recharge reservoirs and water tables.

Key words and concepts

Aquifer
Contamination
Groundwater
Infiltration
Pore space
Precipitation
Percolation
Recharge
Reservoirs
Water table
Wells
Yield rates

Material

Three large funnels or three 2-liter plastic soft drink bottles with the tops cut off
Cheese cloth
Red food dye
*A few kg each dry:
sand
loam
gravel
*Small pieces (about 200 grams each) of different types of rock, such as sandstone, limestone, shale, granite, pumice (briquets from gas grills), or cat litter.
500 ml beakers.

Classroom quantities of "What is an Aquifer? - Student Worksheet" (attached)
(Optional) Transparencies of *The Hydrologic Cycle* from Activity #1.

* You may be able to obtain rock samples at garden, lawn-care or pet stores.

Time required
One class

Background

Water stored in the spaces (pore spaces) between particles of granular materials (rock and soil) is called *groundwater*. When the pore space is completely saturated, the zone holding the water is called an *aquifer* and the surface of the saturated zone is called the *water table*. Water is added to the aquifer by 1) precipitation percolating downward, 2) water moving horizontally by capillary action, or 3) pressure from water moving from above (infiltration).

If the water table is higher than adjoining land (such as on a hillside) the water can escape from the aquifer as *springs*. In some areas, fresh-water marshes or lakes develop where the surrounding topography holds a water table that is higher than the valley floor. Water continually seeps into the lakes or the marsh. Lakes, rivers and reservoirs obtain some of their water directly from precipitation (rain or snow), but most of the water added to these surface-water sources comes from water infiltrating and percolating from surrounding aquifers.

Water can be obtained from aquifers by pumping it up through holes drilled from ground level down to the water table. These holes are called *wells*, and some eastern Massachusetts cities and towns obtain their fresh-water supplies from such wells. If the surrounding water table is higher than the point where a well is drilled, the water may come to the surface under its own pressure. Such a well is called an *artesian* well. Wells drilled during the early development of eastern Massachusetts were quite shallow because less water was being used in those days, thus the water table was close to the surface. Today, shallow wells are prone to contamination because pollutants can easily reach the water table; water from many shallow wells is now unsuitable for human consumption, and in some instances, people have actually died from drinking contaminated well water.

If the demand for water increases or if insufficient precipitation occurs to *recharge* the aquifer, the water table is lowered. When the water table drops, shallow wells run dry, and reservoirs, streams and rivers contain less water.

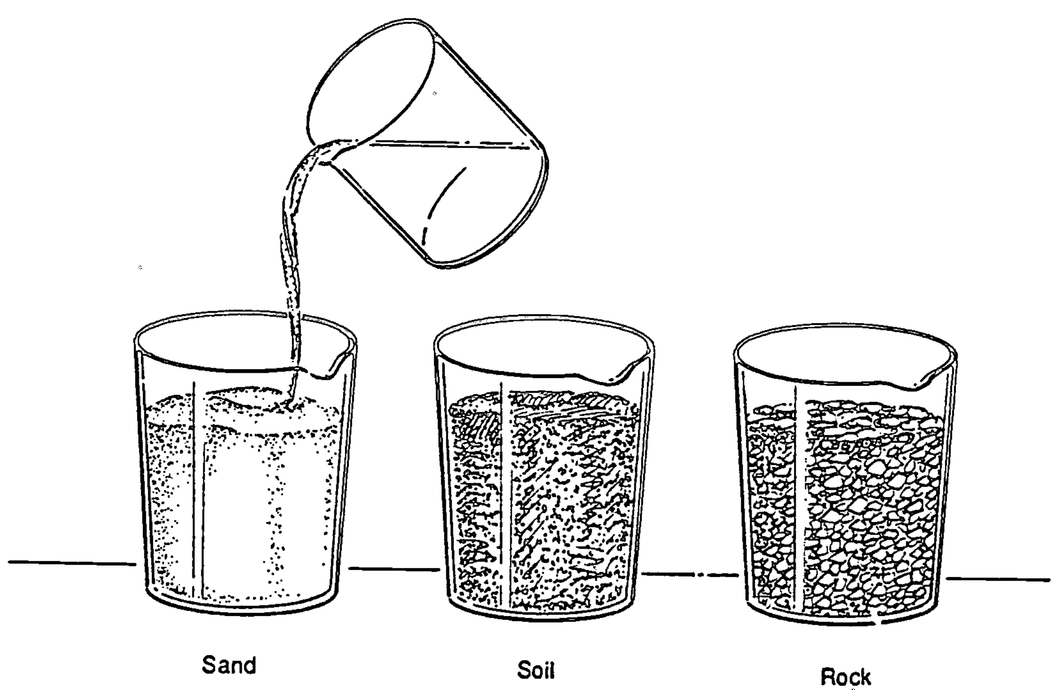
The depth of a well depends on the depth of the water table and the structure of the underground soil and rock. Deep wells generally produce purer water. Underground water from deep wells has percolated through greater volumes of rock and soil and thus has been better filtered to remove contaminants. But deeper wells have disadvantages. They require more energy to pump the water, and they produce water that has been in contact with rock for long periods of time. Small amounts of rock dissolve in the water and the water contains more minerals than shallow wells. Hence the water from deep water tables is described as being *hard water*. Hard water requires more soap for washing clothes and dishes. Mineral deposits build up inside water pipes, thus shortening their usable lives.

Additional teacher notes

We suggest using the demonstrations described below to introduce the concept of an aquifer and water table. Activity #12 *Dispersion of Pollutants* can then be used to demonstrate how pollutants move through an aquifer. You may want to begin the demonstration by displaying a transparency of the "Hydrologic Cycle" and introducing or reviewing the vocabulary needed to understand this activity.

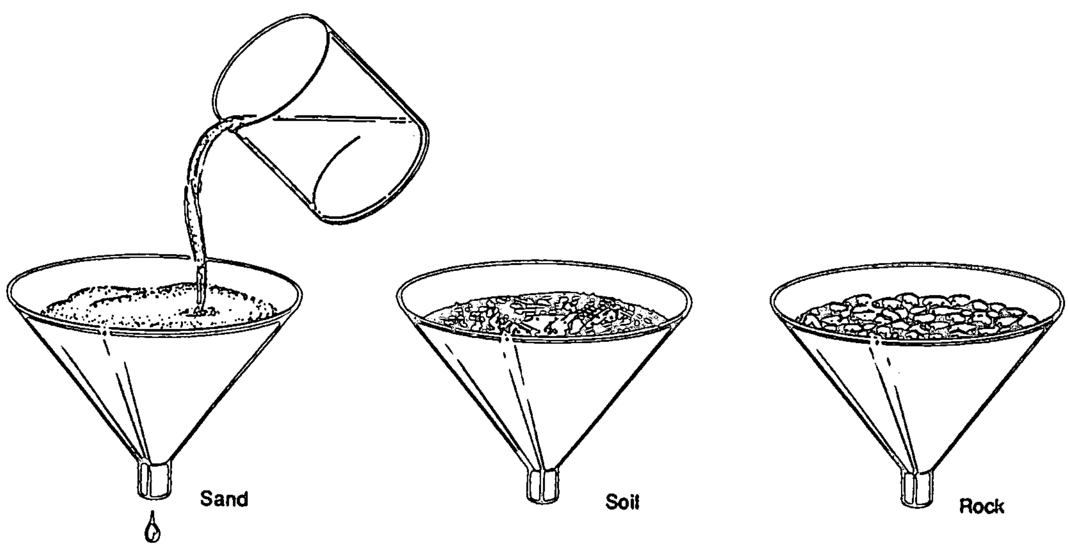
Water-holding capacity

Fill three 250 ml beakers: one with gravel, another with coarse sand, and a third with loam soil. Set them in a spot where each is visible to your students. The sample materials must be dry at the beginning of each class. Add red food dye to the water, then add an equal volume of water to each beaker and observe. Does the water soak into the various materials at the same or different rates? Does the "water table" come to the same level in all three beakers? If not, what determines which water table is the highest or the lowest? What does this indicate about the water-holding capacity of the materials? (The lower the resulting water table, the greater the water-holding capacity of that material.)



Percolation and yield rates

Cover the bottoms of three large funnels with cheese cloth. (If large funnels are not available, cut the bottoms from three 2-liter plastic soda bottles and use the bottles as substitute funnels.) Fill each of the funnels with a different kind of material (sand, loam or gravel). Have students speculate about which material will let the water through fastest. Pour 100 ml of water into each funnel, one at a time. Record the time it takes for the water to flow through the sample. Begin timing when all the water has been poured and stop timing when the stream coming out of the bottom of the funnel becomes a drip. Compare the times. Which was fastest? How does that compare to the students' intuition? How does the time it takes for the water to pass through the samples relate to the yield rates of the materials? (The shorter the time, the higher the yield rate.)



Water-holding capacity of different rock types

Weigh out approximately 200 grams each of small pieces of sandstone, limestone, shale and granite and record the mass of each sample. Place each sample in a 500 ml beaker and add 200 ml of water. Soak the rocks in a container overnight. Pour the water off the rocks and again determine the mass of each sample. Record the mass after soaking. Determine the difference between the rock mass before and after soaking. The difference in mass is the amount of water held by the rock surface and interior. Which rock would make the best aquifer?

Additional Activity Ideas

1. Discuss the need for a good understanding of the subsurface structure of the land chosen for the siting of a well or a reservoir. Obtain topographic and geologic maps of the area surrounding the Quabbin Reservoir. Discuss the possible reasons why this area was chosen as a site for a reservoir from a geologic standpoint. (Maps are available from the United States Geologic Survey or from local maps stores.)

2. Use geologic and topographic maps for the Woburn area and discuss the problems of groundwater contamination that occurred in that area. Explain how important it is to know subsurface geologic structures when trying to determine possible sources of ground water contamination. See Activity #11 *Contamination of an Aquifer* and Activity #12 *Dispersion of Pollutants*.

3. Have a class discussion on why the MWRA must protect the areas surrounding its reservoirs from extensive development. Overdevelopment of the watersheds surrounding the reservoirs and rivers that feed into the reservoirs can introduce pollutants into the water table that feeds into these bodies of water. What are the social pressures to make more use of both the watershed and the reservoirs? People wish to use the areas for more hunting and winter sports. Sportsmen wish to use larger motors on their boats in the reservoirs. How might these human activities affect the quality of the water?

4. Discuss the fact that some eastern Massachusetts cities depend on well water. If the water table surrounding these wells becomes polluted and the water drawn from these wells becomes unsafe to drink, they may have to shut down. As a result, additional water may have to be drawn from the MWRA system and additional conservation measures will have to be undertaken to ensure sufficient water for all the MWRA consumers.

5. Construct a model aquifer using instructions found on page 2 of Activity #12 *Dispersion of Pollutants*. Use it to point out that not all subsurface layers are continuous over large areas. Point out the effect that an impermeable layer has on protecting lower levels of an aquifer from surface pollution by preventing contaminants from percolating downward. These contaminants may be transported laterally over great distances.

Sample Test and/or Discussion Questions

1. The uppermost level of the saturated zone in an aquifer is called the *water table.*

2. Water moving downward through rock and soil layers is called *percolation.*

3. True or False: Deeper wells produce more desirable water than shallow wells?
False. Deeper wells may produce better quality water, but often the water is harder and a high mineral content can cause problems with heating systems, hot water pipes, etc.

4. Discuss the factors that determine the water-holding and percolation rates of water tables.
The type of soil and rock as well as the available pore space of the materials.

5. If you were a geologist responsible for choosing a site for a sanitary landfill that would not harm the area's aquifer, what factors would you have to examine in the region's geology?

#3 What is an Aquifer?
Student Worksheet

1. Look at the transparency "Hydrologic Cycle" displayed on the overhead projector. Using the following list, label the major parts of the water cycle.
   a. Aquifer
   b. Ground water
   c. Water table
   d. Precipitation
   e. Percolation
   f. Well
   g. Evaporation
   h. Condensation

2. Your teacher will fill three containers with three different materials: sand, loam soil and coarse gravel. Your teacher will add an equal amount of water to each of the three containers.

   a. Do you think the water will rise to the same level in each of the three containers?
   Yes______ No______

   b. Explain why you chose either "yes" or "no" for your answer.
   ____
   ____
   ____

3. Observe what happens when the water is added to each of the three containers. Write down what you observed.

   a. Which container had the highest water level?______________________

   b. Which container had the lowest water level?______________________

   c. Which material was able to hold the most water? ______________________

   d. Why do you think that material held the largest amount of water?
   ____

   e. What type of material in an aquifer will hold the most water?______________

4. Your teacher has three containers (soda bottles) with the same types of materials in them as were used in the first part of this demonstration. In a few minutes she/he will pour an equal amount of water through the materials. You will time how long it will take 100 ml of water to run through each of the materials.

   a. Before the experiment, predict which material you believe will allow the water to run through fastest.____

   b. Your teacher will now pour the water through each of the containers. Record (in seconds) how long it took for the 100 ml of water to pass through the material. Begin timing when all of the 100 ml has been added and stop when the water coming out the bottom turns into a drip rather than a steady stream.

      (1) Soil __________________

      (2) Sand__________________

      (3) Gravel__________________

   c. For water to move through an aquifer quickly – and for an aquifer to recharge quickly – what type of material would be best in the aquifer?__________________________

5. Your teacher soaked four rock samples overnight. She or he will provide you with the type of rocks used and mass of each dry sample. After pouring off the excess water from each sample, again determine the mass of each sample. Record the information here:

Rock Sample	Mass Before Soaking	Mass After Soaking	Difference
________	________	________	________
________	________	________	________
________	________	________	________
________	________	________	________

6. In terms of water-holding capacity, what types of materials would make the best aquifer?

#4 Flowing to the Reservoir: What is a Watershed? Teacher's Notes

Purpose

To acquaint students with the concept of a watershed and to provide information about the Quabbin Reservoir and associated watershed area.

Activity in brief

Following a demonstration of a watershed, students will complete an exercise using topographic maps of the Quabbin watershed to learn about the development of the Quabbin Reservoir.

Key words and concepts

Watershed
Topographic maps
Contour lines
Divides

Materials

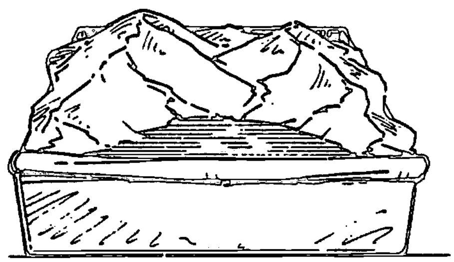
Newspaper
Plastic sheet
Paper towels
Spray bottle filled with water
Plastic box approximately the size of a large shoe box
Waterproof marker
Food coloring
Topographic map reprints of Quabbin area provided with this exercise.
Calculators with scientific notation capabilities (if available)
Massachusetts Water Resources Authority *Water System* poster

Time required

Two class periods.
(The first period may be used to demonstrate a model watershed and to review the use of topographic maps.)

Procedure Period one: Making a Model Watershed

1. Set up a model watershed by crumpling two sheets of newspaper and placing them in the plastic box. Drape the plastic sheet over the crumpled paper; fit it between the two pieces to form a valley and shape hills over the high places. Be certain that water will flow towards the valley and to the front side of the box. Fold the front edge of the plastic sheet up enough to prevent water overflow. The model now represents the hills and valleys that form a small watershed.



2. Explain that the plastic represents the crests of hills and the valleys that lie between them. Use the marker to draw rivers in the basins. With the box in place to catch runoff, spray water into the model. Point out how the water runs down one side or the other of the ridge and forms a stream in the valley. The ridges are called *divides*. Precipitation will run off the land down one side of the divide or the other. All of the land that drains into a stream is called a *watershed*. Food coloring can be added to show water flow better.

3. Call attention to how rapidly the water travels over the hard surface. A *wetland* absorbs large amounts of runoff and slows down this rate of flow. To demonstrate a wetland, put some folded paper towel into the valley and again spray. Point out to students how the water is absorbed and runoff slowed until the paper is saturated. Dams and reservoirs can be created by bunching up the plastic sheet at the end of the valley to form a stream barrier. Spray until water collects behind the barrier.

4. Each branch of a stream forms its own small watershed. As streams join each other, their combined watersheds form larger watersheds. As a result, watershed boundaries do not follow political boundaries, such as town lines, county lines, state lines, or even national borders. Establishing watershed districts requires cooperation and extensive negotiations among separate political entities to protect the interests of all parties involved. The development of the Quabbin Reservoir required years of legislation, litigation and negotiation before construction could begin.

5. Provide photocopies of the topographic maps accompanying this activity. Introduce or review what can be learned from studying topographic maps.

Procedure Period Two: Understanding the Quabbin Watershed

Using copies of the 1898 topographic map covering the Quabbin area and a topographic map of the area after the Quabbin Reservoir was constructed, have your students perform the following exercise.

1. Compare the two maps and identify towns that had to be removed for the reservoir to be built.

2. How would you describe the topography of the area where the reservoir was built? Is it flat, rolling, hilly or mountainous? How do you know?

3. Examine the 1898 map. It was necessary to relocate a major portion of a railroad in order to build the reservoir. Locate the railroad and determine its name. Using the map scale provided, estimate how many miles of railroad were taken up.

4. On the 1898 map see if you can find the West Branch of the Swift River that passes through Prescott (near Turtle Pond). Here the river had an elevation of 500 feet above mean sea level. That same river passed near West Ware where it had an elevation of 400 feet above mean sea level. These two locations are north and south of each other. What direction did this river flow, south-to-north or north-to-south? Why?

5. The gradient of a river is calculated by dividing the drop in altitude (usually expressed in feet) by the distance between the same two points (in miles). Using the map scale provided, estimate the distance between Turtle Pond and West Ware. Using this distance and the 100 feet difference in river elevation, calculate the gradient of the river along this stretch of the river.

6. On the topographic map of the Quabbin Reservoir as it appears today, the reservoir boundaries are marked in heavy outline. Reservoir depths are marked within the confines of these boundaries. Carefully examine the map and determine the greatest depth of the reservoir. What is its greatest depth? Where is this greatest depth located? Why would you expect the depth to be greatest at this end of the reservoir?

7. The intake pipes for the MWRA aqueducts are located on the east edge of the reservoir near the baffle dams. The MWRA does not need to use any electrical power to deliver the water from the Quabbin Reservoir to the Boston area. How is it possible for the MWRA to deliver the water without using power. (Hint: Look at the elevation at the location of the intake pipes.)

8. Using the map scale provided, measure the approximate length of the reservoir. See if your value agrees with the value given in the caption of the current map of Quabbin.

9. (Optional) Using an average depth of 50 feet for the total reservoir, calculate the number of cubic feet of water in the entire reservoir.

Take the total surface area of 39 square miles and convert this number into square feet. (There are 2.8×10^7 square feet per square mile.) Multiply the surface area in square feet times the average depth (50 ft) to obtain the total volume in cubic feet. How many gallons is this? (There are 7.5 gallons per cubic foot of water.) How much water does the Quabbin Reservoir hold when it is full? About 410 billion gallons.

10. (Optional) At an annual daily usage rate of 300 million gallons per day, calculate how many days' supply of water would be contained in the Quabbin Reservoir if it were completely full? *Use the reservoir capacity from step 10 above. Divide this by 300 million (3.0×10^{11} gal/day). The answer? About 3.7 years.*

    Note: The reservoir cannot be drawn down to below about 40% of its capacity and remain safe. Below that level, algae growth and turbidity affect water quality.

Conclusions and discussion

The Quabbin Reservoir was filled to capacity in 1946. It fell to 45% of its capacity in 1967, following a six-year drought. It did not return to full capacity until 1975. Starting in 1985, drought conditions again caused the reservoir to drop below its normal operating level. In addition, water use has far exceeded the capacity of the entire MWRA system. The system is designed to supply 300 million gallons per day under normal conditions. By 1980 the average daily use of water in the MWRA system had reached over 325 million gallons per day. Conservation, including leak repair and the installation of efficient plumbing fixtures, has since reduced consumption to 250 million gallons per day.

Additional Activity Ideas

1. ENGLISH, SOCIAL STUDIES

   Assign students to read about the history of the development of the Quabbin Reservoir. (One good reference is *The Creation of Quabbin Reservoir* by J.R. Greene, published by the author.) Have them create an imaginary person, family or town official who lived in one of the towns destroyed by the creation of the reservoir, and write a short story of the person's reactions to the loss of his or her home and town.

2. GEOGRAPHY, GOVERNMENT

   Obtain a Massachusetts road map and a set of topographic maps (available from Hammett's Map Store) and have the students choose an area for the construction of another large reservoir system. Have them discuss the problems of construction of a new reservoir system at the site chosen. Or alternately, assign students to write an environmental impact statement discussing the problems of siting a reservoir at the place chosen.

Sample Test and/or Discussion Questions

1. True or False. As a rule, watershed boundaries closely follow political boundaries.
   False

2. The ridges between watersheds are called *divides*.

3. The total MWRA system is designed to safely supply *300* million gallons per day.

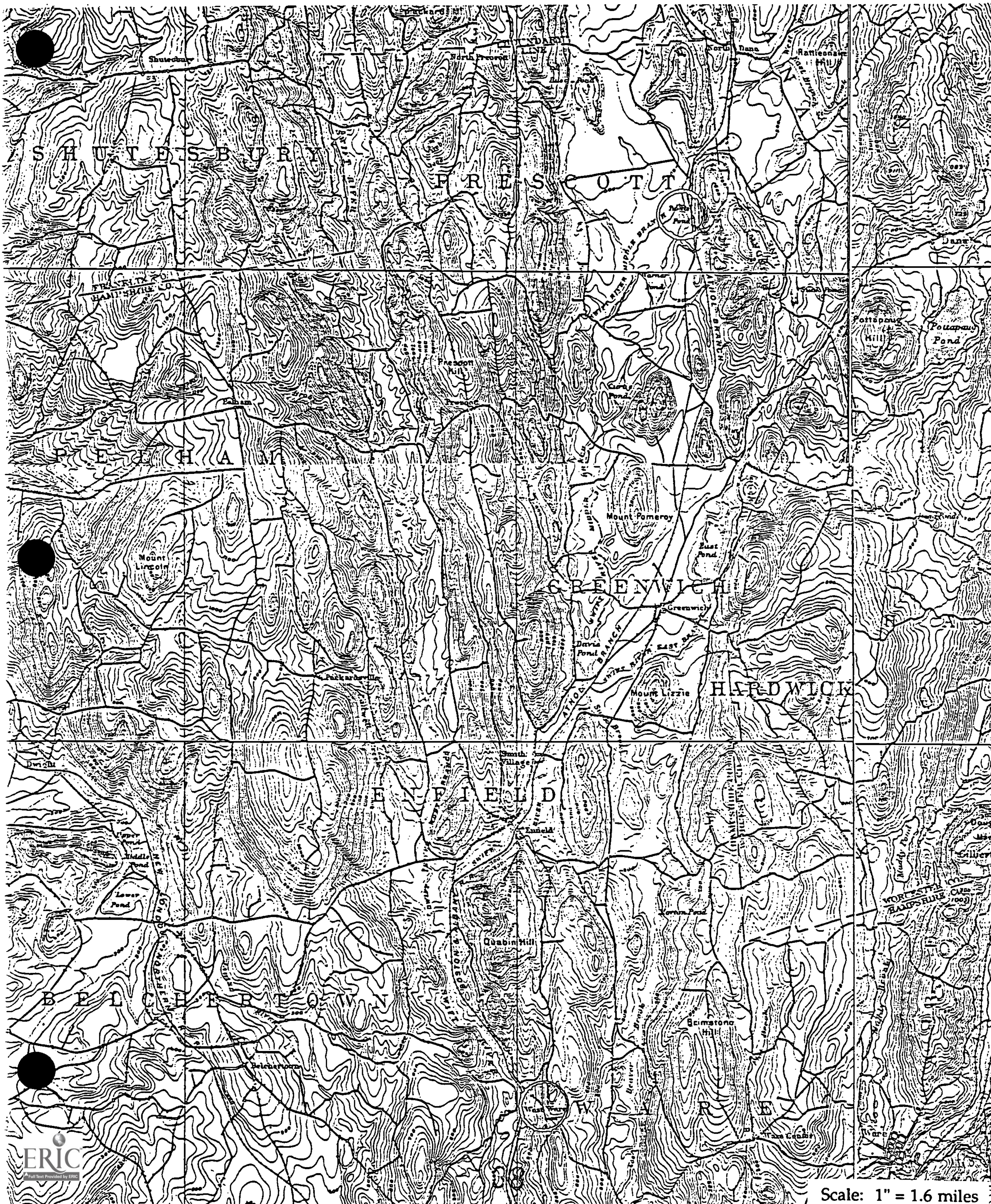
4. Between 1980 and today, average water use reached a high of 335 million gallons per day, and then dropped to an average of about 250 million gallons per day. What strategies and activities accounted for that reduction?
   Conservation, including leak repair and the installation of more efficient plumbing fixtures.

5. In the absence of additional supplies of water, what steps must we take to conserve available fresh water?

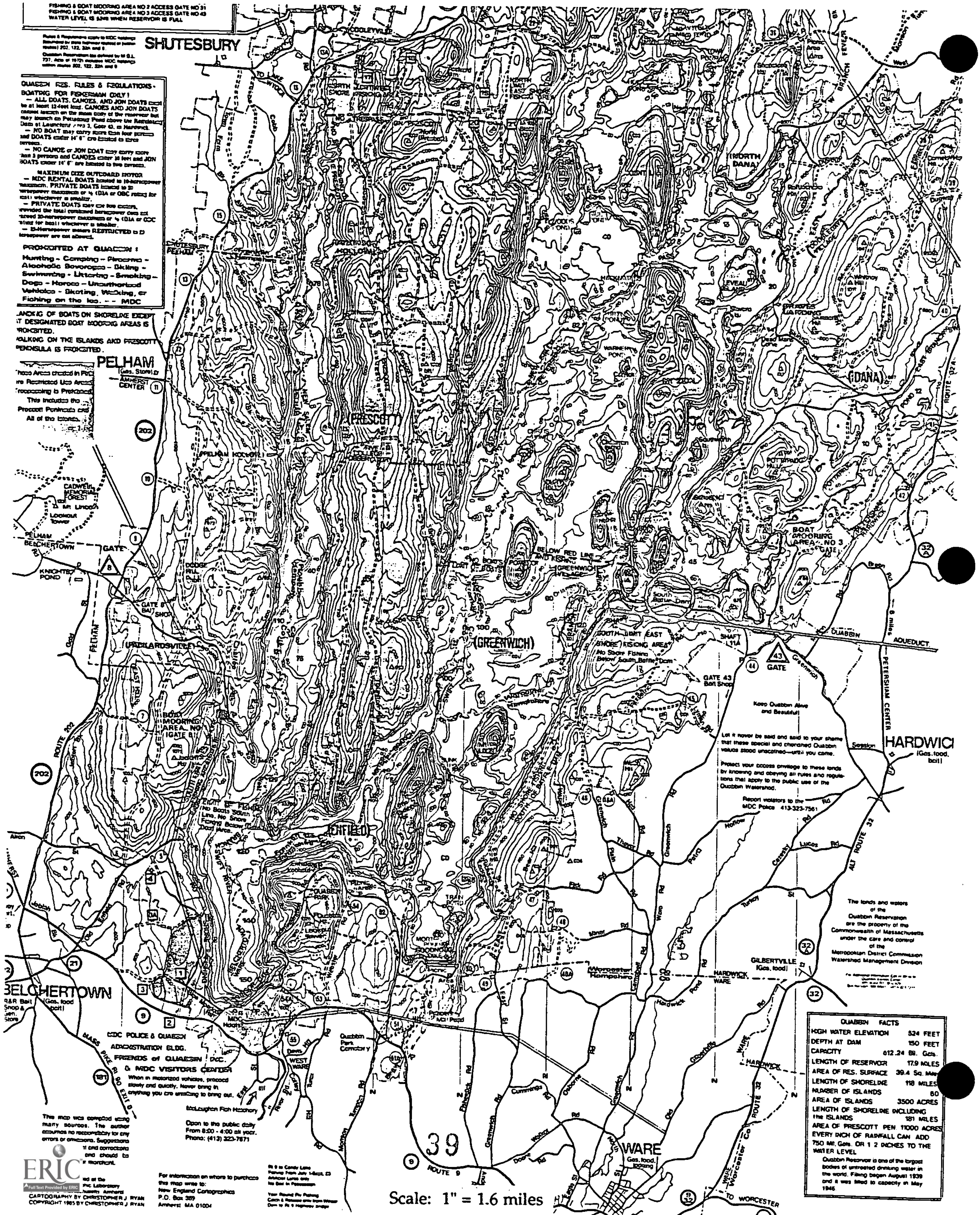
6. During the 1930s, the Quabbin Reservoir was built without the massive public outcry we might expect today. What factors do you think made the construction of the reservoir possible, and if someone attempted to build such a reservoir today, how do you think the public would react?

7. If a new major reservoir were to be constructed today, where in Massachusetts do your think it could be located? Explain your reasons for the choice of location. What factors operating today would make it difficult to construct another reservoir such as Quabbin to increase the capacity of the MWRA system?

Topographic Map of the Quabbin Region in 1898



Topographic Map of the Quabbin Reservoir as it Appears Today



Scale: 1" = 1.6 miles

#5 Evaporation from Reservoirs
Teacher's Notes

Purpose

To demonstrate how much water is lost through evaporation from large storage areas and to examine some of the conditions that influence evaporation.

Activity in brief

Through either student activity or teacher demonstration, students will learn about evaporation from containers of equal volume, but with different surface areas. The results will show that evaporation depends on several variables, including surface area. The exercise will show the importance of having deep reservoirs with minimum surface area to reduce evaporative loss. Calculations completed at the end of the exercise will lead to an estimate of water loss from the Quabbin Reservoir during a typical summer day.

Key words and concepts

Evaporation
Surface area
Area formula for a circle ($A = \pi r^2$)
Volume formula for a cylinder ($V = h \times \pi r^2$)
Evaporation rate formula ($R = V/\pi r^2$)

Additional teacher notes

The exercise effectively applies mathematics to a real problem. It also shows how metric measurement and scientific notation simplify manipulations of large numbers.

Materials

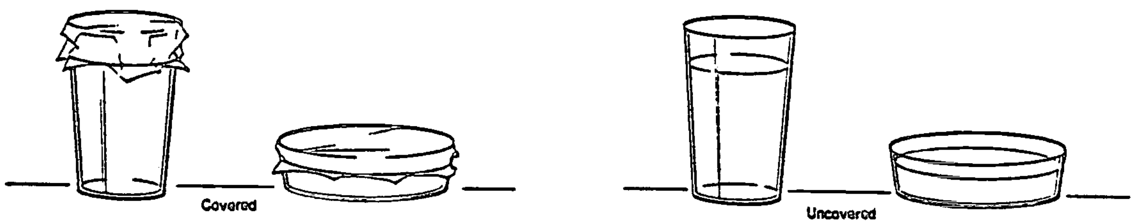
Two pairs of two containers each. Each set of containers should have one with a large surface area and one with a small surface area. Similar containers should have roughly equal volumes and shapes (e.g. a large graduate and a beaker of the same capacity).
Large graduated cylinders
Metric ruler
Felt-tipped markers or grease pencils for marking on glass
Waxed paper and rubber bands
Calculators with scientific notation capabilities
Copies of the attached instructions and Data Collection Sheet

Time required

Two class periods separated by one week.

Procedure

1. Set up the two sets of containers.



2. Determine the surface area of each container using the formula $A = \pi r^2$. Make the measurements in centimeters and tenths of centimeters (i.e. millimeters).

3. Fill the containers with the same volume of water and mark the depth of the water on each container with a felt-tipped marker or grease pencil. Leave one set of containers uncovered. Place the other set of containers in the same location and cover them with waxed paper, held down with rubber bands.

4. Place the two sets of containers in the same environment and allow to stand for one week.

5. Mark each container at the water level after the elapsed time. Measure the difference between the two marks, in centimeters and tenths of centimeters. We will call this difference "h".

6. Why have the closed containers lost practically no water?

7. Calculate the volume lost from the open containers by multiplying the surface area (in square centimeters) by the change in height (h). Use the formula for cylinder volume calculation, $V = h \times \pi r^2$. The container with the largest surface area should have lost a greater volume of water. Discuss why this is so.

8. The *evaporation rate* should have been the same for both open containers if they have been exposed to the same environmental conditions. Knowing the elapsed time and the volume of water that evaporated, the students can calculate the evaporation rate for each container by using the following equation:

   Rate (R) = Volume (V)/ πr^2

   The volume (V) and radius (r) will be different for each container, but R should turn out the same for both. Since the experiment lasted one week, this rate will be the evaporation rate for a body of water evaporating under similar conditions for one week.

9. Discuss why the evaporation rate values may have come out slightly different for each container. Factors include: imprecise measurements, slightly different temperature conditions, air movement over the containers, etc.

10. Apply the evaporation rate calculations to a larger area of water, for instance a swimming pool. Keep in mind that the rate applies only to the same environmental conditions. The volume of water evaporated from a pool in one week under similar conditions can be calculated according to the formula below. Make certain that the length (l) and width (w) measurements are expressed in centimeters.

    $V = R \times w \times l$, where:

    V = volume of water evaporated
    R = evaporation rate
    w = width of the pool
    l = length of the pool.

Conclusion and Evaluation

Allowing for experimental errors, the experiment should show that under similar environmental conditions, the volume of water evaporated is directly proportional to the surface area exposed to the air.

The experiment will also lead to the conclusion that during the summer months, large amounts of water are lost from reservoir surfaces, and that deep reservoirs are more efficient in withstanding evaporation loss than shallow ones with larger surface areas. It also shows why covering swimming pools can reduce evaporation.

Additional Activity Ideas

1. HOW MUCH WATER EVAPORATES FROM THE QUABBIN RESERVOIR?
   The Quabbin Reservoir has a surface area of 39 square miles. Convert this area into square centimeters. There are 5280 feet per mile and 12 inches per foot. Multiply 5280 x 5280 and multiply this by 144. (144 is the number of square inches per square foot.) To convert this into square centimeters, multiply by 6.45. (6.45 is the number of square centimeters per square inch.)

   The answer from step 1 is the weekly volume lost by Quabbin in cubic centimeters under conditions similar to that of your experiment. One thousand (1000) cubic centimeters equals one liter. There are 3.7 liters in a gallon. Using the evaporation rate established in the classroom activity, calculate the number of gallons lost from the Quabbin Reservoir on a day with environmental conditions similar to those of your samples. Let your students brainstorm ways to control reservoir evaporation.

2. CONDITIONS THAT INFLUENCE EVAPORATION
   - -Complete the same experiment for a shorter period of time, but have one set of containers exposed to air moving over them during evaporation.
   - -Compare the evaporation from a container placed in a refrigerator with one left out at room temperature.
   - -Place some containers in a controlled temperature environment and set the temperature at 85 degrees Fahrenheit to approximate summer temperature.
   - -Record the temperature and humidity periodically during the experiment.

3. HOW MUCH WATER EVAPORATES FROM THE OCEANS?
   Have your students calculate the amount of water evaporated from the oceans during one day. There are approximately 1.8×10^{12} square miles of ocean surface on the earth. Keep in mind that your results will be very approximate, as some of the ocean surface is perpetually covered with ice.

Sample Test and/or Discussion Questions

1. If a container has a radius of 10 cm, what is its surface area?
   78.5 cm^2.

2. If this same container has a depth of 10 cm, what is its total volume?
   785 cm^3.

3. What are some factors that influence the amount of water evaporated from a reservoir?
   Temperature of the water surface, wind, humidity, and amount of mixing of water from lower cooler regions.

4. If each person in the greater Boston area uses 420 gallons of water per week for personal use, and there are 2.5 million people in greater Boston, how many weeks of personal water use does a week's worth of evaporation under the conditions of your experiment represent?

#5 Evaporation from Reservoirs
Student Activity

Background

Evaporation, the process by which water changes from the liquid state to vapor, plays an important role in the hydrologic (water) cycle. Evaporation from the oceans, lakes and rivers adds water to the atmosphere. In turn, this water condenses and falls as rain or snow to recharge aquifers, streams, lakes and reservoirs. But evaporation from a large reservoir can cause a significant water loss during periods of warm weather.

The rate at which water evaporates depends on such factors as temperature, relative humidity and wind. The higher the air temperature, the faster water will evaporate. The lower the humidity, the drier the air and the faster water evaporates. The faster the wind blows, the faster the evaporation rate. In addition, surface area affects the amount of water that evaporates; the larger the surface area, the more water is exposed to the conditions that cause evaporation.

The amount of water evaporating from a container can be calculated by using the following formula:

$V = h \times \pi r^2$

Where:

V = volume of water evaporated

h = height difference of water level before and after evaporation has taken place

r = the radius of container water is evaporated from

$\pi = 3.14$

Materials

Two pairs of two containers each. Each set should have one container with a large surface area and one with a small surface area. Similar containers should have roughly equal volumes and shapes.

Large graduated cylinders

Metric ruler

Felt-tipped markers or grease pencils for marking on glass

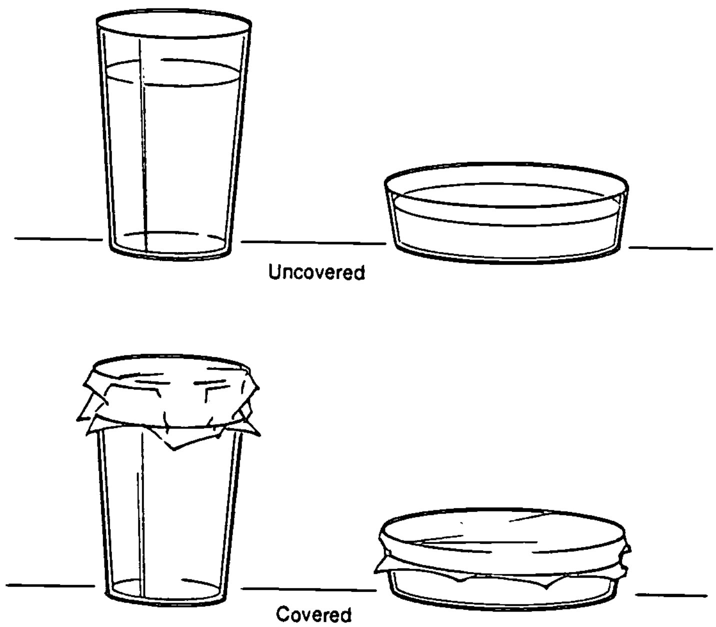
Waxed paper and rubber bands

Calculators with scientific notation capabilities

Procedure

1. Fill both pairs of containers with equal volumes of water.

2. Cover one set of containers with waxed paper and secure the covers with rubber bands.



3. Measure the radius of the open containers with a metric ruler. Measure the radius of each container to the nearest tenth centimeter and record the measurements on your data sheet.

4. Calculate the surface area of each container using the formula:

   $A = \pi r^2$
   Where:
   A = area of the surface in square centimeters
   $\pi = 3.14$
   r = radius of container in centimeters

   Record the container areas on your data sheet.

5. Mark the water level on all the containers with a grease pencil or felt-tipped pen, and allow them to stand for one week.

6. Examine both sets of containers after one week. Have all the containers lost the same amount of water? Record your observations on the data sheet.

7. If your containers lost different amounts of water, how can you explain the difference? Record your answer on the data sheet.

8. Mark the water level in the two open containers. Use your metric ruler and measure the difference between the two marks. We will call this value "h." Record these measurements in your data sheet.

9. Calculate the volume of water lost from each container using the following formula:

   V = h x A
   Where:
   h = difference between the two marks on your containers
   A = the surface area for each container (from step 4).

10. Which container lost the greatest amount of water? Why do you think it lost more than the other? Record your answers on your data sheet.

11. The rate at which water evaporates does not depend on surface area. It is affected only by such conditions as temperature, humidity and amount of air moving over the surface of the water. Determine the rate of evaporation for each container by dividing the volume of water lost in each container (V from step 10) by the surface area of each container (A from step 4).

    R = V/A

    Record your answer on the data sheet. This is the rate of water loss from your containers in one week.

12. Even though your containers were different sizes, the rate of water loss should have been the same. If the rates were not exactly the same, can you think of some reasons why? Record your reasons on your answer sheet.

13. If a swimming pool has a width of about 20 feet (600 cm) and a length of 40 feet (1200 cm), calculate the volume of water lost from the pool in one week. Determine the surface area of the pool in cm and multiply it by the rate (R) from step 11 above. Record your answer in your data sheet. *Slowing evaporation from swimming pools saves water!*

14. The Quabbin Reservoir has a surface area of 39 square miles. Thirty-nine square miles equals one trillion square centimeters. (1.00×10^{12}). If the Quabbin Reservoir were exposed to evaporation conditions similar to those of your experiment, how many cubic centimeters of water would it lose in a week? Simply multiply your rate (R from step 11 times one trillion). Record your answer in your data sheet.

15. One thousand cubic centimeters equals one liter. How many liters of water would be lost in a week from Quabbin Reservoir under the same conditions as your experiment? Record your answer in your data sheet.

16. There are 3.7 liters in a gallon. Calculate the number of gallons that would be lost from the Quabbin Reservoir in one week under evaporation conditions similar to your experiment. Record your answers on your data sheet.

Data Collection Sheet
Evaporation from Reservoirs

Name__________________________ Class/Period______________________

Date___________________________

1. Radius of open containers: (Be sure to indicate the proper units.)

   a. Smaller container___________ b. Larger container______________

2. Surface areas of open containers: (Label units.)
   Show calculations here:

   Smaller container A =_________ Larger container A =____________

3. Mark the water level on all four containers and allow to stand for one week.

4. At the end of one week, have all four containers lost the same amount of water?

   ____

5. How can you explain the results from step 4?

   ____

   ____

6. Mark the water level in the open containers. Use your metric ruler and measure the difference between the two marks (h). (Label units.)

   Small container h =___________ Large container h = ____________

7. Calculate the volume of water lost from each container using the formula $V = h \times A$. Use A from step 2 above.

   Small container V = ____________ Large container V = _____________

8. Which container lost the larger volume of water? Why do you think it lost more water than the other?

9. Calculate the rate (R) at which the water evaporated from each container.
R =V/A. (Use V and A from step 7 and 2 above.)
Show calculations.

Small container R = ______________ Large container R =___________
(Units are in cm3/week.)

10. If your answers are not the same, explain why.

11. Calculate the volume of water lost from a swimming pool that has a width of 6 m (20 ft) and a length of 12 m (40 ft). (Remember there are 100 cm in a meter.)

What is the surface area of the pool in cm^2?

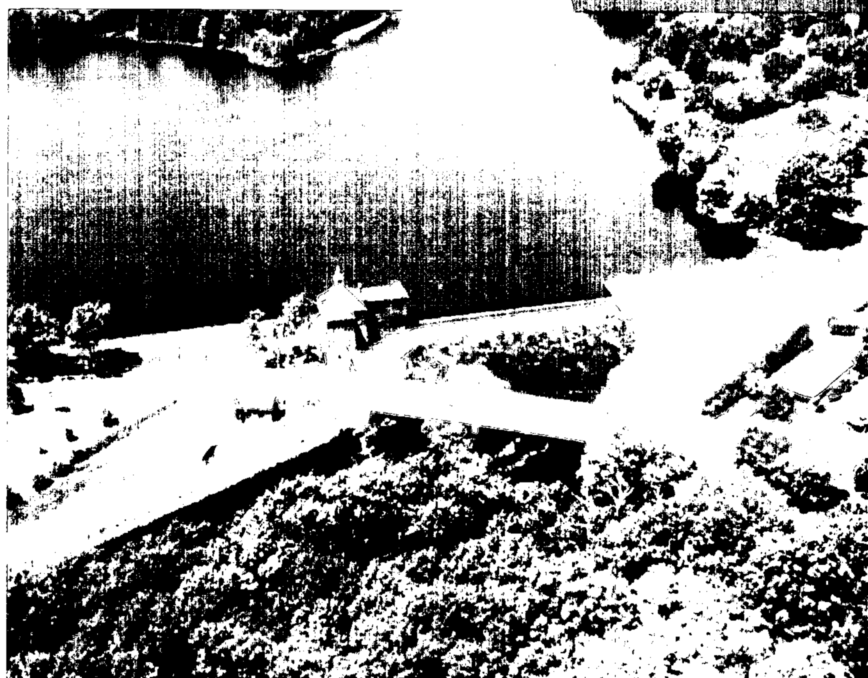
Use the rate determined from step 9 above and calculate the volume lost in one week from a pool exposed to the same conditions as your experiment.

12. The Quabbin Reservoir has a surface area of 39 square miles or one trillion (1.00×10^{12}) square centimeters. How much water would the reservoir lose in one week if the evaporation conditions were the same as your experiment? (Be sure to always work in similar units.)

13. One thousand cubic centimeters equal one liter. How many *liters* of water would Quabbin lose in one week under the conditions of your experiment?

14. There are 3.7 liters in a gallon. Calculate the number of *gallons* the reservoir would lose in a week under conditions similar to your experiment.

Part III: Water and Society



#6 A Brief History of Water in Boston
Teacher's Notes

Purpose

To provide a historical framework for viewing today's water dilemmas.

Activity in Brief

This activity consists of a brief historical essay about water use in Boston since the mid-17th century and a series of questions and activity/follow-up ideas. Students can either read the essay in class or as homework, then use it as a catalyst for discussion or as a stepping stone into an independent or team project.

Key Words and Concepts

Community water supply
Public and private water supply companies
Community fire protection
Boston's reservoir system
Watershed
Water pollution
Quabbin Reservoir
Aqueduct
Safe yield
Connecticut River diversion project
"Unaccounted for" water
Long-term planning

Time Frame

One to five class periods.

Additional Teacher Notes

This activity contains material for discussion, debate, etc. It could serve as a trigger for independent ideas. For example, what was the public reaction to the building of the Quabbin Reservoir and how might the public react today? Perhaps the answer lies in the length of the planning process, the poverty of the region, a depression-era mentality, or it may reflect a genuine shift in societal attitudes toward public works projects. Or, for another example, students could explore water uses and delivery systems throughout history: from the aqueduct system of Rome to bucket brigades.

Sample Test Questions and Discussion Questions

1. Here is a list of uses the colonists had for a reliable water supply. Rate them in what you think the order of importance was for the colonists. (Put 1 by the most important down to 7 by the least important.)

   ___ Drinking
   ___ Watering their animals
   ___ Watering their gardens
   ___ Fire fighting
   ___ Bathing
   ___ Cleaning
   ___ Cooking

   Regardless of the order of the others, firefighting tops the list.

   Discuss your answer with your classmates. Did you all come up with the same answers? What did most of you think was the single most important use?

2. True or False
   A reliable water supply is the most important factor for a new city or civilization to emerge and to thrive.
   True

3. Define these words:

Aqueduct	*A pipe or tunnel used to transport water.*
Reservoir	*A stored body of water that is usually man-made.*
Maximum safe yield	*The maximum amount of water from a supply and distribution system that can be delivered daily without fear of the supply running dry or becoming unfit to drink.*
Water conservation	*The practice of using less water while maintaining a comfortable lifestyle. Water conservation measures can either be behavioral changes, such as running the washer only when it is full, or hardware changes, such as installing a low-flow showerhead.*
"Unaccounted for" water	*Water that is delivered to unmetered users or that is lost through leaks.*
Watershed	*A region on one side of a geological divide that drains into one water system.*

4. What was Boston's first public water supply? When was it built and where was it located?
Built in 1652, it was a 12' x 12' spring-fed cistern near where Faneuil Hall now stands.

5. True or False.
The Jamaica Pond Aqueduct Company was a public agency funded by the citizens of Boston.
False. The Jamaica Pond Aqueduct Company was privately owned.

6. True or False
The Metropolitan District Commission and the Massachusetts Water Resources Authority are both privately owned companies.
False. They are public authorities.

7. True or False
The Greeks had a well developed aqueduct system that provided fresh water to all of the major cities in what is now southern Europe.
False. The Romans had a well-developed aqueduct system.

8. True or False
The entire aqueduct system from the Quabbin Reservoir to the city is powered by gravity rather than electric pumps.
True

9. True or False
At the time each was built, both the Wachusett and Quabbin Reservoirs were the largest man-made water supply reservoirs in the world.
True

10. The first reservoir to be developed west of Boston that was publicly owned was Lake Cochituate in Framingham. By the late 19th century, when the supply was becoming inadequate, the Metropolitan Water Board bought as much land as it could around the site of the next reservoir. Why did they buy this land?
So they could be in possession of a protected watershed.

11. What are the dimensions of the Quabbin Reservoir?

Surface area:	*39 square miles*
Length:	*18 miles*
Size of Watershed:	*186 square miles*
Capacity:	*412 billion gallons (when full)*
Distance to Boston:	*65 miles*

12. What is the derivation and meaning of the word *Quabbin*?
Quabbin is a Nipmuck Indian word meaning "place of many waters."

13. Two aqueducts connect the Wachusett Reservoir to the city while only one aqueduct connects the Quabbin to the Wachusett. Why is this configuration of aqueducts so important?
Redundancy. If the Quabbin Aqueduct needs repair, the Wachusett Reservoir can continue to provide water while it is shut down. If water cannot reach the city from the Wachusett Reservoir, the taps will quickly run dry. With the Weston Aqueduct aging, the new Metro West Tunnel is an important link to improved supply reliability.

14. How is Boston's water treated?
Natural sedimentation in reservoirs, ultraviolet radiation, pH adjustment, and a little chlorine and fluoride.

15. The Massachusetts Water Resources Authority and the state legislature have decided not to develop any new water supplies in the immediate future. How do they plan to meet the people's water demands? Discuss your answer.
Water conservation.

16. List four things you can do to help conserve water.
Take shorter showers
Repair all leaks
Conduct a conservation campaign in the school
Wash laundry and dishes with full loads only
Install low-flow shower and sink devices

Topics for Research Papers

1. In the 1930s, when the Quabbin Reservoir was built, four towns, numerous businesses, and about 2,500 people had to be displaced. What were the economic and social conditions of the Swift River Valley at the time? Do you think such public works project could be undertaken today?

2. Research water delivery systems throughout history.

3. How did people fight fires in past civilizations?

4. Research places in the U.S. where water conservation programs have been implemented during the past ten years. Which efforts have been successful and which have not been? Why? Devise a water conservation campaign of your own. Which people/groups would you focus on, and how would you get them to work toward conservation?

5. Discuss this statement: People will only conserve if they do not have to change their behavior.

6. Research other languages with a word for water similar in sound to the word *aqua*.

#6 A Brief History of Water in Boston

<u>Take a fantasy trip to colonial Boston</u>

Close your eyes for a few minutes and let your mind wander back in time about 350 years, to the mid-17th century. The Massachusetts Bay had been settled by the British for several decades. Boston had not only become a city, it had also become a center of commerce. The city was small though; it then covered much of the area we now know as the North End and Government Center, and it supported a population of several thousand people.

Where do you imagine those people obtained their water? Surely they did not have sinks and tubs with hot and cold running water. How did they wash their clothes and bathe? What did they eat? Where did they go to the bathroom and what did they do with their waste? What did they cook in and eat from, and how did they wash their dishes?

For a city to be founded and for it to thrive, it <u>must</u> have an adequate supply of clean, fresh water. Without water, people simply cannot survive. Mesopotamia, "the Cradle of Civilization," grew because of the Tigris and Euphrates Rivers. More than 1500 years ago, the Romans had built 14 aqueducts that carried 50 million gallons of water each day a distance of 360 miles to Rome; each Roman citizen could use as much as fifty gallons of water every day!

Boston, one of the oldest cities in America and "the Cradle of Liberty," can trace much of its greatness to water. Not only was the city a great seaport, but from the time it was settled, it has had a generous supply of fresh water.

But water supplies are not limitless. In Boston's 350 years, it has faced many water crises and undertaken some truly remarkable public works projects for the purpose of supplying its citizens with water.

By 1652, water had become such a precious commodity in Boston that an entrepreneur saw an opportunity for a business. At a street corner close to where Faneuil Hall now stands, a newly formed company created the first artificial water supply in America. It wasn't fancy — only a 12-foot by 12-foot hole filled with water from nearby springs and covered with planks.

Boston's first public water supply, near the site of Faneuil Hall.

While the citizens wanted ready access to water for the sake of domestic convenience — it made cooking and washing much easier — they really needed it for fighting fires. With its dense wooden structures, a fire would have been disastrous for the young town.

For almost 150 years, Bostonians drew their water from local wells, but had no organized, central water supply. Then in 1795, when the population of Boston totaled about 18,000, the Jamaica Pond Aqueduct Company installed four wooden main pipes from Jamaica Pond to the city. They ran smaller wooden pipes directly to the homes of subscribers who paid for the service.

The Jamaica Pond Aqueduct Company was a private, for-profit corporation. In a manner similar to today's cable TV, they served only those people who paid to be part of their water delivery system. The debate as to whether water utilities should be publicly or privately owned continues today, and many of the nation's water companies do not belong to the public they serve.

When fires broke out in the area served by the Jamaica Pond Aqueduct Company, the firemen bored holes into the wooden mains and tapped them in order to fight the fire. After the fire was out, they plugged the holes and marked the spot so they would be ready in the event of another fire. It was from that practice that the term *fire plug* emerged.

By 1825, the city had suffered a devastating fire that destroyed several blocks, and the population had tripled since the turn of the century, to 50,000. The Jamaica Pond Aqueduct Company simply could not keep up with the increased demand. Low water pressure meant that people living in high areas, such as Mission Hill and Beacon Hill, sometimes had neither water nor fire protection. Worse, the water quality had become unreliable; it sometimes tasted so bad that customers could not drink it, and some reports claim that Boston's spring water was the cause of widespread illness. In a growing vibrant city where everybody needed good water, this situation was intolerable. Something had to be done.

In a pioneering engineering effort, Dr. Daniel Treadwell calculated that each of Boston's 6,000 families required 100 gallons of water per day; each of her 2,000 individual residents required 40 gallons; and industrial/municipal uses required 500,000 gallons per day. Thus, calculated Treadwell, Boston needed an absolute minimum supply of 1,180,000 gallons per day. Indeed, at this bare-bones number, all other uses would have to be halted in order to fight fires. But regardless of the projected need, Boston simply did not have that much supply. They had to locate a source of water and develop it.

The developers looked into Spot Pond in Stoneham, the Mystic River, and the Charles River, but none were acceptable. (Spot Pond later became a source of supply for the northern metropolitan area.) Not only had industries such as tanneries already polluted the Charles, Boston's spring water was notoriously hard, harsh tasting and unhealthy. Regretfully, the heavy machinery of politics and business prevented any new supplies from being developed, so Bostonians had to make do with what they had...at least until 1834.

In 1834, the city hired Laommi Baldwin, a civil engineer from Woburn to again study the water supply issue. He came up with a dramatic idea: connecting the city to Long Pond (which is now Lake Cochituate) in Framingham by means of a buried aqueduct. The lake was high enough that gravity could carry the water the entire distance. That decision marked the beginning of the practice of bringing fresh water to the city from the less populated regions to the west, a practice that continues today.

For ten more years, the politicians and the planners continued to debate the water issue without taking action. Finally, in 1845, the state legislature granted the funds and the necessary legal rights to build an aqueduct system from Framingham to Boston. The legislature's action meant that Boston would be served by a public water system, one owned by all the people, not by private companies as its earlier ventures had been.

Construction began the following year, in 1846. In the system's entire 14.3 mile distance, the aqueduct dropped less than four feet! (3 inches of drop per mile.) The aqueduct ran underground at a depth of at least four feet so it would not freeze. It crossed streams, and at the Charles River, the builders installed an inverted siphon which allowed the water to continue flowing even though it went uphill.

Two years later, in 1848, the system was complete and the citizens of Boston held a great celebration on the Commons. Their decisions and problems, however, were far from over.

The City of Boston now had a good reliable water supply. But that water had to be delivered to each home. Of what material should the pipes be made? Iron was too rigid and the inner diameter tended to become encrusted, thus causing the flow rate to decrease. Copper was considered the best available material, but it required careful craftsmanship and was very expensive. Some people feared that lead pipes posed a potential health hazard. Others, however, concluded that a thin impenetrable layer would build up on the inside of the pipe, eliminating any potential danger. Lead pipes won the debate, although the water company provided copper to anyone who wanted to pay extra. To this day, no one is certain how many old Boston homes still have lead water pipes.

By 1868, the city had more than 1,500 fire hydrants, 20,000 homes, and almost 6,000 businesses and municipal buildings. The population exceeded one-quarter million and for the first time some of the most far-sighted individuals envisioned the day when the water supply from Lake Cochituate would not be adequate for Boston.

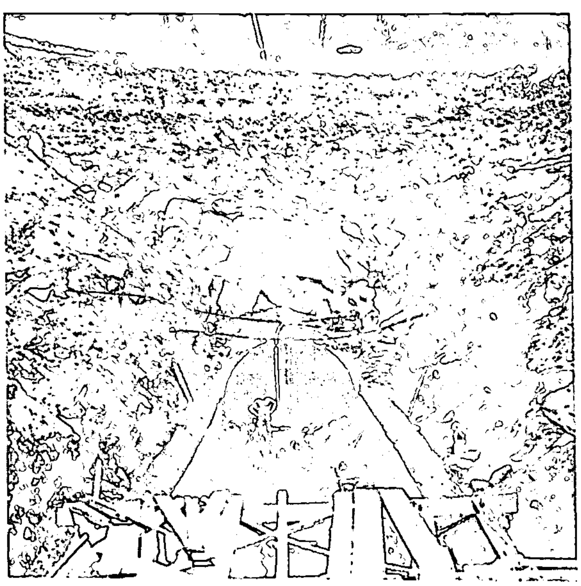
Despite the reliable supply of fresh water from Framingham in the west, the communities to the north of Boston maintained their own water supplies. Most notably, the cities of Charlestown, Chelsea, Everett and Somerville received water from Mystic Lake, the headwaters of the Mystic River. By the 1890s however, the Mystic supply accounted for less than 25% of the total supplied by the western water network, which now included not only Lake Cochituate, but also a series of reservoirs along the Sudbury River, including the Sudbury Reservoir (which could still be put back into use today). Moreover, the Mystic Lake supply soon became polluted, and the northern water supply was abandoned in 1898. Now, almost a century later, we are still relying on waters from the west to bathe and nourish the city.

Just before the turn of the century, the state legislature commissioned a major study of Boston's water needs. Based on population projections and public health criteria, the study was submitted in 1895, and it recommended a long-range plan for developing water sources in the Nashua, Ware and Swift

River watersheds. The first step in that plan, building the Wachusett Reservoir on the Nashua River by the newly created Metropolitan Water Board, began that same year. As a planning document, the 1895 study has served the metropolitan area for nearly a century.

The Metropolitan Water Board, like its predecessors and successors alike, continually searched for new sources of supply. Even though many planners considered water conservation as an option, the general public never thought seriously about using less. Conservation was simply not part of their consciousness.

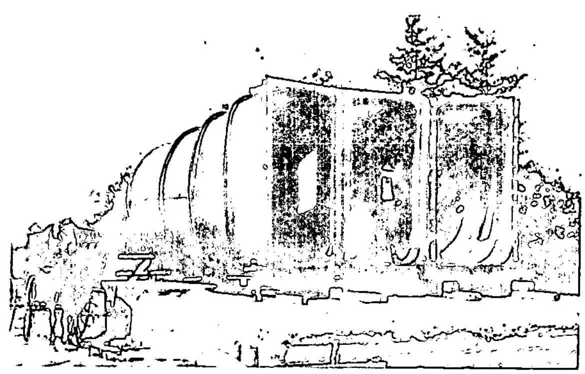
One of the key issues before the planners in 1895 was whether to filter and treat the readily available water or develop a water supply system along the sparsely populated lands to the west. Their conclusion, that the public preferred "a clean, unpolluted upland source,"[1] was pivotal in the decision to build the Wachusett Reservoir.



Building the Wachusett Aqueduct

The Wachusett Reservoir differed from Lake Cochituate in an essential way. The watershed area around Lake Cochituate was small and unprotected, and development was imminent. The water would soon be unfit for consumption. Thus the Metropolitan Water Board built the new reservoir in an area with an undeveloped watershed. Only in that way could they try to protect the water's purity. Of the watershed's 65,000 acres, nearly 5,000 were purchased for protection and more than two million trees were planted.

By 1908, the Wachusett Reservoir was complete and full, and feeding water to Chestnut Hill. Its designer, Frederic Stearns, had been awarded a gold medal at the Paris Exposition for the reservoir's plans. With a capacity of 67 billion gallons, it was at the time the largest man-made reservoir in the world.



The Weston Aqueduct

In 1919, not 15 years after Wachusett's completion, discussions had begun for the construction of "a great reservoir" in central Massachusetts that would be connected to Wachusett. To protect the supply, the plan-

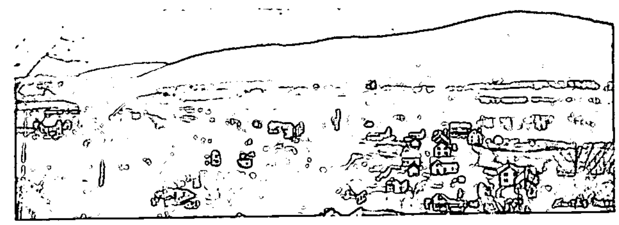
1. SYSTEM DESCRIPTION paper p.III-4, from The Commonwealth of Massachusetts, A General Description of the Water Supply of the Metropolitan District Commission, October 23, 1940, pp.9-10.

ners recommended all forms of public recreation be absolutely banned from the new reservoir. Their motivation was noble: they wanted to ensure an unpolluted supply that would purify the water naturally. The high quality of the water available to us today must be credited to the individuals who successfully fought for such assurances.

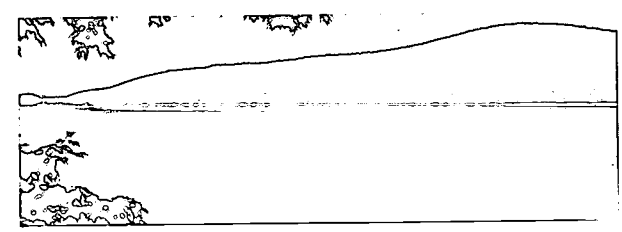
Authorization to begin building the Quabbin Reservoir came in the mid-1920s. Construction began in earnest in the early 1930s after a ruling by the U.S. Supreme Court on a case brought by the State of Connecticut cleared the way. Construction caused the removal of four towns, forced the relocation of 2,500 people, eight schools, eleven churches, six mills, and 34 cemeteries; in the town of Ware, the Quabbin Park Cemetery was established for the reburial of many of the 7,500 bodies that had to be removed. Quabbin is the largest single-purpose man-made water supply reservoir in the world.

The Quabbin Reservoir, in the valley of the Swift River, has 39 square miles of surface area, is 18 miles long, and has 186 square miles of watershed. It stores up to 412 billion gallons of water before sending it on its 65 mile journey to Boston. The Quabbin is so large that one drop of water entering its upper end takes nearly four years before it leaves through the Quabbin Aqueduct on its journey to our faucets and fire hydrants, and it is that feature more than anything else that assures the purity of our water. Time for the natural action of the sun, sedimentation, and the changing seasons is what purifies our drinking water.

The Quabbin Reservoir has touched many lives since its conception 70 years ago. Among them was Xavier Henry Goodnough, for whom the Goodnough Dike was named. He served



The town of Enfield before the building of Quabbin.



Quabbin as it appears today looking across the valley that was Enfield.

as the chief sanitary engineer of the state's Board of Health. Working with Frederic Stearns, he helped to bring the Quabbin project to completion. The critics of Quabbin assaulted the idea, claiming it would cost as much as $200 million to build. Goodnough insisted the price would not exceed $60 million. He was right; the final cost was $56 million. He also correctly guessed that the reservoir would require six years to fill up.

As an interesting side note, the word *Quabbin* is an Indian word from the Nipmuck Indians meaning "place of many waters." It is fascinating that Indians in the center of what is now Massachusetts used a word that is so close to the Latin word for water, *aqua*.

The tunnel and aqueduct system that connects these reservoirs to the city is also a remarkable work of planning and engineering. For the most part, water flows through wide tunnels buried deep underground, pushed along by gravity rather than energy-consuming electric pumps. Pumps take over only in the highest parts of the city.

Only a single tunnel connects the Quabbin to the Wachusett Reservoir. Named the Quabbin Aqueduct, it is 24.6 miles long, thirteen-feet in diameter, and it has a total vertical drop of 135 feet. With only a single link between the two large reservoirs, engineers can ensure that Wachusett is always full. As long it remains full, even if something were to happen to the tunnel to close it down, Boston would still have close to a year's supply of water while it was being repaired.

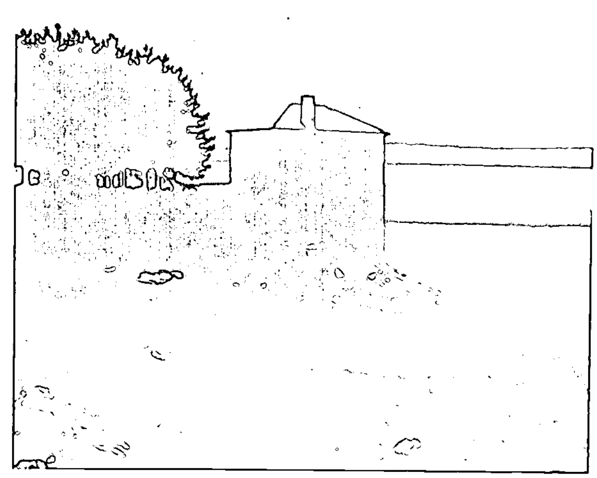
Two aqueducts continue the route from Wachusett Reservoir toward Boston: the original Wachusett Aqueduct and the new Cosgrove Tunnel, built in 1964. The eight-mile-long tunnel is fourteen feet in diameter – wide enough for tractor trailer trucks to drive through! While the Wachusett Aqueduct is seldom used today, it provides essential redundancy to the system, allowing the Cosgrove Aqueduct to be maintained without depriving the city of water.

These two aqueducts lead to the west side of the old Sudbury Reservoir near Southborough (which is not actively used but is still available in the event of a severe water emergency). From there, the Hultman Aqueduct (built in 1940) and the Southborough Tunnel lead to Southborough. From there, the water moves to Weston via the Weston Aqueduct (built in 1903) and the continuation of the Hultman Aqueduct. From Weston, the water flows into the communities of metropolitan Boston through an interconnecting network of aqueducts and water mains, including the Dorchester Tunnel and the City Tunnel.

Once the water has entered the metropolitan area, community-owned pipes and mains carry the water directly to homes, businesses, and large institutions, such as hospitals and universities. Once it reaches your tap, a single drop of water may have fallen as rain or snow as long as four of five years earlier. It may have traveled more than 65 miles to get to your house, and it may have been as far as 650 feet underground at times. With the exception of small amounts of fluoride, chlorine, and pH adjustment, it has been treated primarily by nature.

The System's Safe Yield

The design size of a water system such as ours is determined primarily by water use projections and average rainfall. The total water that can go into the system is limited by several factors: rainfall, the size of the watershed, and the capacity of the reservoirs. Even if we had several years of very heavy rainfall, for example, much of that water might be lost



The Quabbin Reservoir in early 1989 when it was filled to only 70% of its capacity.

downstream because the reservoir system is simply not large enough to hold it all.

The engineers and planners must employ complex mathematics to know how much water the system can provide safely. They must factor many variables into their calculations, including average rainfall, the amount of water that vegetation in the watershed will use, and the amount of water lost from the reservoir through evaporation. From these calculations, they determine "safe yield."

When the engineers designed the reservoir system, they did so with a limited population in mind. They didn't realize how much the Boston area would grow. They calculated the safe yield to be 300 million gallons per day, and for about 25 years we stayed within that limit. But beginning in 1969 (within the time frame predicted by Frederic Stearns 70 years earlier), we began to exceed the maximum safe yield of the system. We exceeded the safe yield every year from 1969 to 1989, when the service area began making significant strides in reducing water consumption.

A major study, begun in 1980, examined a number of alternatives for the metropolitan area's long-range water supply. One option, first suggested by planners in 1967, entailed diverting flood flows of the Connecticut River to the Quabbin. The direction that has emerged from planning, however, first under the MDC and continuing under the MWRA since 1985, has been a comprehensive program to conserve water and protect local sources. The program strives to improve efficiency by reducing waste in the commercial, residential, industrial and municipal sectors. Another major thrust is to reduce "unaccounted for" water, meaning water which is not paid for due to leaks, underregistration of meters, or delivery to unmetered users. Citizens and MWRA leaders have agreed that an aggressive conservation campaign should precede the development of a new water supply.

The leadership of the MWRA, the Commonwealth, and individual consumers have tightened the system, plugged the leaks, and are conserving as much water as possible. This collective action represents an important step in Boston's water history.

This *Water Wisdom* program is the result of the MWRA commitment to water conservation and water awareness. The MWRA is hard at work repairing and maintaining the system, and it is actively promoting water conservation among all of its customers.

This effort requires that everyone practice water conservation, such as:

- using low-flow faucets and showerheads,
- taking shorter showers,
- installing toilet dams and flushing only when necessary,
- watering lawns and gardens only in the late evenings or early mornings,
- running dishwashers and clothes washers only when they are full, and
- finding and repairing leaks.

The long-term future of the water supply system remains something of a mystery. No one knows if — or how long — we will be able to provide water to greater Boston without developing a new supply. It is certain, however, that aggressive conservation efforts have reduced water consumption. Clearly, conservation will push back the need for new supply, but a truly successful conservation initiative will require continuing effort and the help and participation of every citizen.

#7 Examining Water Use and Rainfall Patterns
Teacher's Notes

Purpose

A graph reading exercise that demonstrates that water use is linked to other social factors and that rainfall amounts vary widely over time.

Activity in brief

By examining graphs that show rainfall and daily water use, students can see that a link exists between water use and major social or political events, but that annual rainfall is unpredictable. While students may not be able to draw absolute conclusions from the data presented in the graphs, they will be able to see some interesting trends and to recognize some potentially dramatic links between water use and major world events, such as war, depression and prosperity.

Key words and concepts

Bar graphs
Million gallons per day
Daily water use

Materials

Water-use graphs
Rainfall graph

Time Required

One class period

Procedure

1. Review the concept of a bar graph. A bar graph displays a large amount of numerical information in a manner that makes comparisons easy. The graphs contained in this activity are one of two types. One of the graphs in this activity displays the annual rainfall over the watershed areas serving the Massachusetts Water Resources Authority beginning in 1898. The second set of graphs shows the amount of water consumed by the communities served by the MWRA and its predecessors for the past 150 years.

2. Supply copies of the graphs to your students and assist them in completing the student activity sheets.

3. The activity can be completed as a homework assignment or as a class discussion.

Suggested Answers for Student Activity Sheet

1. Examine "Graph 1 - Water Use - 1900-1996." Estimate the amount of average daily water used in the Greater Boston area for the following years:

   a. 1910 *120 mgd*

   b. 1930 *140 mgd*

   c. 1950 *200 mgd*

   d. 1970 *330 mgd*

   e. 1985 *325 mgd*

   f. 1995 *255 mgd*

2. Estimate the average daily water use from 1970 to 1988. *330 mgd*

3. Why do you think water use in the MWRA service area has increased so dramatically from 1940 through the present?
   The U.S. entered WWII in 1941. This event, coupled with a dramatic increase in our post-war standard of living contributed to increased water consumption. At the end of the war people began buying automatic clothes washers, dish washers and other domestic water-consuming devices. Air conditioning became popular and early air conditioners consumed a great deal of water. At the same time more manufactured products were being made that were water intensive in production. Other factors include an increase in water used for maintaining lawns and automobiles, the increase in popularity in home swimming pools, and the like.

4. Examine "Graph 2 - Water Use - 1849-1874." Notice an increase in use starting in 1860 and ending in 1865. Can you think of some possible reasons for these changes?
   The most likely cause of this rise would be increased manufacturing during the Civil War.

5. Examine "Graph 3 - Water Use - 1875-1899." Notice the dramatic drop in use after 1883. Can you think of any historical reason for this drop?
   Though this is less well known, America suffered a severe depression during this period. In those days it was known as a "panic" and our economy did not recover until the 1890's.

6. Examine "Graph 4 - Water Use - 1900-1924." A low-use pattern followed 1910 and increased sharply in 1916, 1917 and 1918. Can you think of any historical reasons for this increase?
   There was another economic slowdown starting in 1908 and it was the outbreak of WWI that is the most likely cause for the increase in water consumption starting in 1916, although the U.S. did not directly enter the war until 1917.

7. Examine "Graph 5 - Water Use - 1925-1949." Notice that water use was increasing in a regular fashion up until 1930 and then declined and stayed at roughly the same level until 1940. What historical reasons may have caused this pattern?
This period of declining use coincided with the "Great Depression." This depression followed a stock market crash in 1929, but this "crash" did not begin affecting the economy until the early 1930s. The general downturn in the economy affected all aspects of American life, including manufacturing. A decline in water consumption during this period would not be surprising.

8. Notice the sharp increase in water consumption starting in the early 1940s. What historical reasons can you think of that would explain this increase?
This period marks the outbreak of WWII. Even though the U.S. did not officially enter the war until December 8, 1941 (following the Japanese attack on Pearl Harbor the previous day), the country had been mobilizing for the war. The U.S. was the chief overseas supplier of arms for Britain which (after June 17, 1940) had been facing the German war threat alone. America was described by the British as the "Arsenal for Democracy." After the U.S. entered the war, war manufacturing contributed to an increase in water consumption until the end of the war in 1945.

9. Examine "Graph 6 - Watershed Yearly Precipitation." Lay a clear plastic ruler across the graph so that the number of peaks above the upper edge of the ruler are about the same as the number of peaks that fall below the edge. This is one quick way to estimate the average yearly precipitation from 1898 to the present. What is your estimate of the median rainfall?
Student estimates will vary. Answers should be in the range of 44-47 inches per year. On average, the local area receives about 45 inches per year according to meteorologists.

10. List five years of extreme drought and the average rainfall for those years?

Year	Average Rainfall
1917	*37"*
1930	*35"*
1941	*31"*
1949	*35"*
1965	*31"*

11. Since 1946 when the Quabbin Reservoir was filled, the average safe yield of the Quabbin/Wachusett reservoir system has been 300 million gallons per day. On average, how many million gallons per day above safe yield was the MWRA service area consuming in the late 1980s??
The service area consumed approximately 30-35 mgd above the safe yield of the reservoir system.

12. List five ways that you can conserve water.

#7 Examining Water Use and Rainfall Patterns
Student Activity

1. Examine Graph 1, "Daily Water Use - 1900-1996." Estimate the amount of average daily water used in the Greater Boston area for the following years:

   a. 1910______________________________

   b. 1930______________________________

   c. 1950______________________________

   d. 1970______________________________

   e. 1985______________________________

   f. 1995______________________________

2. Estimate the average daily water use from 1970 to 1988. ______________________

3. What do you think some reasons may be for why water use has increased so dramatically from 1940 through the present?

4. Examine Graph 2, "Daily Water Use - 1849-1874." Notice an increase in use starting in 1860 and ending in 1865. Can you think of some possible reasons for these changes?

5. Examine Graph 3, "Water Use - 1875-1899." Notice the dramatic drop in use after 1883. Can you think of any historical reason for this drop?

6. Examine Graph 4, "Water Use - 1900-1924." Notice a low-use pattern following 1910 and a sharp increase in 1916, 1917 and 1918. Can you think of any historical reasons for this increase?

7. Examine Graph 5, "Water Use - 1925-1949." Notice that water use was increasing in a regular fashion up until 1930 and then declined and stayed at roughly the same level until 1940. What historical reasons may have caused this pattern?

8. In Graph 1, notice the sharp increase in water consumption starting in the early 1940s. What historical reasons can you think of that would explain this increase?

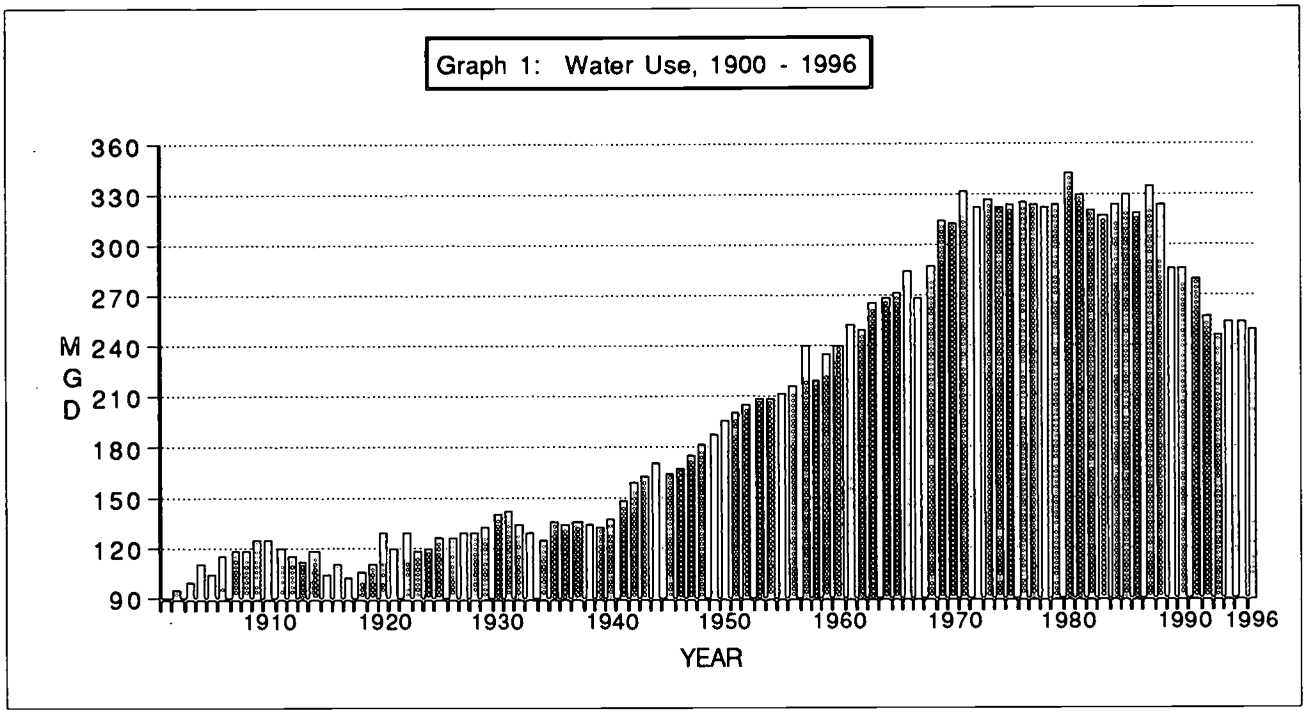
9. Examine Graph 6, "Watershed Yearly Precipitation." Lay a clear plastic ruler across the graph so that the number of peaks above the upper edge of the ruler are about the same as the number of peaks that fall below the edge. This is one quick way to estimate the average yearly precipitation from 1898 to the present. What is you estimate of the average rainfall?

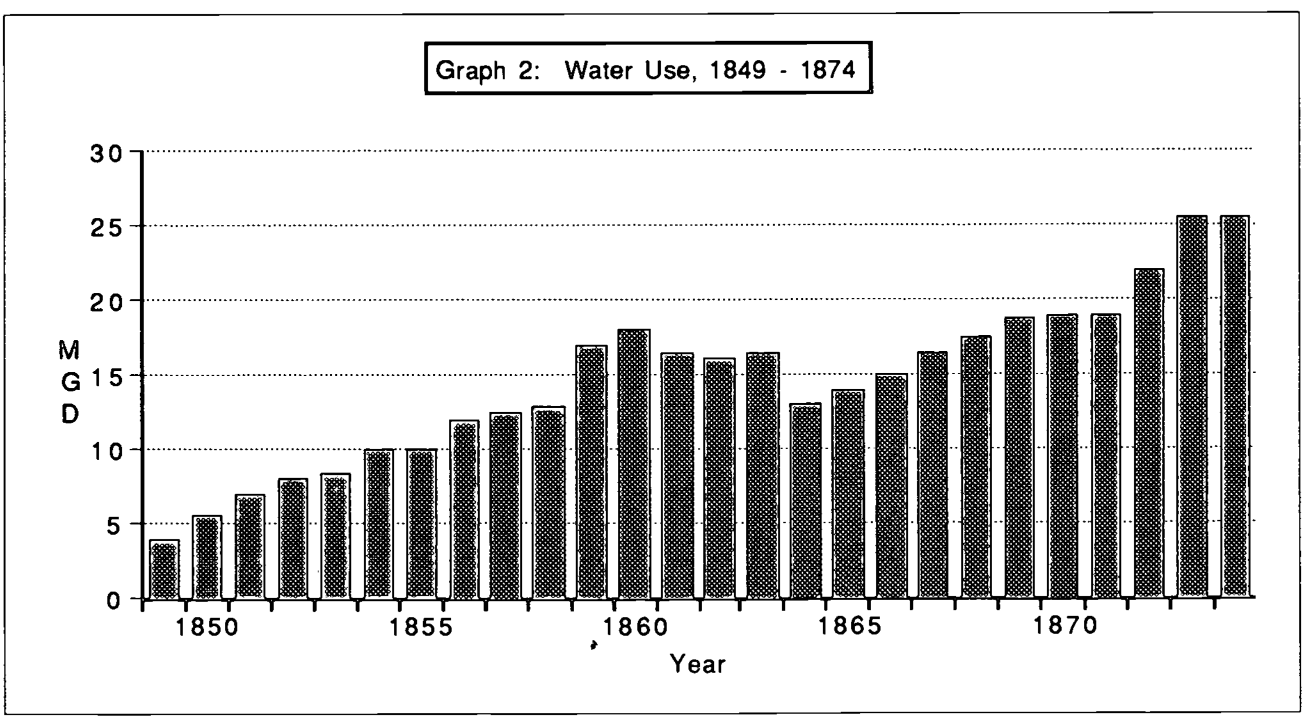
10. List five years of extreme drought and the average rainfall for those years.

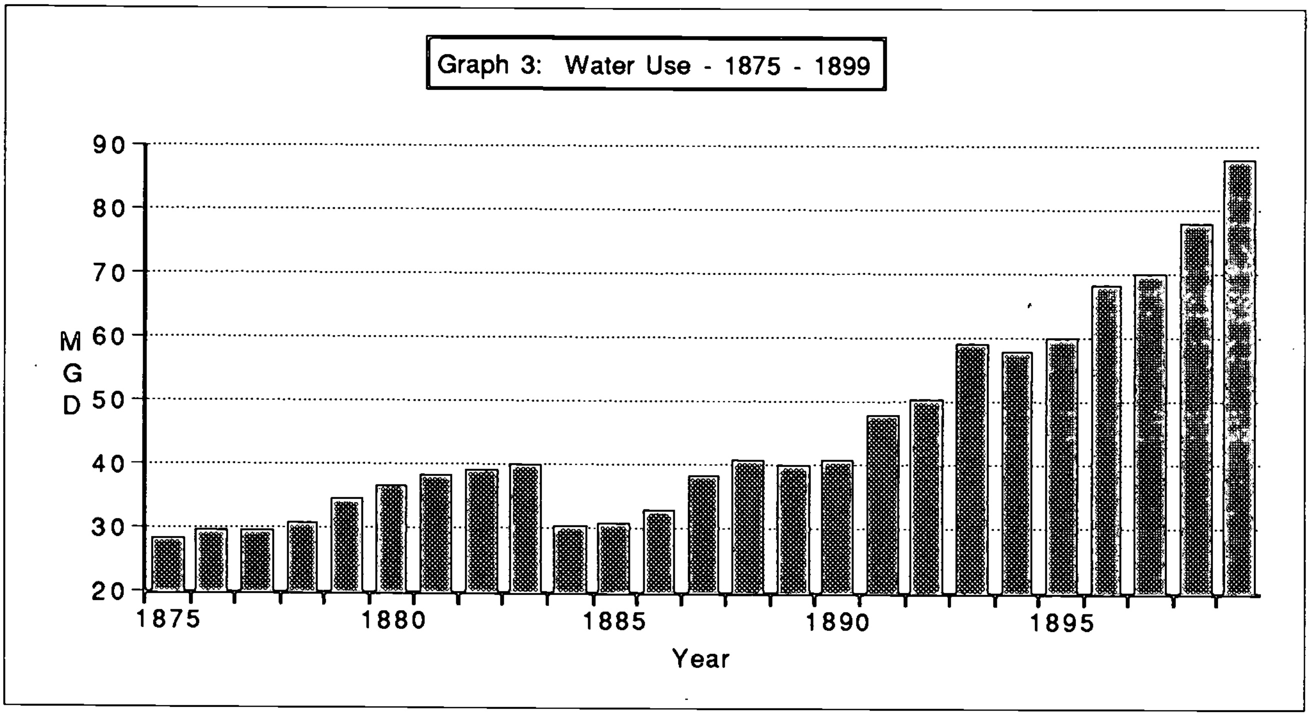
Year	Average Rainfall
________________	________________
________________	________________
________________	________________
________________	________________
________________	________________

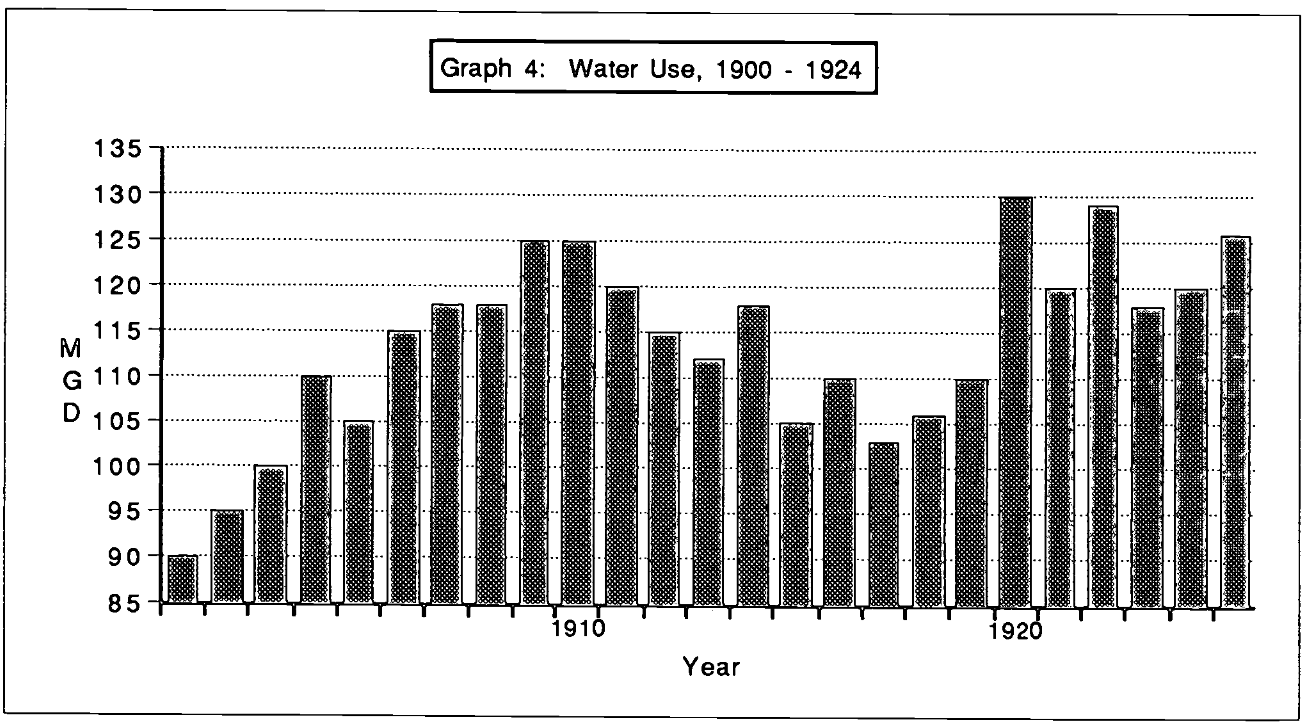
11. Since 1946 when the Quabbin Reservoir was completed, the average safe yield of the MWRA's reservoir system has been 300 million gallons per day. On average, how many million gallons per day above safe yield was the MWRA service area consuming in the late 1980s?

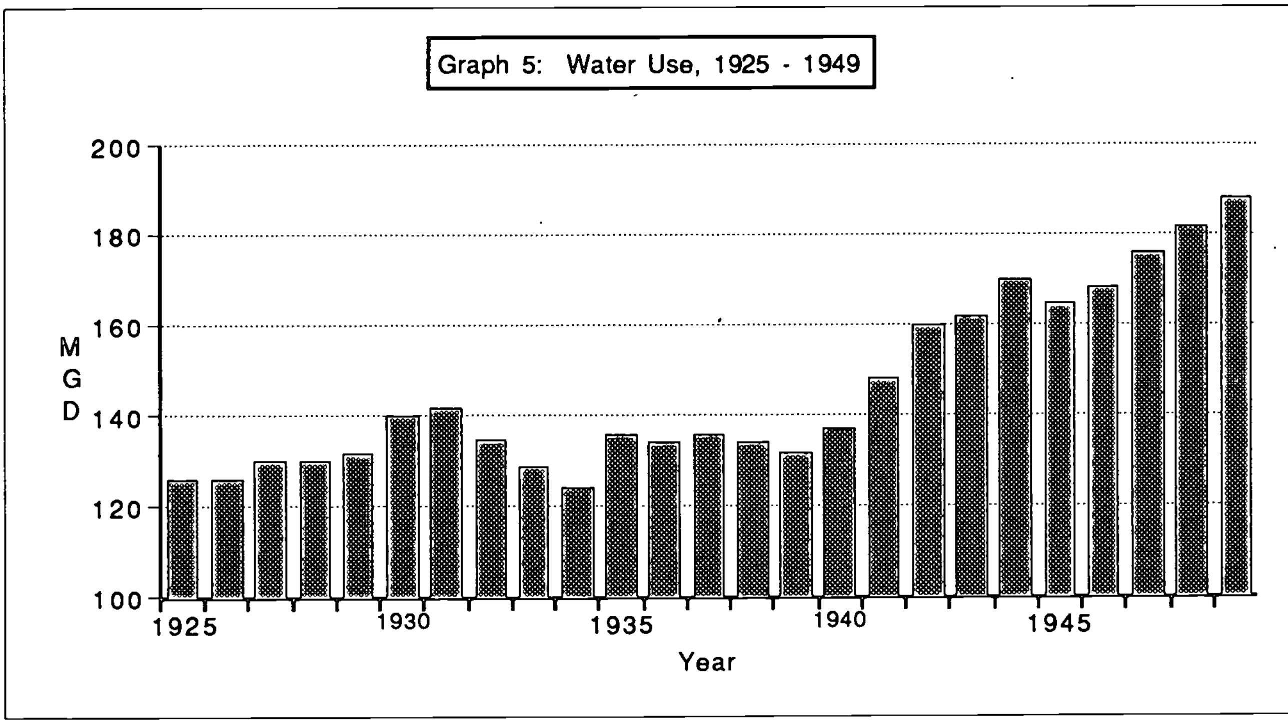
12. List five ways that you can conserve water.

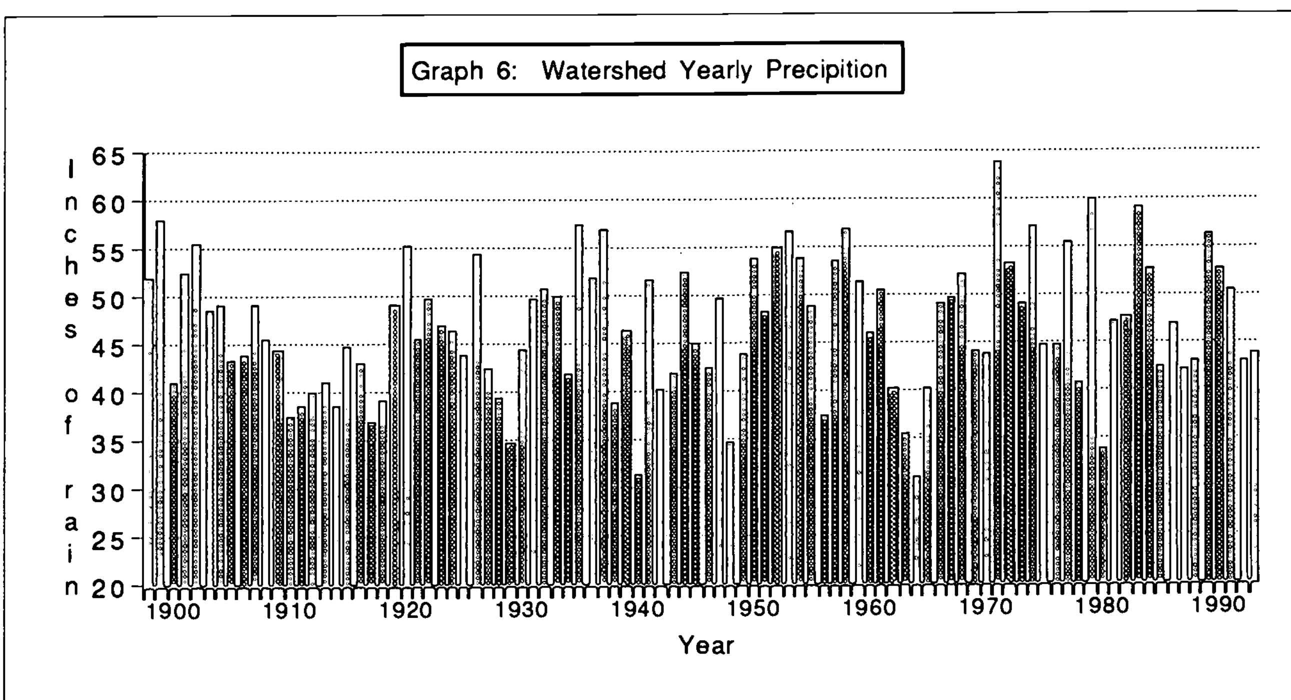

Graph 1: Water Use, 1900 - 1996
360
330
300
270
240
210
180
150
120
90
MGD
1910
1920
1930
1940
1950
1960
1970
1980
1990
1996
YEAR


Graph 2: Water Use, 1849 - 1874
30
25
20
15
10
5
0
MGD
1850
1855
1860
1865
1870
Year


Graph 3: Water Use - 1875 - 1899
90
80
70
60
50
40
30
20
MGD
1875
1880
1885
1890
1895
Year


Graph 4: Water Use, 1900 - 1924
135
130
125
120
115
110
105
100
95
90
85
MGD
1910
1920
Year


Graph 5: Water Use, 1925 - 1949
200
180
160
140
120
100
MGD
1925
1930
1935
1940
1945
Year


Graph 6: Watershed Yearly Precipition
65
60
55
50
45
40
35
30
25
20
Inches of rain
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

#8 Our Aging Infrastructure: Finding and Stopping Leaks in the Water Distribution System Teacher's Notes

Purpose

To introduce students to the need for a leak detection and repair program.
To show the students (via film) how underground water leaks are detected.
To explore issues related to the need for and economics of leak detection and repair.

Activity in Brief

This reading/discussion consists of a report on the MWRA's leak detection and repair program and an optional film. Students read the report and respond to thought questions. The data contained in the report covers the period from 1988 to 1996. With each passing year, the Water Resources Authority and many of its local customers make progress in their battle against an aging infrastructure.

Key words and concepts

Leak detection and repair
Infrastructure
Electronic listening devices

Materials

Technical Report on leak detection (included with this activity).
Water: Every Drop Counts. Film available from the MWRA Education Department.

Time Required

One class period

Additional teacher notes

This activity is written in the form of a simplified technical report. Students should read the report, then respond to the questions and activities at the end.

The problem of leak detection and repair is complicated by the fact that the MWRA is only responsible for a small amount of the total water mains in the entire system. For the most part, the individual cities and town are responsible for maintaining their own water distribution system. Thus towns with higher tax bases tend to be able to keep their system in better repair, while towns with fewer financial resources struggle to provide basic services and seldom have the money needed for repair and maintenance of the *infrastructure*.

Answer Key

1. In 1988, the MWRA found 81 leaks which accounted for 3.7 mgd of losses. They repaired 59 of those leaks, saving 3.4 mgd. Why do you think the first 59 leaks accounted for 3.4 mgd, while the remaining 22 leaks account for only .3 mgd?

   Because the Authority always repairs the most severe leaks first. Even when leaks are detectable, some of them are too small to justify making a repair. Some leakage, therefore, is inevitable within any large water system.

2. According to this report, how do technicians locate water leaks?

   First, they check the flow rate with meters. Once an unplanned flow is located, they pinpoint its location by means of sensitive listening devices that pick up the frequency of flowing or dripping water.

3. In 1988, 28% of the MWRA's delivered water was classified as being *unaccounted for*. Where does *unaccounted for* water go?

   Fire fighting, unmetered municipal buildings and schools, leaks, and inaccurate readings from water meters that underregister use.

4. The MWRA is responsible for finding and repairing leaks in 270 miles of water main. Who is responsible for finding and repairing leaks in the remaining 6400 miles of water main within the greater Boston water delivery system?

   Each of the individual cities and towns is responsible for its own mains.

5. Why do some of the cities and towns within the MWRA system have more successful leak detection and repair programs than others?

   Finding leaks is an expensive proposition in and of itself; repairing the leaks once they are found adds to the expense. Cash-strapped communiites often cannot afford such infrastructure repair programs because they must allocate resources to more basic community needs.

6. List three examples of the *infrastructure*.

   The water distribution system, municipal buildings, sewer lines, roads, bridges, electrical cables, utility poles, gas lines, telephone lines, street lighting, traffic lighting.

Additional Questions for Study or Discussion

7. CIVICS

Does your town have an aggressive leak detection and repair program? How much of the total public works budget goes toward repair and maintenance?

Consider having students check with the local library, the local newspaper, the town manager, and/or the manager of public works. If you have students call individual people, such as the public works manager, be sure to designate only one representative from the class to make the calls, otherwise those people will be inundated with inquiries and will quickly become uncooperative.

8. ENGLISH, CIVICS, SCIENCE, TECHNOLOGY, SOCIOLOGY

Write a research paper on examples of the degrading infrastructure both in Boston and throughout the nation.

9. EXPOSITORY WRITING, TECHNOLOGY

Following the model of this report, write a technical report about a subject relevant to you or your community.

For example, road building and road resurfacing, sidewalk replacement, zoning and development issues, solid waste disposal, hazardous waste and hazardous waste source reduction.

10. CLASS DISCUSSION

Each spring, potholes in the roadways of eastern Massachusetts become severe. This occurs because of the freezing and thawing action of water during the winter. Repairing those potholes and keeping the roadways in good shape requires large sums of money.

Each year, those potholes cause thousands of dollars in property damage, and they have caused several accidents. One year, in fact, a man was killed in an automobile accident on the Southeast Expressway that may have been caused when his car hit a large pothole. Discuss society's responsibility for keeping the infrastructure in good shape.

#8 Our Aging Infrastructure: Finding and Stopping Leaks in the Water Distribution System

TECHNICAL REPORT

Overview

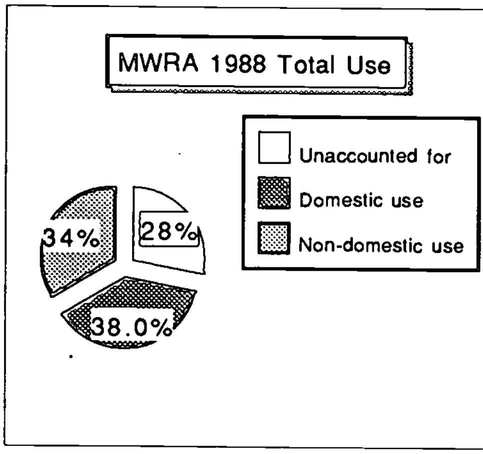
Water mains are part of the system that delivers basic services to the members of a society. This system is known as *infrastructure*, and in addition to providing a way to move clean water, it also includes safe roads and bridges, reliable electricity, and waste disposal. As our infrastructure ages, portions of it begin to break and must be replaced.

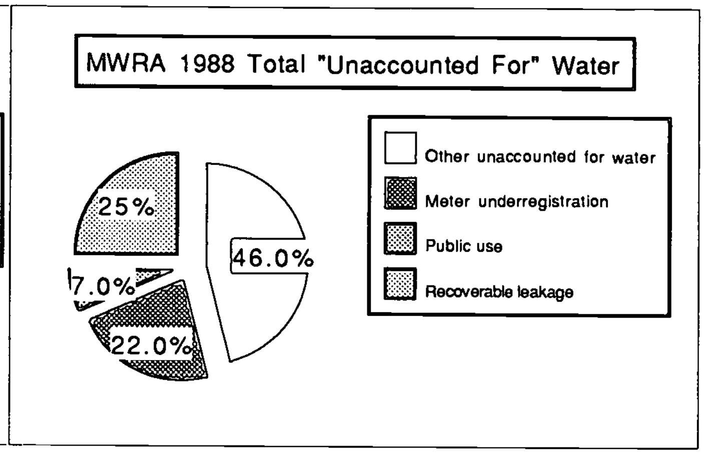
In older sections of the U.S., such as New England, many community water systems are at or approaching 100 years old. As they age, the water mains start to leak, especially at joints, such as those around valves, fire hydrants, and service connections into homes and buildings. Just as society allocates money to repair roads and bridges, so too, we must spend money to keep our water supply system intact. The leaks must be continuously located and repaired to minimize the amount of water we waste.

Leaks: Part of the category known as "Unaccounted For"

Water professionals know exactly how much water is flowing into the delivery system, and they know how much water use is measured by water meters. The amount of water that is metered, though, is always less than the amount flowing into the system. That water – the difference between the amount of water going into the system and the amount that is metered – is called *unaccounted for water*. Through the water industry, water professionals always assumed that it was OK if 85% - 90% of the water was metered and 10% - 15% was *unaccounted for*. Times are changing, though. Society is increasingly intolerant of waste, and water-related costs are rising dramatically as well. As a result, water suppliers are working to improve their performance. At the MWRA, the "leak detection and repair" program has been among the most successful conservation efforts.

In 1988, slightly less that 30% of the total water was classified as *unaccounted for*. The term "unaccounted for," however, was not quite correct, because the Authority was able to account for much of that amount: 22% resulted from meters that underregistered actual use; 7% went to firefighting and other municipal uses; 25% was recoverable leakage; and the remaining 46% – which is 13% of the total water supply – was truly "unaccounted for." In 1988, unaccounted-for water amounted to about 90 million gallons per day (90 mgd).





The Responsibility for Leak Detection and Repair

The overall water supply system is a very complex network. To add to the complication, the MWRA is only responsible for 270 miles of distribution pipeline. The remaining pipes belong to the individual cities and towns. While some of these cities and towns have excellent leak detection and repair programs, others must make difficult financial decisions about where to spend their money. Since the early 1990s, however, every community has been required to survey its entire water distribution system every two years as part of a comprehensive water conservation program.

Locating Leaks

Finding leaks is a technologically intricate, though not terribly difficult, job. Homeowners identify leaks in their homes by turning off all the water and checking the meter to see if the dials move. Likewise, the first step in a community-wide leak detection program entails checking the flow by using system flow meters. If a meter reading changes in an area where no water should be flowing, there is a leak. The next step is to find it. Residential customers would look for drips or leaking toilet tanks, and if none existed, they would suspect an underground leak.

In the water main system, leaks are almost always underground. Technicians search for leaks by means of sensitive listening devices. Water leaking from a pressurized water pipe makes three types of sounds, and a trained professional can readily hear and identify all three. As water escapes a pipe under pressure, the whole pipe wall vibrates, and the sound can sometimes be heard for considerable distances. Water then makes different distinct sounds as it trickles through the soil and flows underground. Modern leak detection equipment filters out all unwanted sounds, leaving only the sound of water, so experienced listeners can literally pinpoint the size and location of leaks. Then the water agency and the community must decide which leaks they will repair and which they will leave until they have more money in the budget.

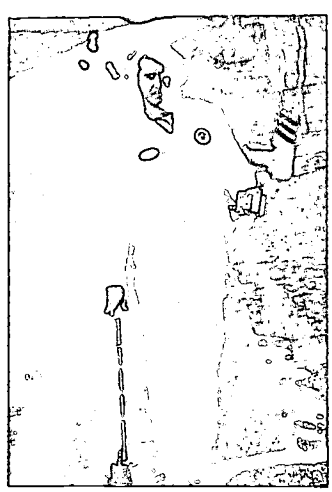
Effectiveness of Leak Detection and Repair in the MWRA Service Area

Since beginning a large scale leak detection program, the MWRA has eliminated millions of gallons of water losses daily.

- Within the 270 miles of MWRA-owned mains, the Authority has continuously repaired leaks. In 1988, when the program was just beginning, they located and repaired leaks accounting for 3.4 mgd. In 1995, after seven years of a successful program, they found leaks totaling only .83 mgd, and in 1996, they found 1.16 mgd in leaks.

- In 1990, local communities completed a two-year MWRA-sponsored survey of their pipes (which is hundreds of miles of piping over and above the 270 miles owned and operated by the MWRA). In 1990, they located 30.4 mgd in leaks; by 1993, that figure had dropped to 24.8 mgd; and by 1995, it had dropped even further, to 14.1 mgd.

An ongoing, effective leak detection and repair program, along with aggressive conservation, have helped the MWRA reduce total water consumption from well above the 300 mgd safe yield (consumption was 324 mgd in 1988) to around 250 mgd in the mid-1990s! (See Activity #7.) Leak detection and repair must be a continuing effort since new leaks constantly occur in our aging water system.



Technicians use sensitive electronic listening devices to locate underground leaks.

#8 Our Aging Infrastructure
Student Question Sheet

1. In 1988, the MWRA found 81 leaks, accounting for 3.7 mgd of losses. They repaired 59 of those leaks, saving 3.4 mgd. Why do you think the first 59 leaks accounted for 3.4 mgd, while the remaining 22 leaks account for only .3 mgd?

2. According to this report, how do technicians locate water leaks?

3. In 1988, 28% of the MWRA's delivered water was classified as being *unaccounted for*. Where does *unaccounted for* water go?

4. The MWRA is responsible for finding and repairing leaks in 270 miles of water main. Who is responsible for finding and repairing leaks in the remaining 6400 miles of water main within the greater Boston water delivery system?

5. Why do some of the cities and towns within the MWRA system have more successful leak detection and repair programs than others?

6. List three example of the *infrastructure*.

Additional Questions for Study or Discussion

7. Does your town have an aggressive leak detection and repair program? How much of the total public works budget goes toward repair and maintenance?

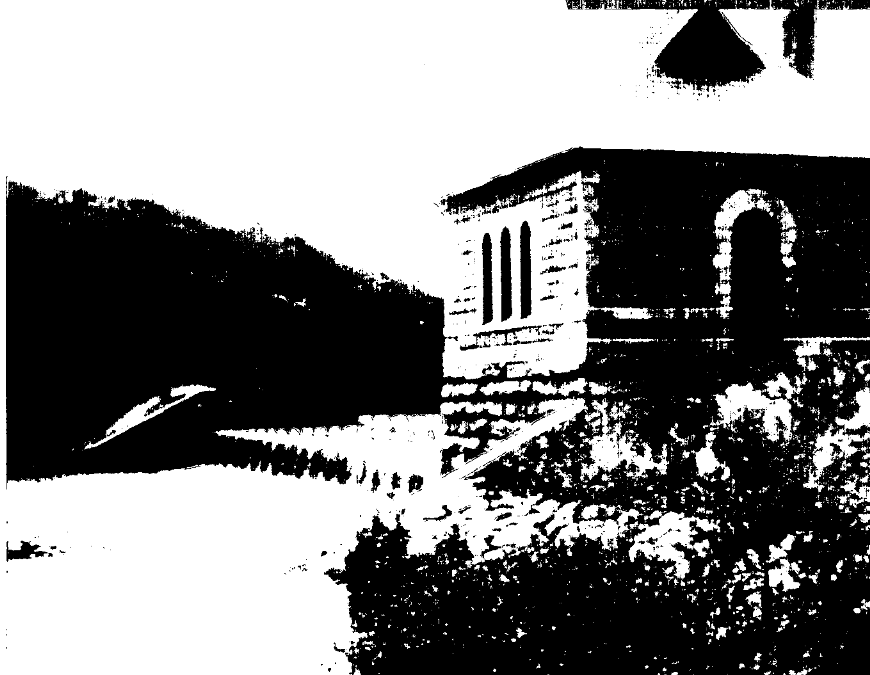
8. Write a research paper on examples of the degrading infrastructure both in Boston and throughout the nation.

9. Following the model of this report, write a technical report about a subject relevant to you or your community.

10. Each spring, potholes in the roadways of eastern Massachusetts become severe. This occurs because of the freezing and thawing action of water during the winter. Repairing those potholes and keeping the roadways in good shape requires large sums of money.

    Each year, those potholes cause thousands of dollars in property damage, and they have caused several accidents. One year, in fact, a man was killed in an automobile accident on the Southeast Expressway that may have been caused when his car hit a large pothole. Discuss society's responsibility for keeping the infrastructure in good shape.

Part III: Keeping Water Pure



#9 How Your Water is Treated
Teacher's Notes

Purpose

To provide an overview of the natural and man-made processes used to purify the water in the MWRA's reservoir and distribution system.

Activity in brief

This narrative provides a basis for discussing how MWRA water is purified. It contains examples of applied chemistry and describes the complex processes nature uses to purify water.

Key Words and Concepts

Ultraviolet light
Sedimentation
Eutrophication
Cellulose
Cellulolytic bacteria
Algae
Copper sulfate
Hydrofluorosilic acid
Chlorine
Ammonia

Materials

Accompanying narrative
(Optional) Chemicals listed in the key words list above and pH paper

Time required

One class period

Suggested activities

1. IN APPLIED CHEMISTRY CLASS
   a. Read the narrative before introducing the concept of neutralization.
   b. After reading the narrative, test the pH of a sample of tap water. The MWRA tries to maintain a pH of 8.5 (slightly basic) within the pipe system itself to reduce lead leaching from old pipes. As water flows from a faucet, it quickly adsorbs carbon dioxide from the air and forms a weak solution of carbonic acid, so tap water will frequently produce a slightly acidic pH reading.

2. DISCUSSION FOR ENVIRONMENTAL SCIENCE
   Discuss the action of cellulolytic bacteria and the reasons why phosphate detergents, common in the 1960s, caused problems in accelerating algal growths in streams.

#9 How Your Water is Treated
Narrative Essay

About 45 inches of rain falls on Massachusetts each year, and for every inch, 3,230 million gallons of fresh water pours into Quabbin Reservoir. Some of that water falls directly into the reservoir as rain, nature's own form of distilled water. Most of the water flows to the reservoir from the watershed possibly carrying bacteria and particulate matter, some of which are potentially harmful (though most are not). Yet other water reaches the reservoir through percolation and infiltration; that water has been filtered by its passage through the rock and soil.

A person standing on the shores of the reservoir has little idea of the dynamic natural processes at work increasing the purity of the water. While the surface of the reservoir appears placid and calm, much is happening both on and below the surface.

To begin with, engineers designed the Quabbin to maximize the water's "residence time." A single drop of water entering the reservoir may spend four years or longer in the system, during which nature has plenty of time to work. Sunlight falling on the reservoir contains *ultraviolet* radiation, high-energy, short wavelengths of light that destroy bacteria near the water's surface. The force of gravity pulls particulate matter down into the water and enables it to remain settled on the bottom. Under the surface, the water turns completely over about once a year, and is alternately exposed to the action of light and to the biological actions that take place under the surface.

Much of the solid matter that enters the reservoir and settles to the bottom contains *cellulose,* a complex chemical compound found in the cell walls of most plants. It is especially important because it does not easily change into less complex compounds. People, for example, excrete most of the cellulose we eat because we lack the enzyme *cellubiose*, which is necessary to digest it. If cellulose accumulated on the bottom of the reservoir, it would gradually replace the water and the reservoir would die. Scientists call this process of cellulose accumulation *eutrophication.*

Fortunately, nature provides a remedy against eutrophication. Certain bacteria, known as *cellulolytic bacteria,* live in the depths of the reservoirs. They ingest the cellulose and degrade it into simpler compounds. This decomposition is representative of a healthy ecosystem. If the ecosystem gets out of control, however, which can happen if the sources of oxygen and nutrients get out of balance, the health of the aquatic plants and animals, as well as the health of the water body itself, becomes threatened. The material released by the cellulolytic bacteria provides nutrients for algae, which grow near the surface of the water. As these algae die, they settle to the bottom and the decomposition cycle, or the process of *eutrophication* starts over again.

Algae feed on other nutrients in addition to the decomposition products produced by bacteria, especially *phosphates* and *nitrates*. These chemicals occur primarily in inorganic fertilizers used on farms and lawns, among other sources; when they are allowed to flow into the reservoir, they stimulate the growth of algae. For this reason, the watersheds surrounding reservoirs should be protected. Quabbin Reservoir is well protected but Wachusett is less so because of nearby development. When a rich diet of chemical nutrients is present, the algae grow in large numbers and *algal blooms* may develop. When the algal population reaches a certain level, the water can can take on a distinct fishy odor and taste. When this occurs in the Wachusett Reservoir, water managers use the first of five chemicals that are ultimately added to our water.

To retard algal growth during the summer months at Wachusett Reservoir, the water managers periodically drag mesh bags containing *copper sulfate* ($CuSO_4$) across the surface of the reservoir. This simple chemical controls algae. In the summer season, our water may contain about 0.10 parts per million of $CuSO_4$.

Up to four years or more after the water enters the reservoir, it enters the first steps of the distribution system. Quabbin Reservoir, all 39 square miles and (when full) 412 billion gallons of it, sits 530 feet above sea level. Gravity takes this water 25 miles through an aqueduct more than 100 feet underground. The water from Quabbin then joins with water collected at the Wachusett Reservoir, and that water then enters the aqueduct system leading to Boston.

Eight miles east of the Wachusett Reservoir, at a site called Walnut Hill – where the Cosgrove Tunnel feeds the Hultman Aqueduct – the water is treated with potash (potassium sulfate) and carbon dioxide. These two chemicals raise the water's pH and increase its alkalinity, making it less corrosive – and thus, less dangerous – when it comes in contact with lead pipes or lead-based solder on its way to your faucet. (See Activity #14: Lead in the Water.) One more chemical is added at Walnut Hill: hydrofluorosilic acid. You know it as fluoride, and it is the same stuff in your fluoride tooth paste. About one part per million of every glass of water in and around Boston is devoted to dental hygiene. It is estimated that every dollar spent in fluoridating water saves $50 in dental bills.

At other points in the distribution system, the water is disinfected with a combination of chlorine and ammonia. This disinfection kills the microorganisms – the bacteria, parasites, and viruses – that cause illness. The chlorine actually kills the organisms, the ammonia prevents the chlorine from breaking down, so it stays active, and the water stays safe from the byproducts that sometimes result from the chemical breakdown of chlorine.

The combined "water wisdom" of nature and humankind continues to be applied to ensure a supply of clean, safe drinking water in the MWRA system. Moreover, water purification standards continue to change. As a result of recent amendments to the Federal Safe Drinking Water Act, the control of bacteria by chemicals will be increased. Some open storage reservoirs will need to be covered. A new aqueduct will be built, and new corrosion controls may be implemented to further limit the possibility of lead contamination. Finally, the Authority may build a filtration plant to further ensure that our drinking water meets and exceeds all water quality standards.

#10 Water Purification
Teacher's Notes

Purpose

To acquaint students with some of the ways drinking water can be treated.

Activity in brief

This laboratory exercise demonstrates two steps in water treatment: settling (sedimentation) and filtration. This activity may be done either as a demonstration or a student activity.

Key words and concepts

Sedimentation
Filtration
Distillation
Turbidity

Materials (For each pair of students)

200 ml sample of untreated water (See instructions below for preparation)
Soil or ceramic clay, either wet or dry
Almond or lemon extract
250 ml beaker
250 ml graduated cylinder
Metric ruler
Funnel 7-8 cm diameter top
Ring stand and clamp
Wire triangle
Paper cup
50 g fine sand from garden shop or hardware store
50 g small gravel
25 g powdered charcoal (Aquarium supply shops frequently sell this item)
Filter paper
(Optional): 10 grams of table salt (NaCl)

Time required

10-15 minutes at the end of one class period and the following class period.

Procedure

1. Prepare (the day before) a quantity of "untreated" water so that each pair of students will receive 200 ml. For a class of 25 students, mix the following:

To 5 liters of tap water, add:

a. 25 grams of fine sand
b. Approximately 100 grams of soil or ceramic clay. (Do not use plasticine or oil clay.) Break off small chunks of the clay and stir into the water.
c. About 5 ml of almond or lemon extract to give the water a noticeable odor.
d. (Add 10 grams of NaCl if you plan to do a distillation procedure following this activity.)

2. Stir the water so that it is evenly murky and contains some small sand particles in suspension. This sample represents a quantity of water from a surface water source.

3. Have each pair of students dip out slightly more than 200 milliliters of solution and then carefully measure out 200 milliliters of that water into a 250 ml graduated cylinder.

4. Have students observe the color, clarity, odor and presence of solids, and record those observations on their data sheet. Cover the graduated cylinder and leave it undisturbed overnight.

5. In the following class period, complete the remainder of the activity.

Additional Activity Ideas

1. Build a solar still or set up a conventional water distillation apparatus and distill some salt water. Discuss the problems associated with distilling large amounts of water.

2. Have students do a library research report on water quality. An important piece of federal legislation is named the Federal Safe Drinking Water Act. Compliance with this act will require many communities to upgrade their water supply systems. As a result of this act the MWRA / MDC may need to institute filtration procedures in the future. Check if your school library has any information about this important piece of legislation.

Sample Test and/or Discussion Questions

1. Currently the MWRA does not filter its water. What may be some of the reasons why MWRA water may have to be filtered in the future?
   Currently MWRA water meets federal turbidity standards. If reservoir levels were to remain consistently low, more bottom sediment would be carried into the distribution system, and the water might not meet current standards. It is also possible that the federal government may make its turbidity standards more stringent.

2. What are some factors that make distillation of sea water an impractical method for obtaining fresh water for the Boston area?
   High cost of conventional energy. Lack of regular sunshine for solar distillation. Removal costs of the extracted minerals. Energy costs for distribution from sea level to higher elevations.

#10 Water Purification
Student Activity

Background

Water entering the MWRA / MDC reservoirs is quite clean and requires little treatment. In this exercise, you will learn two ways that the MWRA water is purified: filtration through the soil and rock of the watershed aquifers, and by standing in the reservoir system so that sedimentation removes most of the particulate matter.

At present, in addition to pH adjustment and fluoride for dental health, the water we receive from the MWRA requires only the natural process of sedimentation and the addition of small amounts of chlorine to kill harmful bacteria. At normal reservoir levels, any one drop of water entering the reservoir from the watershed may stay in the reservoir for four years or more before moving into the distribution system. This length of time allows gravity to pull the slightly heavier suspended solid particles to the bottom of the reservoir. If we use more water than rain is able to replace, the reservoir levels will drop. As a result, less time will be available for sedimentation and additional treatment may be required.

There is a second reason why water may have to be filtered in the future. When water contains small particles of clay and other substances, it appears cloudy. The water is then described as being *turbid*. The federal government has set *turbidity* standards for water and MWRA water meets current standards. But, if federal turbidity standards become stricter, the MWRA may have to begin filtering its water supply.

So, if we overuse our water supplies or if the federal government tightens its standards, artificial filtration may be required. What would happen? The MWRA would have to pay to build and maintain a filtering plant. For now, at least, nature – with a little help from us – is doing a fine job of cleaning our water...as you will see.

Procedure

1. Your teacher has a supply of untreated water. Using one of your 250 ml beakers, obtain slightly more than 200 ml of the water.

2. Carefully measure 200 ml of this water into your 250-ml graduated cylinder. Dispose of the rest of your sample and rinse out your beaker.

3. Carefully observe your sample. Record its color, clarity, odor and presence of solids in the appropriate spaces in Table I on the data sheet provided.

4. Cover your graduated cylinder with a piece of paper labeled with your name and allow it to stand overnight.

On Day II:

Sedimentation

1. Without disturbing your graduated cylinder, again observe your sample and record your observations on the data table.

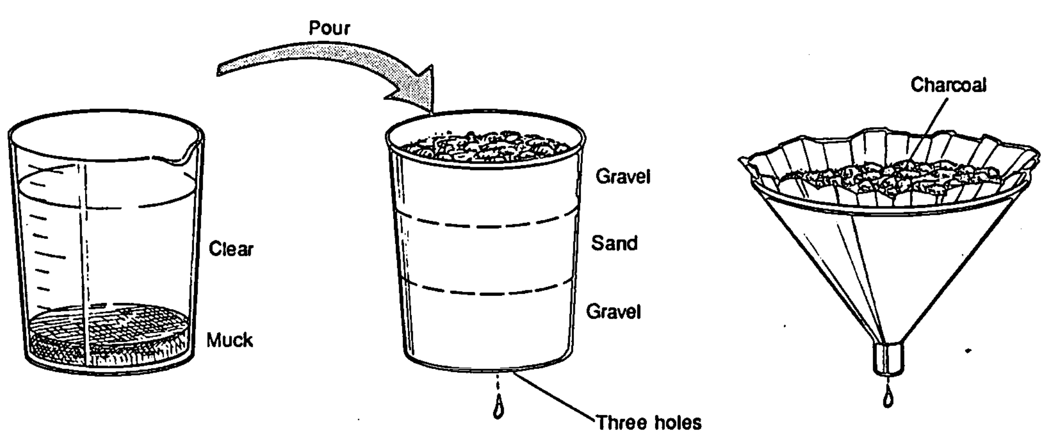
2. Estimate how much water in your graduated cylinder is clear. Record the amount in Table I.

Sand Filtration

1. Use the end of the wire of a large, opened paper clip to make three small holes near the center of the bottom of a paper cup. The holes should be close enough to each other so that they can be blocked by your thumb or finger.

2. Build a miniature sand-filtration device.
   a. Place a layer of fine gravel 2 cm thick on the bottom of the paper cup.
   b. Add about 4 cm of fine sand on top of this gravel layer.
   c. Add another 2 cm layer of gravel on top of this layer.

3. Pour the water from your graduated cylinder gently into the cup. Catch the filtered liquid in a beaker as it drains.



Sedimentation Sand filtration Charcoal Filtration

4. Rinse your graduated cylinder and use it to measure the amount of water you recovered from the sand-filtration procedure. Record this amount in Table I.

5. Observe the sample and record your observations of the sample in Table I.

(The sand in the filter removes impurities too large to fit between sand grains. The bottom gravel prevents the sand from washing through the holes and the top gravel keeps the sand from being churned up when the sample is poured in.)

Charcoal Filtration

If we draw down our reservoirs below safe levels, our water may become more turbid, and filtration may become necessary. Powdered charcoal, a common filtering agent, adsorbs many substances that give a bad taste, odor or cloudy appearance to water. Home fish tanks include charcoal filters to serve a similar purpose.

1. Fold a piece of filter paper in half, and then fold it again. Open the filter paper and place the folded paper into a funnel. Open one section of the paper and dampen it with tap water so it adheres to the funnel cone.

2. Place the funnel into a wire triangle supported by a ring clamp.

3. Lower the ring clamp on a ring stand so the funnel stem is 2-3 cm inside a clean 250 ml beaker.

4. Add enough powdered charcoal to fill the bottom one third of the filter paper.

5. Gently pour your sample water into the funnel. Keep the liquid level below the top of the filter paper. Continue filtering the rest of your sample.

6. If the filtered liquid (called the filtrate) is darkened by small charcoal particles, you can re-filter the liquid by using a clean piece of filter paper and no charcoal during the second filtration.

7. Measure the amount of filtrate you obtained. Record this amount on your activity sheet and record your observations on clarity, color, odor, etc.

Questions and Calculations

1. Calculate the percentage of the original, untreated water sample you actually purified. Use the following formula:

$$\text{Percent of water purified} = \frac{\text{Vol. of water purified} \times 100}{\text{Vol. of untreated water sample}}$$

2. On your data sheet, record the percentage of water purified.

3. Do you believe this treated water is safe to drink? Record your response on your data sheet.

4. List some reasons the water may not be safe to drink even after sedimentation and filtration.

5. Can you think of additional purification processes that might be necessary to make the water sample safer to drink? Record your answer on your data sheet.

Water Purification
Student Data Sheet

Name__________________________ Section/Class____________________

Date__________________________

1. As soon as you have obtained your sample of untreated water, record the following observations in Table I (on the back of this page): color, clarity, odor and presence of solids.
2. After allowing your water sample to stand overnight, again record your observations.
3. After completing the observations, estimate the amount of water in your graduated cylinder that appears to be clear. Record the amount in your data sheet.
4. Complete the steps necessary to do a sand filtration on your entire sample of untreated water. Rinse your graduated cylinder and measure the amount of water you recovered from the sand filtration procedure. Record your observations and measurements in Table I.
5. Using the water you filtered from the previous step, complete the process necessary to do a charcoal filtration procedure. After the water has been filtered with charcoal, rinse your graduated cylinder with tap water and measure how much water you now have left. Record your volume measurement and observations in Table I.
6. Using the amount of filtrate from the charcoal filtration process, calculate the percent of water purified. Show your calculations here.

Percent of water purified.____________

TABLE I

	Color	Clarity	Odor	Presence of solids	Volume (ml)
Untreated Water					
Untreated Water Next Day					
Sand-Gravel Filtered					
Charcoal Filtered					

#11 Contamination of an Aquifer
Teacher's Notes

Purpose

To demonstrate how water flows through an aquifer, and to demonstrate the difficulties of cleaning a contaminated aquifer.

Activity in brief

In this activity, which may be completed either as an activity or demonstration, students first build a model aquifer. They then contaminate that aquifer with food dye and observe the environmental impact. (This activity does not contain a student data collection sheet.)

Key words and concepts

Aquifer
Contamination
Pollutants

Materials

6" x 8" (approximate) disposable aluminum cake pans or plastic boxes
2 lbs. non-water soluble plasticine modeling clay or floral clay
3-4 lbs. white aquarium gravel
Food coloring
6 oz. paper cups (no larger)
Pea gravel
Small drinking straw
Water

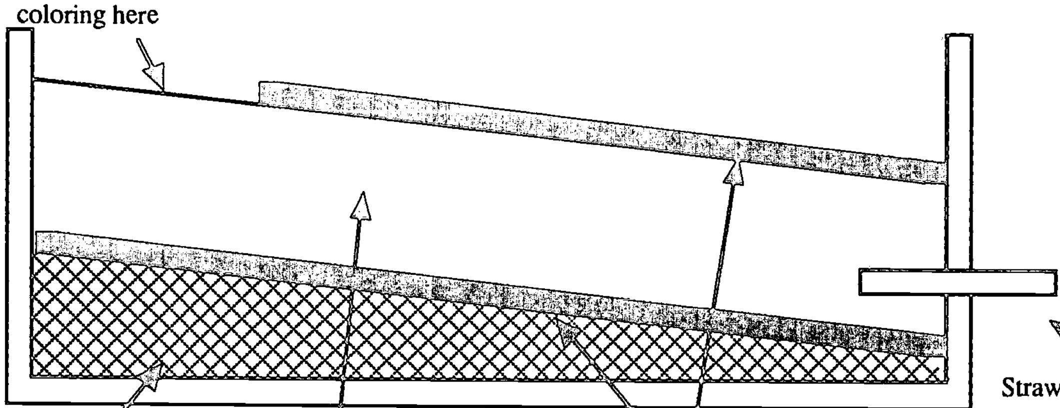
Time required

One class period

Procedure

1. Set up a model aquifer as shown on the diagram on the following page. If you use a disposable aluminum baking pan, make a small hole in one end and insert a section of a drinking straw to serve as the drain spout. Seal the hole around the straw with glue or clay. In addition, both clay layers should be well sealed against the side of the container.

Model for Contaminated Aquifer



2. Fill the aquifer model with clean water.

3. "Pollute" the aquifer by placing 10 drops of food coloring on the surface of the model near the highest end. This dye represents an application of chemicals or other pollutants added to the surface of the ground.

4. Before beginning the activity, allow the students to consider such questions as:
   - Where does the water go that falls on the surface of an aquifer?
   - How much water would it take to flush an aquifer 40 miles long and 100 feet deep?
   - What things might influence the time needed to flush an aquifer clean?

5. Slowly pour one 6-ounce cup of clean water on the aquarium gravel area as shown on the diagram above. Collect it as it runs out of the straw. Repeat this process starting with 6 ounces of clear water and continue the flushing process until all the food coloring is washed out and the discharge water is clear. Collecting the water in white paper cups or in test tubes held up against a white background will help you detect faint coloration.

6. Record the number of flushings required until you reach an output with no visible color. This may require up to ten flushes.
   NOTE: 6 ounces of water in this model equals about one inch of rain.

7. Ask the students if they believe that the water is completely free of food coloring, and ask them to guess the amount of contamination that may remain. (See Activity #18, *Understanding the Concept of Parts per Million and Parts per Billion.)*

8. *(Optional)* Nitrates are a problem in agricultural areas where large amounts of nitrate fertilizer are applied. To simulate nitrate pollution, add a small amount of a soluble nitrate to the aquifer and perform a standard nitrate test after each successive flushing. The nitrate contaminant would not identify its presence by color alone. (Safety note: Be certain students are wearing safety glasses for the following activity.)

   Standard nitrate test: Collect 2 ml of the flushed water. Add 10 small crystals of iron (II) sulfate and mix the contents thoroughly until the crystals are dissolved. Carefully drip 10 drops of concentrated sulfuric acid down the inside wall of the test tube so the acid forms a layer on the bottom of the tube. Do not mix the two layers. In the presence of nitrate ions, a brown ring will form where the two liquid layers meet.

Additional Activity Ideas

1. Discuss the need for proper disposal of hazardous industrial wastes and household chemicals. *A Clean Environment Begins at Home*is available from the MWRA by calling (617) 241-4662. Many unused household chemicals should not be disposed of by flushing down the drain, and waste oil should never be poured out on the ground.

2. If you can obtain geologic maps for your area, examine a region near your home and try to determine from the area's geologic structures the direction of groundwater flow in your area. What features of the geologic formations are factors in establishing landfills or industrial sites?

Sample Test and/or Discussion Questions

1. What could be contaminated by chemicals poured on the ground?
   aquifer or water table

2. What keeps chemical contamination from reaching lower levels of an aquifer?
   Layers of material that are relatively impermeable. In the model aquifer, the clay layer was impermeable to the food dye.

3. What would be the problems resulting from a major chemical spill, such as a tank truck of hazardous chemical tipping over in a watershed area? What steps could be taken to avoid damage to the area's aquifer?
   If the chemicals were allowed to seep into the ground they could be carried by the groundwater into the aquifer. Chemical spills should be contained by temporary dams, neutralized by other chemicals (if possible), and/or removed.

#12 Dispersion of Pollutants
Teacher's Notes

Purpose
To make students aware of some of the complex problems related to the contamination of underground aquifers.

Activity in brief
Using ordinary coffee filters and food dye, students see the unpredictable ways soluble materials (such as contaminants) can move in underground rock and soil. This activity can either be completed as a demonstration or student activity.

Key words and concepts
Aquifers
Dispersion
Contaminant

Materials
Coffee filters (6-8 inch diameter) or regular filter paper-- one per pair of students
Colored food dyes -- red, yellow and blue
Aluminum foil -- one 12" x 12" piece per pair of students
Catch basins -- one for each pair of students
Water -- to wet filters
Eye dropper

Time required
One class period.

Procedure
1. Have the students work in pairs.
2. Prepare a mixture of one part each of the three food dyes and one part water in a large enough quantity so that each pair of students can receive about five drops. (This mixture will have a very unappealing appearance. Do not tell students what it is.)
3. Provide each pair of students with one coffee filter, a small catch basin to protect table surfaces (such as a paper plate or tray) and a piece of aluminum foil.
4. Additional procedures are listed on student activity sheets.

Additional Activity Idea: Building an Aquifer
Using an aquarium or clear plastic box, build a three-dimensional water table. Put "test wells" in the water table by taping clear drinking straws against one side of the container. Once they are

in place, add the first layer of sand and gravel, and saturate that mixture with water. Place a layer of non-water-soluble clay, such as plasticine, over this mix, taking care to seal the edges of the clay against the side of the container and around the straw representing well No. 2. Add a few more inches of sand and gravel and place clay over a portion of this layer. Seal the clay against the sides, one end of the box, and the straw representing well No. 1. Finish filling the container with sand and gravel. Sprinkle food dye at several places on the top of the model. Use a watering can to represent rain and see how long it takes the dye to reach each test well.

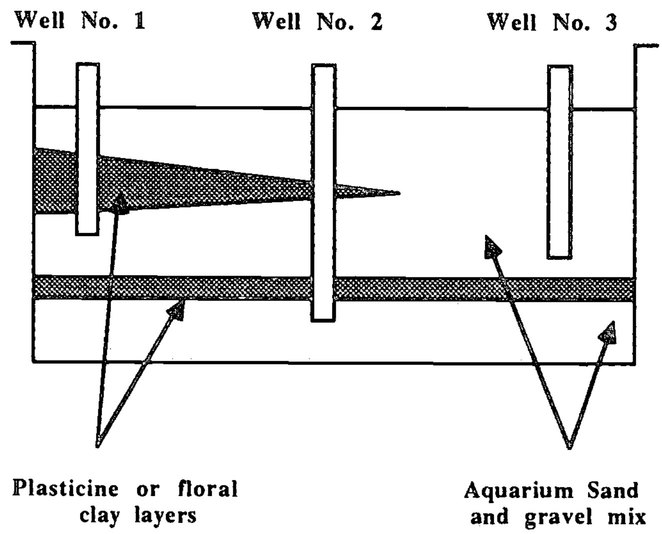


Figure 1 - Model Aquifer

1. Have the students predict which well will first show color contamination.
2. Why are deeper wells less apt to be subjected to contamination? Why will Well No. 2 be protected from surface contamination in this model ?
3. What affect would pumping from Well No. 1 have on the movement of contamination? Pumping from Well No. 2?

Sample Test and/or Discussion Questions

1. True or False: Pollutant dispersion paths are relatively easy to predict. *False*
2. What are some factors that determine the direction and rates of movement of pollutants. *Soil types, rock types, shape of rock formations and type of pollutant.*
3. You are a local official in a small town which draws its water supply from local wells and a chemical company wishes to establish a plant in your town. What information would you need to know about the geological make-up of your local area, the type of plant being established, and the wastes the plant will generate? *You would want to know the general structure, type and permeability of the sub-surface rock in the area of the proposed plant. You would also want to know if the plant uses, produces or discharges any chemicals that are toxic or carcinogenic. You would also want to know how they intend to store, transport or dispose of their waste.*

12 Dispersion of Pollutants
Student Activity

Background

Water supplied by the Massachusetts Water Resources Authority (MWRA) is some of the best water available anywhere in the U.S. But not all communities in eastern Massachusetts draw their water from the MWRA. Some communities maintain their own reservoir systems or wells. In some of these towns, wells have been contaminated. The result of such contamination is at best, costly (because towns must buy their water from another supplier), and at worst, a serious health hazard. Protecting and conserving safe drinking water is everyone's concern. This activity will help show you how pollutants move through aquifers and how difficult pollution sources can be to trace.

Identifying the source of pollution is often complicated by the fact that different types of soil and rock cause water and contaminants to move in different directions at different rates. Not all chemical pollutants are equally soluble in water, and some bind to rock and soils in different ways. Such variables as the shape of underground rock formations and soil types also affect how water and contaminants travel.

Activity

In this activity you will watch pollutants travel, and you will be able to see that they do not always follow predictable paths.

Materials

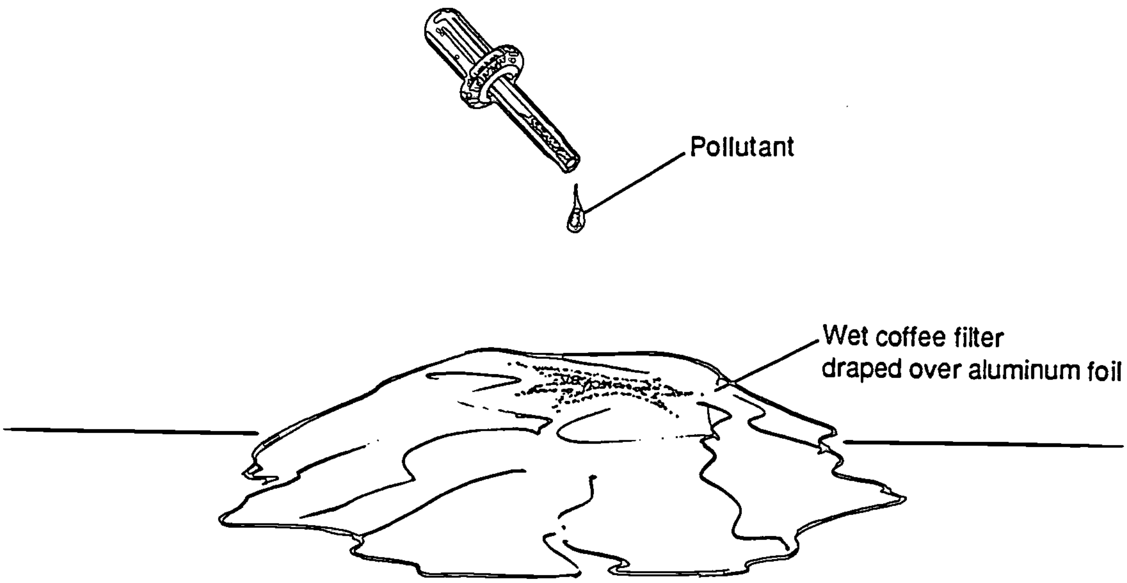
One 6-8 inch coffee filter or regular filter paper
Solution of pollutants from your teacher (about 5 drops)
12" x 12" piece of aluminum foil
Catch basin
Water -- to wet filters
Eye dropper

Procedure

For this activity, you will work in groups of two.

1. Write your names on the coffee filter with a pencil. Each of you should mark an "X" or "Y" somewhere on the paper to represent imaginary wells from which you draw your water.

2. Loosely crumple a piece of aluminum foil and place it in the middle of the catch basin.



3. Dampen the filter paper with water and drape it over the crumpled aluminum foil. The shape of the filter paper as it drapes over the foil and over the edge of the basin need not be symmetrical or uniform. In this model, the filter paper represents the underlying soil through which water permeates and the aluminum foil represents the shape of the bed rock on which the soil layer rests.

4. Obtain a small amount of a brown solution from your teacher and place five drops at a random location on the filter paper. This solution represents a pollutant.

5. Set the basin and filter paper aside for ten minutes, then examine the filter paper.

6. Leave the paper overnight and examine it again tomorrow.

7. Record and describe all your observations in the spaces provided.

Questions

1. Describe what happened to the "contaminant."________________________________
   ____

2. What color contaminant traveled the farthest from the point of contamination? _______

3. Did any of the contaminant reach both "wells"? _________________

4. Did any of the contaminant travel uphill (against gravity)?________

5. What additional changes occurred when you observed the filter on the following day?

   ____

Discussion

Examine all of the dispersion models made in your class. How are they alike and how are they different? Are any of them identical? What are the factors that may contribute to their differences? Guess what was in the mixture. Can you think of some reasons why some of the molecules of pollutant traveled farther than others?

This exercise demonstrates the difficulty of determining the source of a chemical contaminant. The geologic formations underlying aquifers are disjointed and discontinuous, and tracing the precise path of the source of the suspected contamination to the wells is often nearly impossible.

#13 *Cryptosporidium:* Mystery Spore
Teacher's Notes

Purpose
To help students develop the decision-making skills required to make difficult public policy decisions regarding the costs and benefits of investing in expensive water treatment systems to ensure a safe drinking water supply.

Activity in Brief
Students learn about the disease-causing microorganism *Cryptosporidium parvum* and the options available to water agencies to prevent outbreaks of the disease cryptosporidiosis. You will then assign students to groups, each of which represents a different community interest. Each group will decide which option they would recommend and explain their reasons. The class then votes on the options.

Key Words and Concepts
Parasite
Oocyst
Weakened immune system (immuno-suppressed)
Contamination
Cost and Benefits

Materials
Student handouts of decision sheets

Time Required
two to three days

Additional Activity Ideas
Have your students write newspaper editorials explaining and justifying their position to the public at large.

Sample Test and/or Discussion Questions
1) What kind of organism is *Cryptosporidium parvum?*
It is a parasite, a one celled organism that depends on a "host" organism for food and survival. It travels from one host to another as an "oocyst" in a protective shell that can survive in the environment without a host for long periods of time.

2) What kind of health threat does it pose?
It causes the disease cryptosporidiosis, which causes severe diarrhea, nausea, vomiting, and headaches.

3) Why does affect different people differently? Who is at most risk?
This disease may last one or two weeks in a healthy person, but can cause long-term illness or even death to a person with a severely weakened immune system, such as people undergoing chemotherapy, transplant patients, and people with AIDS.

4) What are at least two reasons why it is hard to keep out of the water supply?
   1) Cryptosporidium's hard shell makes it very difficult to kill with conventional disinfection, most notably chlorine, which is widely used to disinfect water.
   2) Cryptosporidium's small size makes it hard to filter out of water reliably.
   3) Water can become easily contaminated by different animals and human activity.

5) What are at least three reasons why it is hard to tell when *Cryptosporidium* poses a health threat?
   1) The existing tests for Cryptosporidium not very accurate. (They are also expensive and difficult.)
   2) The tests for Cryptosporidium do not indicate if it is "viable" or dead. Dead Cryptosporidium does not cause disease.
   3) The existing tests do not distinguish between the disease-causing and harmless species of Cryptosporidium.
   4) Scientists are not sure how many oocysts of Cryptosporidium parvum are necessary to cause disease in people.

6) What are the major sources of contamination? What source usually causes widespread outbreaks?
   The feces of an infected animal (person, pet, farm animal, wild animal, bird) – or through water and food that has been contaminated with such feces. Most widespread outbreaks are attributed to contaminated water supplies., even though transmission occurs primarily through direct contact with an infected person or animal.

7) What is the best ways to protect an individual from contamination?
   Boil water for at least one minute before drinking and cooking, or use bottled water. Don't drink water directly from streams or lakes. Most other sources of infection can be prevented by thoroughly washing hands after using toilets, changing diapers, and handling animals – and before handling food.

8) What are at least three options water agencies have for protecting the public from Cryptosporidium outbreaks?
   1) Ozonation to disinfect the contaminated water.
   2) Source protection to reduce chances of contamination by animal feces.
   3) Public warnings to boil water when Cryptosporidium is present and thus kill the oocyst.
   4) Public education in the at-risk communities.

9) What is at least one drawback to each of the options?
   1) Ozone is expensive and does not provide lasting protection to water in the distribution system.
   2) Source protection cannot guarantee the absence of Cryptosporidium
   3) Public warnings: people may not want to boil water on a daily basis.
   4) Public education efforts generally do not reach or are not effective with every individual.

10) What do you think about this statement as it concerns cryptosporidiosis: "It is the responsibility of the community to protect the health of the most sensitive population regardless of the cost."

#13 *Cryptosporidium:* Mystery Spore

Background

What is *Cryptosporidium?*

In much of the developing world, people get sick from drinking untreated water. Here in the United States, we are accustomed to trusting our tap water. Our water supply, however, is increasingly under attack by a tiny protozoan named *Cryptosporidium parvum* that causes a disease called *cryptosporidiosis*. *Cryptosporidium* means "mystery spore" in Latin, and in many ways that is exactly what it is.

Until 1976, scientists did not know that the "crypto" organism made people sick, and the symptoms of cryptosporidiosis were attributed to other causes, such as "just a little stomach bug." In a person with a healthy immune system, these symptoms may last for as long as one or two weeks, but during that time, they are simply unpleasant – diarrhea, nausea, vomiting, and headaches – but they are not fatal. Victims may feel like they're going to die, but they don't.

The outcome can be different for people with severely weakened immune systems, such as people with AIDS, people undergoing chemotherapy treatment for cancer, and transplant patients. For them, the symptoms may be more severe and may last months or even years, and the loss of fluids from diarrhea and vomiting can be life-threatening.

Cryptosporidium is a parasite, an organism that depends on a "host" organism for food. *Cryptosporidium* is passed from one host to another as an "oocyst" (pronounced "oh-oh-sist"), an infective stage of the protozoan's life cycle, that can survive for long periods without a host. The oocyst lives inside a hard protective shell that allows the organism to survive for a long time outside the body of a host. *Cryptosporidium's* hosts include mammals and birds. It can be spread through the feces of an infected animal – or through water and food that has been contaminated with such feces. Once it is swallowed by a potential host, it causes illness in two to ten days.

Sidebar:

Spreading *Cryptosporidium*

Humans can become infected with *cryptosporidium* several ways:

- Drinking water that has been contaminated with infected feces. The most common source for this contamination is cattle, since young calves are among *cryptosporidium's* favorite hosts.
- Eating food that has been contaminated by improper sanitation in food handling warehouses, restaurants, or private homes.
- Contact with feces while using the toilet, changing diapers, or handling animals, followed by failure to properly wash hands.

Controlling *Cryptosporidium*

- If a water supply has been contaminated with *Cryptosporidium*, the best protection is to boil the water before drinking and cooking for at least one minute.
- Most other sources of infection can be prevented by thoroughly washing hands after using toilets, changing diapers, and handling animals – and before handling food.

Why *Cryptosporidium* Challenges Water Agencies

The hard shell of the *Cryptosporidium* oocyst does more than allow it to survive a long time while waiting for a host. It also makes the organism immune to most conventional water disinfection methods, especially chlorination and chloramination, the most widely used methods. In addition to being hard to kill, *Cryptosporidium* is also hard to filter because it is so small: only 3 - 7 microns (3 to 7 millionths of a meter), and it can pass through improperly maintained filtration systems.

On the other hand, *Cryptosporidium* is easily killed by boiling water. Thus, when a water agency does find *Cryptosporidium* in its water, it can alert the public and advise them to boil water before using it for drinking, cooking, or feeding pets. Boiling water can save the life of people with weakened immune systems.

The tests for *Cryptosporidium* available to water suppliers present a number of problems. First, they are unreliable, often reporting no *Cryptosporidium* when some is present, mistaking live (viable) oocysts for dead (non-viable) ones, or confusing *C. parvum* with other species. Second, they are difficult to perform. They require running 100 to 200 gallons of water through a membrane filter, and microscope technicians need a great deal of experience to identify *C. parvum* correctly. Finally, they are costly, making multiple tests, needed for confirmation, very costly. Fortunately, new and better tests are on the horizon.

Yet another complication is that scientists do not know how many oocysts of *C. parvum* are necessary to make people sick, so they don't know when or if there is a "threshold" or level below which *Cryptosporidium* poses no health risk. Because no effective medical treatment for cryptosporidiosis yet exists, the disease must run its course, which for healthy people might mean a week or two of discomfort, and for immuno-suppressed individuals, might mean death.

Cryptosporidium, Health, and Society

The difficulties associated with detecting and treating *Cryptosporidium* are having a tremendous impact on society. Since the 1980s, there have been several major outbreaks and a number of minor ones in the United States. The worst of these outbreaks struck Milwaukee in 1993. Almost half of Milwaukee's 800,000 citizens became ill, and more than 50 people with AIDS and at least one elderly person died of cryptosporidiosis.

This outbreak occurred despite the fact that Milwaukee's water treatment system met or exceeded all federal regulations for water quality. Current water treatment regulations provide a measure of protection against *Cryptosporidium*, but they don't address all the special challenges that *Cryptosporidium* presents. This lack of regulation was partly due to an incomplete understanding of what levels are "safe," and partly because of the lack of effective (and cost-effective) treatments and safeguards. Today, this much is known: more than 95% of raw water in the United contains some *Cryptosporidium*, and every water agency that treats surface water has the potential for a *Cryptosporidium* outbreak.

To reduce the chance of an outbreak, water agencies are looking at possible prevention/treatment methods. Watershed management can reduce the likelihood of *Cryptosporidium* getting into the source water. Filtration at the treatment plant will remove most *Cryptosporidium* oocysts. Lastly, disinfection with ozone is far more effective against *Cryptosporidium* than chlorination.

What is Ozonation:

Ozone consists of three atoms of oxygen (O_3), and it is a powerful disinfectant when added to water. As water agencies upgrade their disinfection systems, many are installing ozone systems. Ozone, however, does not continue to work as a disinfectant after the water enters the distribution system, while chlorine does. As a result, ozonated water must also be chlorinated so the water stays disinfected until the moment it comes out of your faucet.

The Benefits of Ozone:

1) When ozone gas bubbles up through water, it breaks into the *Cryptosporidium*'s oocyst, thus killing it. It can also kill other microorganisms that are resistant to chlorine.
2) Ozonated water tastes better than chlorinated water.

Costs of Ozonation:

1) Ozone systems are expensive, and existing disinfection systems must be completely retrofitted to accommodate the new technology. Milwaukee invested $60 million dollars in an ozone system following its *Cryptosporidium* outbreak.
2) Ozone systems do not replace conventional chlorine systems. Instead, they must be operated in tandem.

The most cost-effective strategies for water agencies, however, include source protection and public outreach.

Source Protection: Protecting the Quality of Raw Water in Nature

Benefits:

1) Reducing *Cryptosporidium* near the water supply in the first place could reduce the need for costly new treatments.
2) Since sources of *Cryptosporidium* also contain other pollutants and bacteria, prevention would also protect water from other contaminants.

Costs:

1) Source protection may be cost-effective.. Even with the best source protection, however, there will always be occurrences such as an unexpected increase in suspended matter, which could include *Cryptosporidium*, and water agencies must be prepared to protect people from an occasional outbreak.

Public Outreach: Educating and Warning the Public

Benefits:

1) By educating people about how *Cryptosporidium* spreads through unsanitary practices, water agencies, public health officials and healthcare providers can reduce the spread of the disease and help people protect themselves if an outbreak occurs.
2) By providing information to people at risk for serious illness, such as transplant or chemotherapy patients, or people with AIDS, water agencies can tell people when to take extra precautions, such as boiling water, buying properly treated boiled water, and using good sanitary practices, such as hand washing.

Costs

1) The cost of public outreach and education is minimal compared to building or retrofitting water treatment plants.

As you can see, upgrading water treatment plants against *Cryptosporidium* is a huge expense and is not 100% effective. Water consumers will pay for those upgrades through higher water bills. In deciding whether to pay for those upgrades, society must answer some very difficult questions. That is what you and your classmates will do in the activity below.

Activity

Your teacher will divide you into groups representing different interest groups in society. Your group must define its goals and purposes, review the information about *Cryptosporidium*, and decide whether you support spending large sums of money to make your water system cryptosporidum-proof for all members of your community of 100,000 people. You will make these recommendations to the board of directors of the water department, which will then decide which action to take.

The Groups and Their Purposes:

A) Water Department:
Your role is to provide the public with the safest water possible at the most reasonable rates. Above all, your water cannot make people sick, but you must be concerned about the cost-efficiency of the water treatment plant, because if you cannot justify your rates to the public, they will challenge them in court. You must meet all federal water quality regulations, and your community expects the highest quality drinking water.

B) AIDS Support Group:
You help people with HIV and AIDS get the best available health care, and you educate them about how to take care of themselves and maintain an active lifestyle. In the past few years, medical breakthroughs have been restoring patients to health who might have previously died. It is tragic that these same people are now at risk of dying from a preventable disease like cryptosporidiosis.

C) The League of Concerned Scientists:
You educate people about risks they face to help them learn how to place these risks in perspective. For instance, you tell people who are concerned about the extremely small chance getting cancer from barely detectable amounts of contaminants in the drinking water that there is a much higher risk of getting cancer from coffee, tea, soda, chocolate, sugar substitutes, and many other common substances. You question the effort to spend ever-higher amounts of money to remove ever-smaller risks from our environment. You encourage people to attack major, preventable kinds of risks, such as drinking and driving, smoking, consuming lead, and breathing radon in air-tight houses.

D) The Urban Poor Coalition:
Your role is to ensure that public services go toward programs that assist the poor in your community. You see many poor people struggling to pay for food and minimum health care. If a poor household's water bill rose by even a few dollars a year, that money would reduce their budget for food and medicine even further. You question the wisdom of spending additional money to help so few people when it would hurt so many.

Procedure:

1) All the groups attend a public hearing to gather information and to hear the concerns of the citizens.

2) Here is some of the information you learn:
   - Adding ozone disinfection will cost a typical family of four an average of $30 a year in additional water bills.
   - The ozone system will not protect the water from pathogens (germs) after it leaves the water treatment plant, so the water must also be disinfected by conventional methods, such as chlorination.
   - Your community has never had levels of *Cryptosporidium* higher than 50 oocysts per 100 liters of water. Even this low level could be enough to make some people sick, and could therefore be life threatening to immuno-compromised people.
   - Improving source protection will reduce the probability of *Cryptosporidium* levels reaching 50 oocysts.

3) Here are some of the statements you hear from the public:

   A) "Clean drinking water is not a privilege. It is a right that everyone shares equally."

   B) "Every time scientists identify a new contaminant, we have more and more costly regulation. At some point people just have to realize that we don't have the money to eliminate every single risk that exists."

   C) "Our drinking water is safe enough for most people. Those who are vulnerable to low levels of *Cryptosporidium* know who they are, and they know what to do protect themselves. Isn't that enough of a safeguard?"

   D) "You have to decide: Is it worth every family in this community spending up to $100 more per year on their water bills to prevent deaths that may or may not happen?"

   E) "Providing the public with water that might cause illness or death would make you responsible for those people's lives! How dare you attach a price to a life."

   F) "We should not be asking ourselves whether it is cheaper to allow a few people to get fatally ill or cheaper for utilities to remove all the *Cryptosporidium*. We should not ask questions of cost when it comes to fatal diseases like cryptosporidiosis."

   G) "Even if we spend the money on an ozone system, *Cryptosporidium* could still invade our water delivery system and still kill a few people. Why spend money on something that has no guarantee of protecting the people we want to protect?"

4) Making a Recommendation:The mayor has asked your group to recommend one of these options for action:

   A) Invest in an ozone disinfection system.

   B) Invest in additional watershed protection and source protection, which would add $10 per year to every family's water bill.

C) Invest in public education to ensure that people at risk know what to do if *Cryptosporidium* is found in the water, adding $1 to every family's annual water bill.

D) Provide distilled or highly filtered water to at-risk persons at ratepayers' expense, at an additional cost of $30 for every family.

5) Before your group decides what position to take, think through your own personal position in private.

6) Share your responses with your group and discuss any differences of opinion. Reach a consensus and then fill out your group's recommendation sheet:

7) Each group will share its recommendations and supporting reasons with the class. After listening to all the group presentations, the class will take a vote by private ballot. Each individual student may vote his or her private opinion; you do not need to vote according to the position of your group.

Private Decision Sheet: one per group

1) In your own words, describe the responsibility of your group as it relates to a safe water supply.

2) Given this responsibility, which option will be best for my group?

3) What are three reasons why this is the best option:
   1.
   2.
   3.

4) Which option is the worst for my group?

5) What are three reasons why this option would be bad:
   1.
   2.
   3.

6) Which of the statements made at the pubic hearing do you agree with the most?

7) Give at least two reasons why you agree with them:
   1.
   2.

8) Which of the statements do you disagree with the most?

9) Give at least two reason why you disagree with them:
   1.
   2.

10) "It is the responsibility of the community to protect the health of the most sensitive population." Give at least two reasons why you agree or disagree with this statement?
   1.
   2.

#14 Lead in the Water
Teacher's Notes

Purpose

- To teach students the dangers of lead exposure.
- To demonstrate ways to reduce exposure to lead in drinking water.

Activity in Brief

- Students compare the rate at which a small piece of sugar candy dissolves in water with three variables: hot and cold water, and room-temperature sugar-saturated water.
- The differences between the rate at which sugar dissolves in regular water and sugar-saturated water relates to the different rates at which lead leaches in hard water ("mineral saturated") and soft water.
- The difference between the rate at which sugar dissolves in hot and cold water relates to the different rates at which lead (and other minerals) leaches out of pipes and plumbing fixture in hot and cold water.

Key Words and Concepts

Lead poisoning and contamination
Cumulative effect
Leaching metals from pipes
Saturation
Hard and soft water

Time Required
One class period

Teacher Notes

1) About 80% of exposure to lead comes from the dust and chips of lead paint. Of the remaining 20%, drinking water is the largest single factor. Thus, while water is not the highest risk factor, it must be considered a primary opportunity for reducing the population's overall exposure to lead. Because metals such as lead leach into the water at a higher rate in hot water, people should never use hot tap water for drinking, cooking, or watering garden plants that are consumed (since lead can be absorbed by the plant). Also, letting the "cold" water run until it becomes "colder" is a way of letting the water that has been sitting in pipes for a long time escape. The colder water indicates that it is just being drawn into the household plumbing and has not had time to leach many metals from the pipes and fixtures.

2) A 1990 follow-up study of children who had elevated lead levels in their teeth reported that, eleven years later, these children had a sevenfold increase in the failure to graduate from high school, lower class standing, greater absenteeism, more reading disabilities, and deficits in vocabulary, fine motor skills, reaction time, and eye-hand coordination. Thus, lead exposure

has disastrous consequences for society, and learning to reduce lead exposure is a critical life skill that students can take home to their families and communities.

3) The rate at which lead is absorbed in the body depends on several metabolic conditions. One of these conditions is the level of calcium, iron, and vitamin D in the body. Lead is absorbed at a higher rate if the body is deficient in these nutrients.
This is one more reason why it is important for children and teens to have good nutrition. Unfortunately, many of the children who suffer lead poisoning are poor and live in old housing with lead pipes or fixtures, and have substandard nutrition.

4) Recent studies have shown that lead is released into the blood stream during times of physiological stress (such as illness, pregnancy, lactation). Thus, the level of lead in the bloodstream can vary over time and even increase when there is no longer any external exposure to it.

Additional Activity Ideas

1) In protecting themselves from the dangers of lead, people should NEVER use hot tap water for cooking or drinking, and they should always let the tap water run for a few minutes after the water has been sitting in the pipes so the leached metals will have a chance to flow out. Doing those things, however, wastes water. Have your students brainstorm about ways to use this otherwise wasted water productively. They can capture it for use in washing, cleaning, watering plants, etc. However, they should not use the water on garden plants that will be eaten because plants can absorb lead.

2) Students taking biology may explore the ways in which lead interferes with cell growth, maturation, and tooth and bone development. They might try to determine whether there is a connection between the bones' ability to release minerals such as calcium from the bone and their release of lead.

Sample Test and/or Discussion Questions

1) What are some of the effects of lead on the body?
Lead interferes with the development of the brain and central nervous system, and can cause possible organ damage.
2) Why are children at greater risk than adults?
Young children's central nervous systems are still developing, and are thus more readily affected by lead.
3) Why would the blood level of lead fail to drop within a few days after a complete removal of lead exposure in the environment?
The body accumulates and stores lead, and slowly releases it back to bloodstream.
4) Why does using hot tap water increase a person's exposure to lead?
Hot water dissolves more lead than cold water.
5) What is one way to reduce the level of lead when drinking or cooking with tap water?
Let the water run until it is cold, allowing water that has stood in the pipes to flow down the drain. To avoid wasting water, keep acontainer of lead-free water in the refrigerator for cooking and drinking.

#14 Lead in the Water
Student Activity

Background
Of the possible contaminants in drinking water, lead is one of the more common and more dangerous – especially to children.

It is common because lead has been used in household water pipe lines since the time of the Romans. After its health dangers became known in the 1930s, lead pipes were no longer made, but in many cities, buildings and homes still have them. (In this country, community water mains have always been made of iron and steel.) Furthermore, lead continued to be an ingredient in the solder used on plumbing joints until it was replaced in1986, and it is also added to the metal alloys bronze and brass that are still widely used in plumbing fixtures. Today, more than 98% of US homes have some pipes or plumbing fixtures that contain lead or lead solder. More than 30 million Americans drink water with lead levels above the "action level for the first flush" set by the EPA – 15 parts per billion (meaning that the water contains 15 ›pb first thing in the morning, after the water has been sitting all night and before any water has "flushed" the lines free of the lead).

Lead is so toxic to humans that it is considered the greatest preventable health threat to children by the Centers for Disease Control - CDC. Several elements conspire to make lead so dangerous to humans:

1) The effects of high concentrations of lead in the body cause "lead poisoning" which includes permanent damage to the central nervous system, the brain, and the kidneys, as well as stunted growth and anemia. (If lead poisoning is severe, it can even be fatal). Exposure to low levels of lead can reduce a child's IQ and attention span, result in reading and learning disabilities, memory and concentration problems, and hyperactivity and behavioral problems. Some of the subtle behavioral changes recently attributed to low-level lead exposure include sleep and appetite disturbances and violent, anti-social tendencies. Other effects include high blood pressure, heart attacks, hearing loss, headaches, slowed growth, reproductive problems (such as miscarriage and infertility), digestive problems, and muscle and joint pain.

2) Lead's effects are cumulative , meaning that the body stores lead rather than excreting it. As a result, even low levels of lead in drinking water will cause health effects as the body stores lead over time. Recent studies show that levels once considered safe because they showed no immediate damage actually cause long-term, life-long health effects. Lead can be absorbed by the blood, soft tissues (brain, kidney, bone marrow, liver), or mineralizing tissue (bones and teeth). In the blood, it interferes with the ability to make hemoglobin and can lead to anemia. In the soft tissues, it can damage organs, and since it is a neurotoxin, it attacks the central nervous system. The bones and teeth store more than 98% of total lead in the body. They accumulate lead over time and release it into the blood stream. Thus, even after a person is no

longer exposed to lead in the environment, they are still "exposed" to it by their own body. Furthermore, the bones release lead at a higher rate during disease, pregnancy, and lactation (thus exposing a fetus and newborn child to lead).

Because the effects of lead are cumulative, a person can develop lead poisoning with exposure to very low levels, and exposure early in life can cause life-long problems.

3) The effects of lead are irreversible There is no "cure" for the damage caused by lead, both because the damage to organs and the nervous system is permanent, and because the body continues to "expose itself" to lead stored in the bones. There are, however, treatments for high blood lead levels.

4) An equal amount of lead is much more harmful to children, pregnant women, and fetuses than to an average adult. Lead levels less than *10 µg/dL in blood* can adversely affect a child's developing nervous system.

In the 1850s, when the city of Boston first ran water supply pipes to every home, the water officials had to decide what material to use for the pipes. Iron was brittle and would become encrusted, thus reducing the pipe's capacity. Copper was expensive and required very careful craftsmanship. Lead was inexpensive and easy to install. As a result, all Boston residents received lead service at no additional cost, but they had to pay extra for copper service As a result, many old homes in buildings in the city of Boston still have lead service pipes from the street to the meter, and those buildings have a serious potential health problem. In addition, the main reason some schools in Boston dispense bottled water instead of tap water to students is not because Boston's water supply is unhealthy, rather it is because many of the old schools in Boston still have lead somewhere in the system of pipes leading to the school, so the lead levels are too high to be perfectly safe for young children. (See Activity #6:*A Brief History of Water in Boston.*")

Activity: Identifying Conditions Under Which Lead Leaches into Drinking Water

This activity illustrates how lead leaches into the water from pipes and plumbing fixtures. It should help you think of ways to reduce your own exposure to lead in water

Materials

3 clear plastic cups, approximately 8 ounces
1 box of Nerds™ (tiny pellets of colored sugar candy)
Hot and cold water
About 1 cup of sugar
Clock or watch for timing
Permanent marking pen for labeling the cups

Procedure

1) Label the cups as follows:
   Cup #1: Cold water, pure
   Cup #2: Hot water, pure
   Cup #3: saturated sugar water
2) To make saturated water, slowly add sugar to a cup of room-temperature water, and stir. Continue adding sugar and stirring until the sugar no longer dissolves easily. At that point, you will have a saturated solution.
3) Fill the other two cups with hot and cold fresh water.
4) Put one Nerd pellet in each of the three cups and record the time on the data sheet.
5) Observe the cups every two minutes for 10 minutes.
   - Record the time for when the Nerd pellets start dissolving
   - Every two minutes, describe what is happening to the Nerd
   - For each cup, record the time when the Nerd is completely dissolved.

DATA SHEET

Allot ten minutes for the experiment. At each two-minute interval, record your observations.

Cup #1 ______________________________
description of contents

2 minutes ______________________________

4 minutes ______________________________

6 minutes ______________________________

8 minutes ______________________________

10 minutes ______________________________

Cup #2 ______________________________
description of contents

2 minutes ______________________________

4 minutes ______________________________

6 minutes ______________________________

8 minutes ______________________________

10 minutes ______________________________

Cup #3 ______________________________
description of contents

2 minutes ______________________________

4 minutes ______________________________

6 minutes ______________________________

8 minutes ______________________________

10 minutes ______________________________

Questions

1) Rank the cups in order of the time it takes for a Nerd to dissolve completely, from longest time (1) to shortest time (3).

RANK	CUP
______	Cold water
______	Hot water
______	saturated sugar water

2) What do these result tell you about how fast a substance will dissolve in:

Hot Water?

Saturated Water?

3) Now assume that hard water has qualities similar to those of your saturated water (even though it is saturated with mineral salts rather than sugar); soft water has qualities similar to those of your hot and cold water samples; and lead behaves like your sugar pellet. Which cup would be safest to drink? Why?

Discussion

1) The sugar solution represents "hard water;" that is, water with a high mineral content. The plain water represents "soft" water; that is, water without many minerals. What do the results of your experiment tell you about the ability of hard and soft water to dissolve a soft material like lead? (Note: when metals dissolve in water, we say they "leach" into the water.)

2) What will happen to the lead level if water stays in a pipe for a long time?

3) What will happen to the lead level in water that flows rapidly through a pipe?

4) Based on what your experiment, do you think lead leaches at a higher rate in hot or cold water?

5) Given the nature of your tap water, what should you do and not do to limit your exposure to lead in water?

Part IV: Visualizing Volumes

#15 How Much Water Do You Really Use?
Teacher's Notes

Purpose

To help students visualize the quantity of water they actually use.

Activity in brief

Students think of numeric and visual analogies for the water they use. Then they use these analogies to create cartoons, collages, articles, stories or songs. Encourage *bizarre* analogies. They are more fun and more memorable.

Once students create their examples, they could work alone or in small groups to create artful presentations of their analogies. For example, they might sketch plans for or actually make a three-dimensional sculpture of gallon jugs, or they could make multiple copies of pictures of whatever "containers" they visualize and arrange them in a collage. They could write a limerick using the amounts of water in their analogy. They could perform a rap using one of their most humorous analogies as a basis.

Key words and concepts

Analogy
Visualization
Volumetric measurement

Materials

Paper, pencils and other media (for making collages, sculptures, etc.)

Time required

One class plus homework or several class periods (depending on subject-area objectives).

Teacher notes

Have students critique each other's work for accuracy, and have them display their projects in either the classroom or the school. Some of the visualizations might be appropriate for submitting to the school paper, posting on a central bulletin board, or for presenting to other students. (They may even perform something, such as a rap song, for a grade school audience.)

Additional Activity Ideas

1. Have students design creative over-sized containers (in the manner of Claes Oldenburg) to show the volume of water required for some specific purpose. For example, an "egg" large enough to hold the amount of water it takes to produce a real egg.

2. As a way to build water-use awareness, have students build one or more "junk" sculptures using water-related waste materials, such as old garden hoses, toothbrushes, drinking cups, or water jugs.

Sample Test and/or Discussion Questions

1. A good visual analogy for the amount of water one person consumes for personal use in one week is:
   a. An average-sized bathtub filled to the brim with water (about 60 gallons).
   b. 14 average-sized garbage cans filled with water (about 420 gallons).
   c. An average mid-sized family car filled with water (about 1,050 gallons).
   d. An MBTA subway car filled with water (about 22,000 gallons).
   b. (7 X 60 or 420 gallons)

2. The average American consumes about 60 to 70 gallons of water for personal use each day yet, according to U.S. Department of Agriculture estimates, the average family of four consumes about 295 gallons a day. How might you explain the extra water use?
   Such things as car washing, lawn watering, swimming pools, and leaky faucets and fixtures are not calculated into individual daily averages.

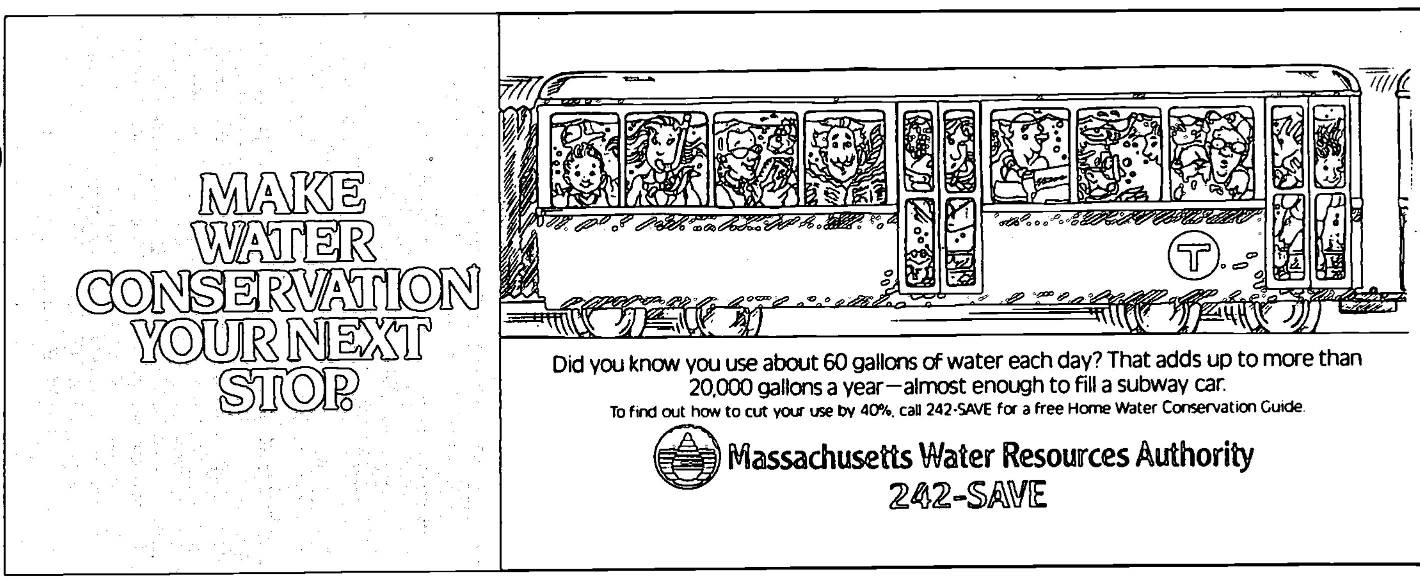
#15 How Much Water Do You Really Use?
Student Activity

Background

When you read a news story about about water consumption, do the numbers in the article really mean anything to you? How much water is 30 cubic feet or .02 cubic meters? This activity will help you visualize these quantities.

For example, if you stacked up the number of gallon jugs of water used in one day by one person, how high would the stack reach? To the ceiling in the school gym?

A typical mid-size family car contains about 140 cubic feet of interior space. How many cars would you have to fill to supply the personal water needs of a family of four for a week?



The average person uses about 60 gallons of water per day. At that rate, in one year that person would use about 21,900 (60 x 365) gallons of water. How much water is that? Someone has estimated that 22,000 gallons of water would about fill an MBTA subway car. That would mean that the interior space of a subway car is about 40' x 9' x 8' or 2,880 cubic feet. A cubic foot contains about 7.5 gallons, so an MBTA car that size would hold about 21,600 gallons. You may want to measure a subway car yourself to see if those measurments are accurate.

In this activity, you will create your own visual analogies of volumes of water.

Procedure

1. From the charts at the end of this activity, calculate how much water something requires. For instance, how much water did farmers use creating the food that went into your breakfast? Or if everyone in the class had one leaky faucet, how much water would be wasted every month?

2. Once you have selected something and figured out how many gallons (or liters) of water are involved, calculate the volume. (Don't forget to factor in time: one month = 30 days; one year = 365 days.)

3. Create a visual analogy for the volume and write a verbal description of the mental image created by your analogy.

4. Work with a friend and choose your best (most interesting, funniest, most illustrative) analogy.

5. From your description, create an artful presentation, such as a cartoon, poem, collage, etc.

6. Write a caption or title, such as the one on the MWRA subway poster, telling what your presentation represents.

NOTE: You may have to do a little library research or telephoning to experts to ensure that you are accurate. For example, if you are going to compare something to the amount of water twenty-seven elephants would drink in a year, be sure you know how much water an elephant drinks in a year. Be creative, and clear.

CONVERSION CHART

1 cubic meter = 35.3 cubic feet
1 gallon = 231 cubic inches
1 cubic foot = 62.4 pounds
1 cubic foot = 7.5 gallons
1 gallon = 8.3 pounds

Average Water Consumption for Selected Uses in the U. S.

Use or Product	Gallons
Personal Use	
Total direct use (per person per day)	60
Drinking water (per person per day)	.25
Toilet (per flush)	5
Bath	37
Shower (per minute)	5
Shaving, water running (per minute)	2
Cooking (per day)	8
Washing dishes, water running (per meal)	10
Automatic dish washer (per load)	14
Clothes washing machine (per load)	30
Watering lawn (per minute)	10
Leaky toilet (per hour)	2 -10
Leaky faucet (per hour)	1 - 5
Family use (four persons)	
Dish washing (per day)	60
Cooking/drinking (per day)	42
Bathing (per day)	80
Toilet (per day)	100
Miscellaneous (lawn watering, car washing, etc, per day)	13
Total (per day)	295
Agricultural use (primarily irrigation)	
Total indirect use per person (per day)	693
One egg	40
454 grams (one pound) of flour	75
Loaf of bread	150
454 grams (one pound) of rice	500
454 grams (one pound) of beef	2,500
.9 liters (one quart) of milk	223
454 grams (one pound) tomatoes	125
454 grams (one pound) oranges	47
Industrial uses	
Total indirect use per person (per day)	784
Cooling water for electric power plants per person (per day)	632
Industrial mining and manufacturing per person (per day)	183
Refine 0.04 cubic meter (1 gallon) of gasoline from crude oil	10
454 grams (1 pound) of steel	35
Sunday newspaper	280
454 grams (1 pound) of aluminum	1,000
Automobile	100,000
Municipal Use	
Fire fighting or an open hydrant (per minute)	1,000

#16 How Much Water Can the MWRA Safely Provide Every Day? How Much Water Have We Saved? Teacher's Notes

Purpose

This math-based activity promotes creative thinking and provides a personal understanding of 1) the amount of water supplied to greater Boston by the MWRA each day and 2) the amount of water consumers must save every day in order to ensure a reliable supply.

Activity in Brief

Students use math, estimation and creative thinking to find ways to describe two quantities: 1) 300 million gallons, which is the capacity (safe yield) of the MWRA water system, and 2) 80 million gallons, which is the reduction in average use since 1987, when daily use was 330 million gallons per day. Students make up their own illustrations of 300 and 80 million gallons and offer those illustrations to the class.

Key Words and Concepts

Volume
Estimation

Materials

Calculators

Time Frame

One class period for work and discussion plus optional homework.

Additional Teacher Notes

This activity provides students with an entertaining opportunity to think creatively. Some of their illustrations may be very funny; others may be profound. Thus this activity can be the basis of a classroom wall display, a school bulletin board display, an article for the school newspaper, or a class contest (with the students voting on the most creative, most humorous, and most meaningful illustrations).

To get you started, we learned that the Prudential Tower is 150' x 175' x 750'. Its volume is 19,687,500 cubic feet, so it would hold 147,656,250 gallons of water, or about half the amount of water the MWRA can supply every day.

Answer Key

1. *1,245,000 tons*
2. *a. 40 million cubic feet per day (14.6 billion cubic feet per year)*
   b. 4,266 swimming pools
   c. 13,889 trucks that would stretch 158 miles
   d. 57,607 miles, or about 2.3 times around the world
3. *332,000 tons*
4. *10.67 million cubic feet*
5. *1,138 swimming pools*
6. *3,704 trucks that would stretch 42 miles*
7. *40 gallons per person per day*

#16 How Much Water Can the MWRA Safely Provide Every Day? How Much Have We Saved? Student Activity

***Background:** 300 million gallons per day sounds like a lot. How much is it really?*

We live in a world that is very often described in numeric terms. *The MWRA provides water to more than two million people in 47 Massachusetts communities. The system's two reservoirs, Quabbin and Wachusett, can reliably deliver 300 million gallons of water every day, a volume known as Safe Yield.* As those numbers get larger, they tend to lose their meaning because they stray so far from personal experience. Ten, for example, is an easy number to understand; we need only to look at our fingers. We can easily count to a hundred or even a thousand, but beyond a thousand, our ability to visualize begins to diminish.

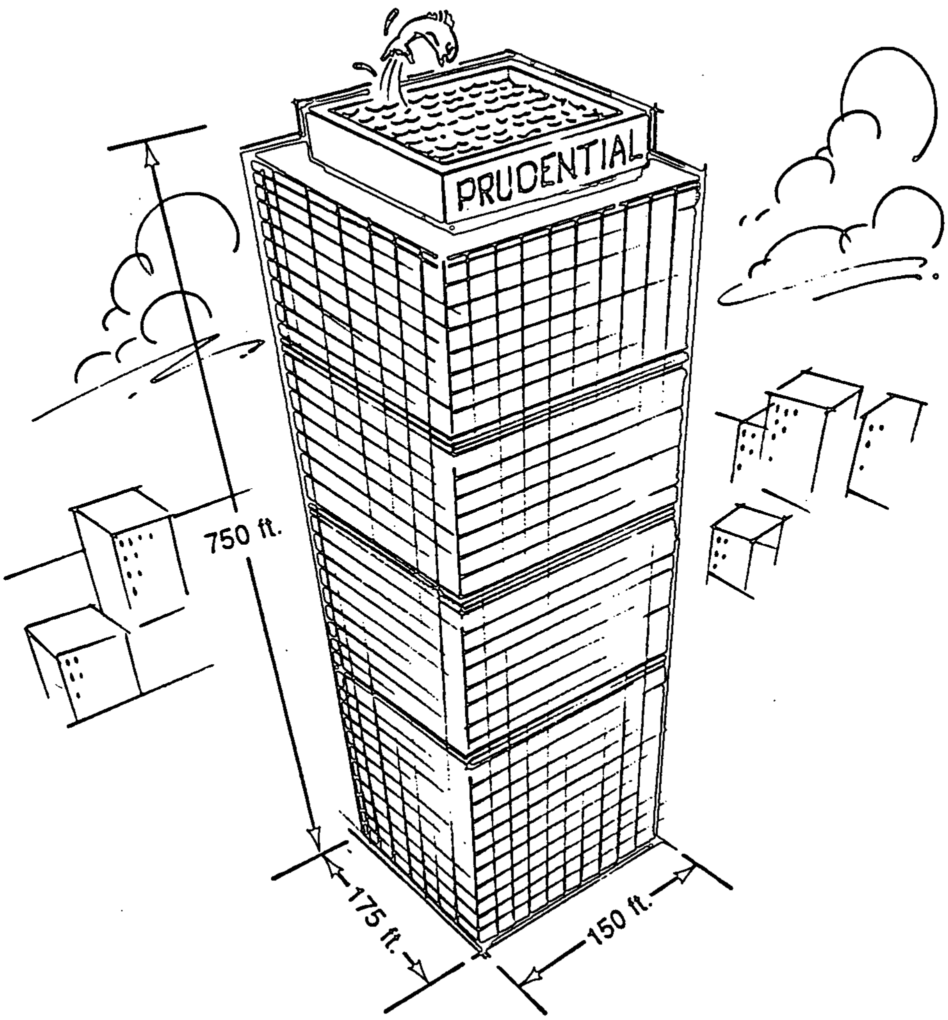
If we say that the MWRA can provide 300 million gallons of water to 2-plus million people every day, what does that mean? How much water is 300 million gallons? Is it enough to fill Fenway Park or the Prudential Center? Is it enough to fill Boston Harbor? How many trailer trucks would it fill? If they were placed end-to-end, how far would they stretch? How much does 300 million gallons of water weigh? These may seem like silly questions, but it's fun to make guesses about how much 300 million gallons is and to calculate answers to see if your guesses are correct. It's also fun to think of your own illustrations. Without doubt, you will find the enormity of 300 million gallons to be astounding.

Introduction

In Part I of this activity, we provide a series of arithmetic problems that will help you create "frames of reference" for the meaning of 300 million gallons of water. In Part II, we offer similar problems to help you understand the meaning of 80 million gallons, which is average daily reduction in water deliveries since 1987. In Part III, you will have a chance to make up your own ways of describing such large quantities and you will be able to try them out with your classmates.

Conversion Table

1 gallon of water weighs 8.3 pounds
1 cubic foot of water contains 7.5 gallons
1 cubic yard contains 27 cubic feet
1 gallon contains 231 cubic inches



Boston's Prudential Tower is 150' x 175' x 750'. If it were filled to the top with water, it would hold almost 150,000,000 gallons, or one-half of the water the MWRA could provide safely every day.

Part I: The MWRA can provide an average of 300 million gallons of water to eastern Massachusetts every day. How much is 300 million gallons?

1. Water weighs 8.3 pounds per gallon. How many tons of water can the MWRA provide each day? (2000 pounds per ton.)

2. a. Seven and one-half gallons of water fill one cubic foot of volume. How many cubic feet can the MWRA safely provide every day? How many can it provide every year?

b. An olympic-size swimming pool is 75-feet long by 25-feet wide by 5-feet deep. How many olympic-size pools can the MWRA fill every day?

c. The trailer of a semi-trailer truck is about 45-feet long by 8-feet wide by 8-feet high. How many tractor trailers could the MWRA fill every day with the water it is currently supplying? With the tractor unit, a large truck is about 60 feet long. If all of the trucks that could be filled by the MWRA every day were placed end-to-end, how far would they stretch? Check a map. What lies that far away from Boston to the east? west? north? south?

d. How far would the trailer trucks stretch if they were filled with a year's supply of water? (Hint: The Earth's circumference is about 25,000 miles.)

PART II: Since 1987, the MWRA's water consumption has been reduced by 80 million gallons per day. These problems will help you get an idea of the size of 80 million gallons.

3. How many tons of water have we saved every day?

4. How many cubic feet of water have we saved every day?

5. How many olympic-size swimming pools could we fill each day with 80 million gallons?

6. How many tractor trailer trucks would 80 million gallons fill? If placed end-to-end, how far would they stretch?

7. There are about 2 million people in the MWRA water supply system. How much water would each person need to save every day to reduce consumption by 80 million gallons?

8. Create a visual illustration of your answer in #7. For example, would the amount of water each person had to save fill your school locker?

Part III

Make up at least two examples that would help you understand the enormity of 300 million gallons of water. Find the information you need to make your calculations, and carry them out. Here are a few examples: How many homes the size of your home would it fill? (You may have to measure the total cubic footage of your house or apartment.) Would it fill the Fleet Center? If it were a long tube only 1" wide and 1" high, how far would it stretch? Would it go to the moon? (250,000 miles away.) To the sun? (93,000,000 miles away.) Farther?

Work with a few of your classmates. Explain to them what you did and have them work out your problems. Listen to their explanations and work out their problems.

Discussion

Which of these examples had the most meaning for you? Why do you think some were more meaningful than others?

#17 Fresh Water: How Much Is There...and How Much is There For You? Teacher's Notes

Purpose

To involve students in an exercise that demonstrates how little fresh water is available on Earth in proportion to the Earth's total water supply.

Activity in brief

Through demonstration/discussion, students examine the total water on Earth as it exists in its various forms: freshwater and saltwater lakes, rivers, subsurface water, sea ice and glaciers, atmospheric water vapor, and oceans. They then create a visual analogy (or scale model) to see how much exists in the form of accessible fresh water.

Key words and concepts

Global water supply
Subsurface water (aquifers)
Atmospheric water vapor
Available fresh water

Materials

10-liter container (or several containers with a combined volume of 10 liters)
Graduated cylinders
Medicine droppers
Five clear-glass or plastic drinking glasses
Transparency of 100 liters (to be copied from page 3 of this activity)

Time required

30-40 minutes

Additional Activity Ideas

1. BUILDING A SCALE MODEL OF WATER SUPPLIES
Obtain two or three rolls of adding machine tape. Have the students work outdoors (weather permitting) or in a hallway. Measure out 100 meters of tape. Let each meter represent one percent of the Earth's total water supply. Using the information listed in the procedure below, measure off sections representing each category of water. For example, .009% of the Earth's water is in freshwater lakes. This percent, .009%, equals the decimal fraction, .00009 (.009% x 100), so freshwater lakes would be represented on the tape by .00009 x 100 m x 100 cm/m, or 9

mm. Make a mark at 9 mm on the tape and label this section "Freshwater Lakes." Continue marking the other categories. For added visual effect, color each section a different color. Since oceans represent the largest category, leave that section uncolored.

2. CLASS DISCUSSION
Because so little water on the Earth is accessible fresh water, do you think governments should pass laws to help keep water clean? If so, how and what should the laws require? If not, what can be done to keep our water supplies clean?

Sample Test and/or Discussion Questions

1. What percent of the Earth's surface is covered with water?
75%.

2. What percent of the Earth's total water supply is in the form of accessible *fresh* water?
One-third of one percent (0.33%).

3. What are two sources of fresh water on the Earth?
Freshwater lakes, rivers, subsurface water, glaciers and atmospheric water vapor.

4. What are some possible ways to increase the available supplies of fresh water? What do you think some of the problems associated with these techniques might be?
Desalination can be used, but it requires large amounts of energy and requires disposal of large amounts of minerals. Improved pollution control can preserve available fresh water and this requires expenses associated with enforcement. Cloud seeding has been tried in some area to increase rainfall.

Answer Key to Question #4

Category	*Equivalent (in milliliters)*
1. *Freshwater Lakes*	*1 ml*
2. *Saltwater Lakes*	*.9 ml*
3. *Rivers*	*.01 ml*
4. *Subsurface Water*	*63 ml*
5. *Sea Ice and Glaciers*	*215 ml*
6. *Atmospheric Water Vapor*	*.1 ml*
7. *All Oceans*	*9720 ml*

#17 Fresh Water:
How Much Is There...and How Much is There For You?
Student Activity

Earth: The Water Planet

Water is one of the most essential ingredients for life. In fact, the Earth could really be called "The Water Planet." Of all the planets in the solar system, Earth is the only one dominated by water. Mars is a cold and dry planet; Venus, hot and dry. In liquid form, water covers about three-fourths of the Earth's surface. It also exists as a gas (water vapor in the atmosphere) and as a solid (ice in glaciers and polar ice masses).

Pick up a globe of the Earth and look at it from the southern hemisphere. What do you see? Water, water everywhere! Most of the world's water is salt water, but human beings cannot drink salt water directly. We depend on fresh water and it must be accessible.

Hydrologists estimate that *only one-third of one percent (0.33%)* of the total water on Earth is accessible, *fresh* water. (It may not be economically feasible to obtain water from a deep aquifer. Hence even if the water is there, it is not assessible for human use.) To give you an idea of how little 0.33% of the total water on the Earth is assessible fresh water, imagine that 100 liters (about 30 gallons) represents all the water on Earth. The amount of accessible, fresh water (rivers, lakes, water in the atmosphere and in the water table) therefore, would be about 325 milliliters. Pick up an ordinary soft-drink can and read the label; it has a capacity of 354 milliliters!

Fresh water must come from rivers and reservoirs, such as those managed by the Massachusetts Water Resources Authority (MWRA) and the Metropolitan District Commission (MDC), or from underground aquifers and underground wells. These fresh-water sources are replenished periodically by rain and snow...unless there is a drought. When droughts occur, less water is available to recharge our rivers and aquifers and steps must be taken to conserve our available supplies of fresh water.

Not only must water be fresh, it must also be relatively pure and accessible. As a result, the total amount of useable water on Earth is even smaller than the 0.33% of the total Earth's fresh water supply. The quality of some water is just too poor, and in other cases, high quality water is simply too difficult and too costly to extract. Engineers and geologists, in fact, estimate that only about half of the world's subsurface water is accessible for extraction.

Procedure

1. What do you think is the percentage of the Earth's water that is both fresh and accessible.

2. Look at the following table:

Total Global Water Supply

Category	% of the Total Water in the World
1. Freshwater Lakes	.01%
2. Saltwater Lakes	.009%
3. Rivers	.0001%
4. All Subsurface Water	.63%
5. Sea Ice and Glaciers	2.15%
6. Atmospheric Water Vapor	.001%
7. All Oceans	97.2%

3. Label 3" x 5" cards with the categories listed above.

4. Calculate how many milliliters or liters would represent each category if the total water supply of the earth equalled the 10 liters on display.

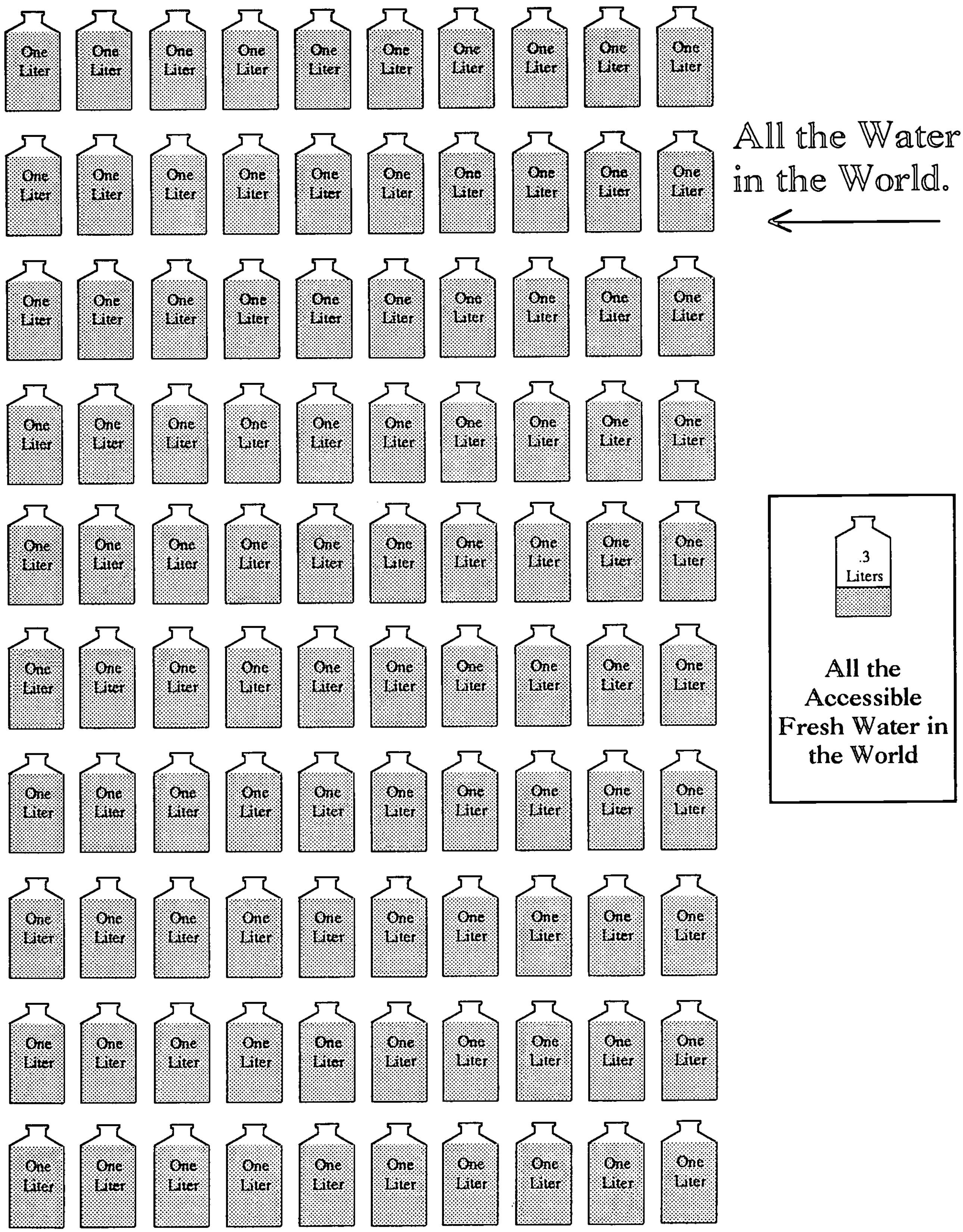
   For example, saltwater lakes represent .009% of all global water. (.009% is equal to the decimal fraction .00009.) By multiplying .00009 x 10 liters, you would find that saltwater lakes would account for about .0009 liters of the ten liters on display. Each liter contains 1000 milliliters, so saltlakes would account for .9 milliliters. Write the amount in the equivalent column. Complete the calculation for the other categories.

Category	Equivalent (in milliliters)
1. Freshwater Lakes	________
2. Saltwater Lakes	________
3. Rivers	________
4. Subsurface Water	________
5. Sea Ice and Glaciers	________
6. Atmospheric Water Vapor	________
7. All Oceans	________

5. Using your graduated cylinder, measure out the amounts of water from the 10 liter total supply into the smaller, labeled containers. After the amounts of water in categories 1-6 have been transferred, the water remaining in the larger supply will represent ocean water.

6. Assuming that about half of the underground water is accessible, calculate the equivalent amount of *accessible* underground fresh water in your classroom model. (The percentage of subsurface water (category 4 above) was .625%. Half of this is considered accessible.)

How Much Fresh Water in the World?



#18 Understanding the Concepts of Parts per Million and Parts per Billion
Teacher's Notes

Purpose

To show the concepts of parts per million and parts per billion.

Activity in brief

Food coloring, as it comes from the container, is a 1:10 dilution. By carrying out a series of successive dilutions, students quickly arrive at solutions of one part per million (or billion) and can see that contaminants exist even if they are invisible. This activity works well either as a demonstration or a student activity.

Key words and concepts

Parts per million (ppm) and parts per billion (ppb)
Pollutant
Aquifer

Materials

For each pair of students:

Solid coffee stirrers or toothpicks
Medicine dropper
Set of 9 small, clear plastic or glass containers, such as watch glasses or plastic spoons
White paper
Clean water for rinsing the medicine dropper

For each four students:

Food coloring to represent contaminant
Clean water for diluting

Time Required

15-20 minutes

Procedure

Listed in student activity sheet.

Additional Activity Ideas

1. Perform this activity and save the results, then perform Activity #11, *Contamination of an Aquifer.* Have the students estimate the amount of dye in the aquifer after each flushing.

2. This list contains the 1995 maximum contamination levels in drinking water of some toxic or carcinogenic chemicals as listed by the Environmental Protection Agency (EPA).

Substance	Concentration (ppb)	Substance	Concentration (ppb)
arsenic	50	nitrate/nitrogen	10,000
barium	1,000	selenium	50
cadmium	5	endrin	2
lead	15	lindane	.2
mercury	2	2,4-D herbicide	70

Have each student select one substance from this list and complete a library research project to determine what effect that substance has on the human body.

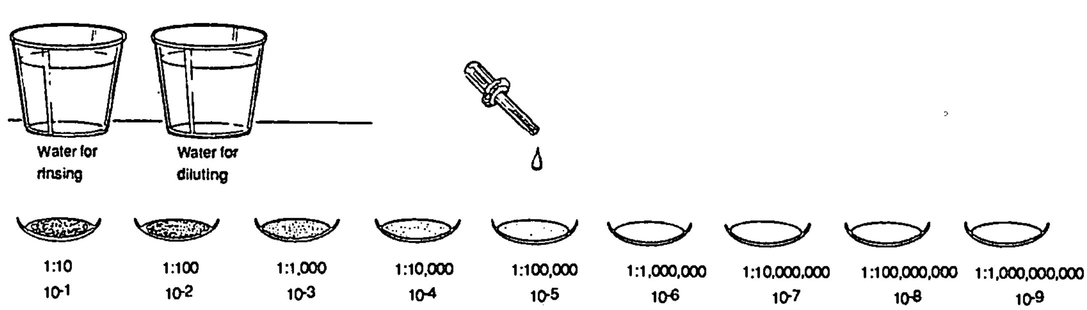
3. To better understand how small a ppm or ppb is, assign your students the task of expressing either unit in terms of familiar experiences.
For example:
   a. The average distance to the moon is 239,000 miles, or about 1.2 billion feet. So if you jump only 1.2 feet in the air, you have jumped one part per billion of the distance to the moon.
   b. The average distance to the sun is 93,000,000 miles. When you drive 93 miles you have driven one part per million of the distance to the sun.
   c. The Earth's surface contains about 200 million square miles. If a large square stadium parking lot is 2400 feet on a side (.45 mi) then the lot contains about .2 square mile. That lot then equals about one part per billion of the Earth's surface.
   d. If a record sells one million copies, then a single record is one part in a million.
   e. Challenge your students to find other examples. Allow for creative imagination.

Sample Test and/or Discussion Questions

1. The expression *parts per billion* is usually abbreviated __(ppb)__.
2. List some possible reasons why our senses alone may not be sufficient for detecting pollutants.
Pollutants may be colorless, odorless or tasteless even in high concentrations. In low concentrations chemicals which do have taste, odor or color may be so dilute that our senses cannot detect them.

Additional Notes

Food dye as it comes from the bottle is a 1:10 dilution. This information is important because it allows students to number the containers in such as way as to see the derivation of scientific notation. The first container is 10^{-1}, the second 10^{-2}, and on through 10^{-9}.



#18 Understanding the Concept of Parts per Million and Parts per Billion Student Activity

Background

Concentrations of such materials as chemical pollutants and minerals are frequently expressed in units of "parts per million" (ppm) or "parts per billion" (ppb). For example, chemical fertilizers contain nitrates, a chemical which can be dangerous to pregnant women even in quantities as small as ten (10) parts per million.

The purpose of this exercise is to demonstrate what is meant by these concepts and how chemicals may be present in concentrations which are dangerously high and yet may not be detectable by sight, taste or smell.

Materials

Solid coffee stirrers or tooth picks
Medicine dropper
Set of 9 small, clear plastic or glass containers
White paper
Clean water for rinsing the medicine dropper
Red food coloring to represent contaminant
Clean water for diluting

Procedure

1. Line up the clear containers side-by-side and place a piece of white paper under each one. From left to right, number the paper from 1 to 9.
2. Place 10 drops of food coloring into container #1. (Food dye, as it comes from the bottle, is already a dilution of about one part in ten (1:10).)
3. Place one drop of food coloring into container #2.
4. Add 9 drops of clean water to container #2 and stir the solution. Rinse the medicine dropper.
5. Use the medicine dropper to transfer 1 drop of the solution from container #2 into container #3. Add 9 drops of clean water and stir the solution. Again, rinse the dropper with clear water.
6. Transfer 1 drop of the solution in container #3 to container #4. Add 9 drops of water and stir. Rinse the dropper with clean water.
7. Continue the above process until all nine containers contain successively more dilute solutions.
8. Complete the PPM and PPB Data Sheet.

PPM or PPB Data Sheet

Name______________________________

Class/Section______________________________

Date______________________________

Container #	1	2	3	4	5	6	7	8	9
Color									

Questions

1. The food coloring in container #1 is a food coloring solution which is one part colorant per ten parts liquid. What is the concentration for each of the successive dilutions?

Container #	1	2	3	4	5	6	7	8	9
Concentration	1/10	1/	1/	1/	1/	1/	1/	1/	1/

2. What is the concentration of the solution when the diluted solution first appeared colorless?

3. Do you think there is any of the colored solution present in the diluted solution even though it is colorless? Explain.

4. What would remain in the containers if all the water were removed?

5. (Optional) Allow the water in the containers to evaporate and record your observations on what remains in the containers.

Part V: The Economics of Water Use

#19 Can Water Rates Promote Conservation?
Teacher's Notes

Purpose

To introduce different rate structures and to show how rate structures influence usage patterns, with some promoting conservation and others tacitly promoting heavy use.

Activity in Brief

Students will learn various approaches to rate setting and then examine some implications of each. They examine the economic implications using mathematics, graphing, and data interpretation, and they examine the behavioral implications through reflection and role play.

Key words and concepts

Supply and demand
Demand management
Inclining and Declining blocks
Per capita

Materials

Worksheet (provided)

Time required

One class period

Introduction

Rate structures that promote conservation raise the per-unit cost of water as more water is used. Rate structures that do not promote conservation lower the per-unit cost with increased usage. (In creating the MWRA, the legislature discouraged the rate structure that most blatantly rewards large usage, *declining block rates*. As of the 1990s, the legislation no longer permits declining block rates at all.)

Additional teacher notes

This activity will lend itself well to a term paper or extra-credit activity wherein the students can find and evaluate the rate structure for their town. *Please do not have your students inundate the town manager or manager of public works with telephone calls!* If you want to examine your local rate structure as a class activity, we recommend appointing an individual or a small group to meet with the appropriate local officials.

A Note About Rate Structures Within the MWRA Water System

The Massachusetts Water Resources Authority sells water on a wholesale basis only to each of the cities and towns it serves. Each city and town, in turn, sets its own rates within its own rate structure. While the Authority would like to promote conservation throughout the system by means of rate structures, it cannot mandate an approach to water pricing.

Water and sewer rates have risen dramatically in the MWRA service area since 1987. Water rate increases include repairs to the water system, and the sewer rate increases have paid for the rebuilding of the wastewater treatment plant at Deer Island. Water bills and sewer bills are both based on water consumption; therefore, each family's efforts to cut water use will affect both bills.

Sample Test and/or Discussion Questions

1. Water rates that promote conservation are: (Circle the correct answer(s).)
   a. supply-based b. demand-based
   c. inclining block d. declining block
   b and c

2. Rates than ensure that low-income people will be able to afford an adequate supply of water are called <u>*Lifeline rates*</u>.

3. Do businesses and homes have similar water needs? Explain your answer.

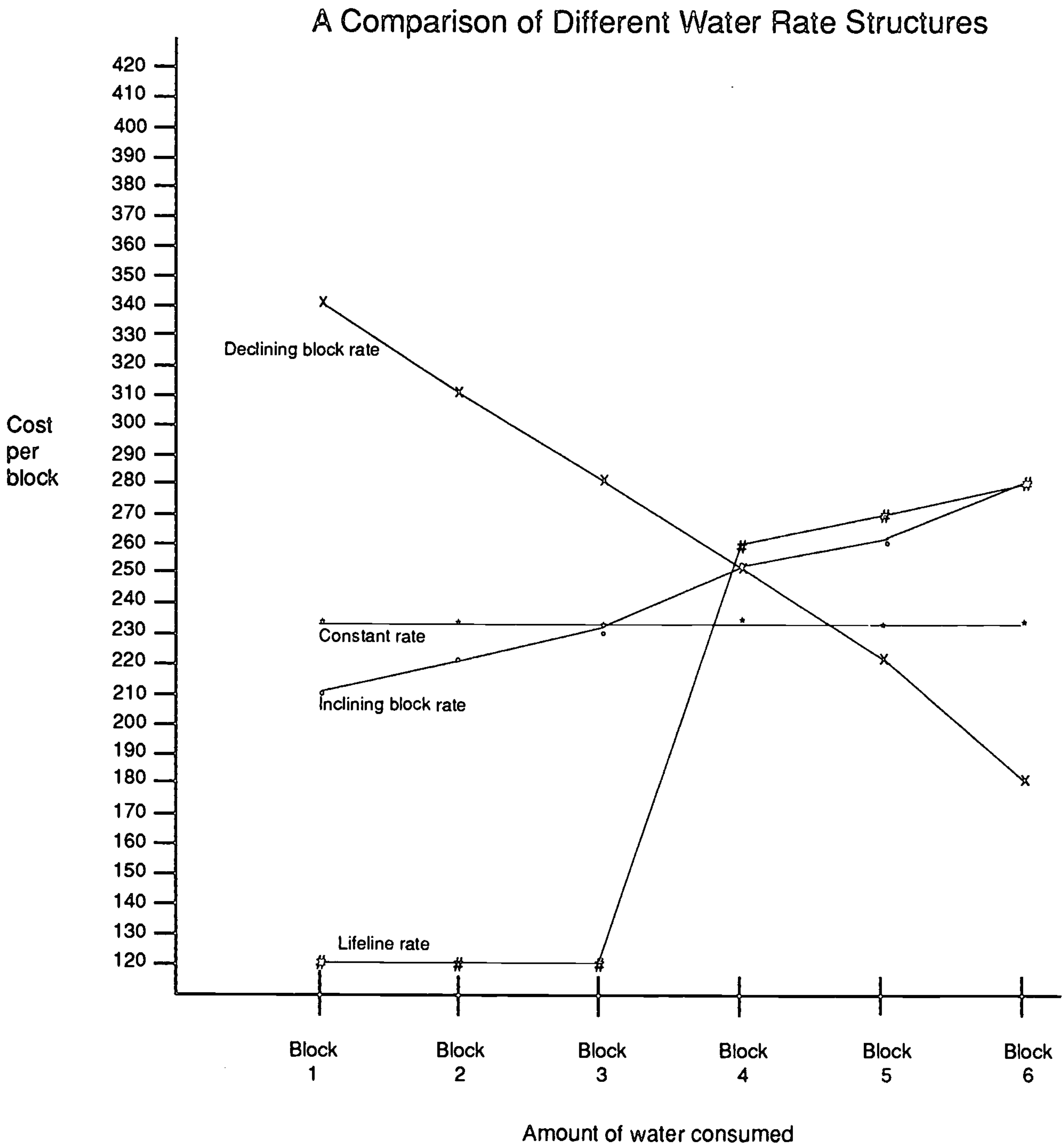
Teacher's key to student questions:

7. If each person uses 60 gallons of water each day, how much money would a family of four spend for water under each of the defined water rate structures?
   1. First, calculate the number of gallons the family would consume:
      60 X 4 X 365 = 87,600 gallons per year.
   2. Convert the gallons to cubic feet: 87,600 ÷ 7.5 = 11,680 cubic feet
   3. Convert cubic feet to hundred cubic feet: 11,680 ÷ 100 = 117 ccf.
      Declining block rate: $3.40 + $3.10 + $2.80 + $2.50 + $2.20 + ($1.80 * 112) = $215.60
      Constant rate: $2.30 * 117 = $269.10
      Flat rate: $300.00
      Inclining block rate: $2.10 + $2.20 + $2.30 + $2.50 + $2.60 + ($2.80 *112) = $325.30
      Lifeline rate: $1.20 + $1.20 + $1.20 + $2.60 + $2.70 + ($2.80 *112) = $332.50

   If they used only 40 gallons of water per person, how much would they spend on water?
   1. 40 X 4 X 365 = 58,400 gallons
   2. 58,400 ÷ 7.5 = 7787 cubic feet
   3. 7,787 ÷ 100 = 78 ccf
      Declining block rate: $3.40 + $3.10 + $2.80 + $2.50 + $2.20 + ($1.80 * 73) = $145.40 ($70.20 less)
      Constant rate: $2.30 * 78 = $179.40 ($89.70 less)
      Flat rate: $300.00 (same)
      Inclining block rate: $2.10 + $2.20 + $2.30 + $2.50 + $2.60 + ($2.80 *73) = $216.10 ($106.40 less)
      Lifeline rate: $1.20 + $1.20 + $1.20 + $2.60 + $2.70 + ($2.80 *73) = $213.30 ($109.20 less)

   When the family uses 35% less water, they save 33% with a declining block rate, 33% with a constant rate, nothing with a flat rate, 33% with an inclining block rate, and 34% with a lifeline rate.

8. GRAPHING (Teacher's Key)
Plot each of the rate structures explained in this activity (except for the flat rate). Put the amount of water used on the X axis and the cost per unit on the Y axis. Plot each of the four structures on the same piece of graph paper using a different color pen for each. Write a one paragraph description of the graph.



#19 Can Water Rates Promote Conservation?
Student Activity

Introductory Reading

Water covers the earth. Because it is a natural resource, should we be required to pay for it? If not, who should pay for the water delivery system: the pipes, pumps and aqueducts? If so, how should the costs be divided? Should those who use the most water pay the least or the most per gallon? Should customers be rewarded for conserving or should they pay less for using more?

Traditionally, as populations have increased and as the income level within a community has increased, per capita water consumption has also risen. As communities change, therefore, their ability to provide basic services, such as water, could also change. Without water, communities cannot exist, so controlling water usage patterns is critically important.

Sometimes, water shortages are only short-term or seasonal problems. If water use were averaged over the year, in fact, many water-short communities have ample supplies of water. During the afternoons of hot summer days, for example, many residents may be washing their cars and watering the gardens; others fill the children's wading pools, and commercial air conditioners throughout the community use water as part of the refrigeration process. At times like that — times called *peak use periods* — there may not be enough water to satisfy the demand, but only for that short period of time. Controlling peaks by spreading water use over each 24-hour period is a good tool for making the most effective use of the available water supply.

Water rate structures are one of the tools available to water utilities that can help influence how much water customers use. Under some types of water rates, customers using large volumes of water pay less per unit consumed. These are called *supply-based rates* because they assume that an adequate supply of water will always exist. Other types of water rates reward people for using less water. They do this by charging low rates up to a certain rate of consumption, and once that amount is passed, the rates start to rise. These are called *demand-based rates* because they can help customers to be more aware of the amount of water they use. The effort on the part of utilities such as water and electric companies to control demand and promote conservation is called *demand management.*

Sometimes, the needs of the community are best served by establishing two water rates, residential and commercial. Commercial customers who do not contribute to peak use periods may pay less per unit (but more in total) than residential users. Without doubt, establishing a rate structure that is both fair to all customers and that allows the water utility to recover all of its costs is a difficult challenge.

What is a "block"?

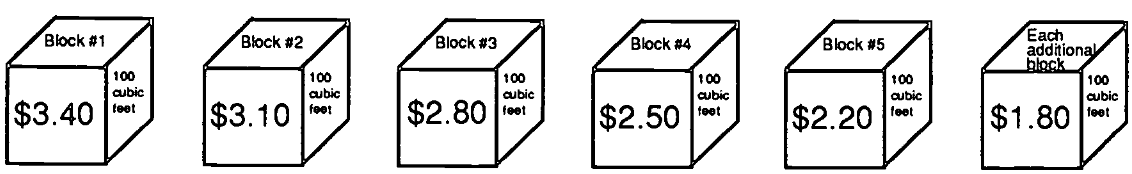
Most water rate structures break water use into units, or "blocks." This analogy may help you understand the concept of blocks and how they influence usage patterns:

Imagine that you own a car, and like all cars, you must continually fill it with gasoline. (In this analogy, each gallon of gas represents a "block.") In a *declining block* situation, the first block is more expensive than the last: The first gallon (or block) may cost $4.00, the second, $3.20, the third, 2.40, the fourth, 2.00, and each subsequent gallon costs $1.50. In an *inclining block* situation, the rates could be reversed: the first gallon costs $1.50, the second, $2.00, the third, $2.40, the fourth, $3.20, and each subsequent gallon costs $4.00.

Theoretically, in a *declining block* situation, drivers would have little motivation to save gas because the more they drove, the less their per-mile costs would be. In an *inclining block* situation, on the other hand, the more the car is driven, the more it would cost to drive each mile. The owners would save a great deal of money by either driving less or driving more fuel-efficient cars. The cost of the gasoline, in this case, could influence the usage pattern, or demand, on gasoline.

Supply-based Water Rates: *Rates which provide* <u>*no conservation incentives*</u>

Declining Block Rates: The more water customers use, the less they pay per unit. Declining block rates provide no conservation incentive. (When the legislature created the MWRA, they encouraged communities served by the Authority to discontinue declining block rates.)



Declining Block Rates

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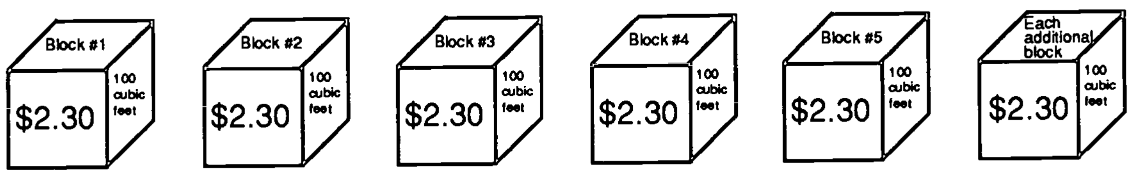
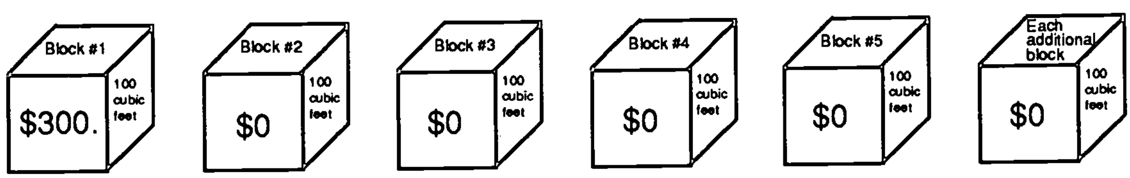
Constant Rates: Customers pay the same amount per block regardless of how much water they use. In many communities, constant rates have been the simplest answer to the usage problems caused by the declining block rates. While constant rates do not necessarily promote conservation, they at least do not reward consumption.



Constant Rates

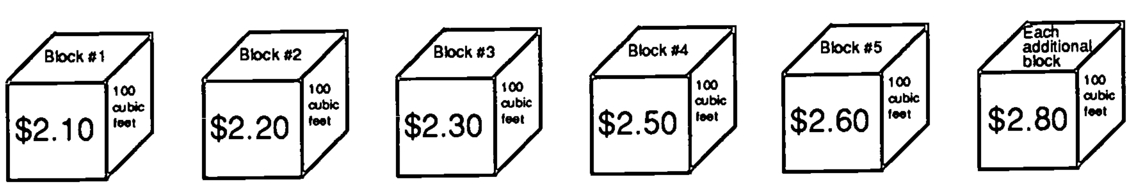
Flat Rates: Flat rates must be used whenever water use is unmetered. Customers pay a flat rate for the right to use water. The amount they use is irrelevant. Flat rates, while without conservation incentives and unfair to small customers, allow communities to budget their resources very accurately. They know exactly how much money they will earn from the sale of water, and thus they are often able to fully recover their costs.



Flat Rates

Demand-based Water Rate (Rates which ***do provide conservation incentives****)*

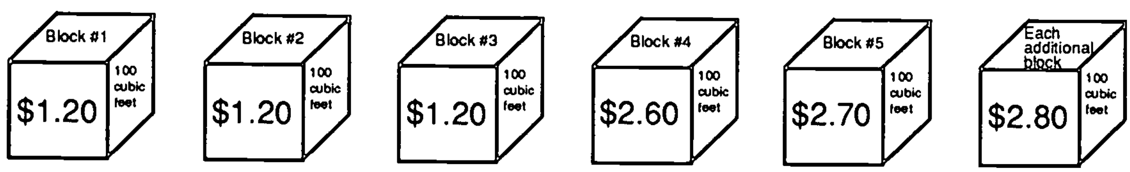
Inclining Block Rates: The more water customers use, the more they pay per unit. Each customer pays a set amount for the first unit of water. Each additional unit costs more. Such a system penalizes very large water users and people who waste water.



Inclining Block Rates

Lifeline Rates: This rate structure charges an artificially low rate for the first quantity of water used. That initial quantity is the amount considered to be the minimum required for a family's personal use, (which is approximately 1200 - 2000 cubic feet per year or 25 - 40 gallons per person per day). Customers then pay increasingly high rates as their consumption goes up.

Lifeline rates try to ensure that low-income customers can afford to live a comfortable, if modest, lifestyle, but really doing so is very hard. Very often, for example, the people who most need lifeline rates live in apartments or other types of multiple-unit dwellings, so they do not pay for their own water; their landlords do. When these residents use less water, the landlord benefits, but the people who are working to conserve do not.



Lifeline Rates

Activities

1. TOWN MEETING ROLE PLAY

The following people are debating water rates at a town meeting. Hold the town meeting in class and try to agree upon a rate structure that will be equitable for everyone.

The **manager of the water department**, who has identified the need for a new rate structure that will enable the town to recover its costs, and is not sure which rate structure would be best. All the manager knows for certain is that without some sort of rate increase, there will not be enough money to continue operating.

The **town manager**, who is primarily concerned with balancing the budget and knowing exactly how much money will be spent on what services.

The **owner of a large metal plating business** which uses 5,000 gallons of water each day. This person opposes measures that penalize large water customers with high rates. The business already pays very high taxes and employs many residents of the town.

An **environmental engineer** whose specialty is water conservation. This engineer believes that the metal plater could save 2,250 gallons per day through conservation and the town could save 25% of its water budget through leak detection and repair. These measures, however, require major investment and neither the town nor the business want to spend any more money than they must.

A **representative of a neighborhood group from the town's most affluent neighborhood**. This person believes that the town's charm lies in its beautiful landscaping and that the homeowners should not be penalized for keeping the town beautiful by being charged extra for watering their lawns.

The **owner of an energy-efficient, water-efficient home** who has planted the yard with grasses and plants which require very little water. This person believes that anyone who wastes water should be forced to pay for that waste, and that conservation-oriented rates might bring about a change in everyone's behavior.

A **representative of the elderly** population of the town, most of whom are forced to live on fixed incomes. The elderly cannot afford to pay any more, and they have conducted research that shows that elderly people use less water than others.

2. CLASS DISCUSSION AND ESSAY
   You are the sole owner of a water company that supplies water to 1,000,000 people. You have no more property or available water supply so you know that if people demand more water they will have to find another source of supply (which would introduce competition to you). You also have a tremendous amount of equipment that needs constant maintenance and upgrading. You are free to set whatever type of rates you wish, but the amount of profit you can earn is limited by the local utility regulatory agency. How will you charge for your water?

3. SOCIAL STUDIES
   Work in groups of three to decide which rate structures you think would be most equitable in eastern Massachusetts. Keep a list of the pros and cons of each structure so you can justify your conclusion to others. Compare your conclusions to those of other groups in your class.

   Did any of the other groups say anything to make you want to change your mind? If so, what did they say that influenced you and why did that make you change your mind?

4. ESSAY
   Write an essay on what you think the most equitable rate structure would be for eastern Massachusetts. Explain why you think it would be most fair and for whom it would be most fair. Also explain its weaknesses; describe who would be most penalized and explain why.

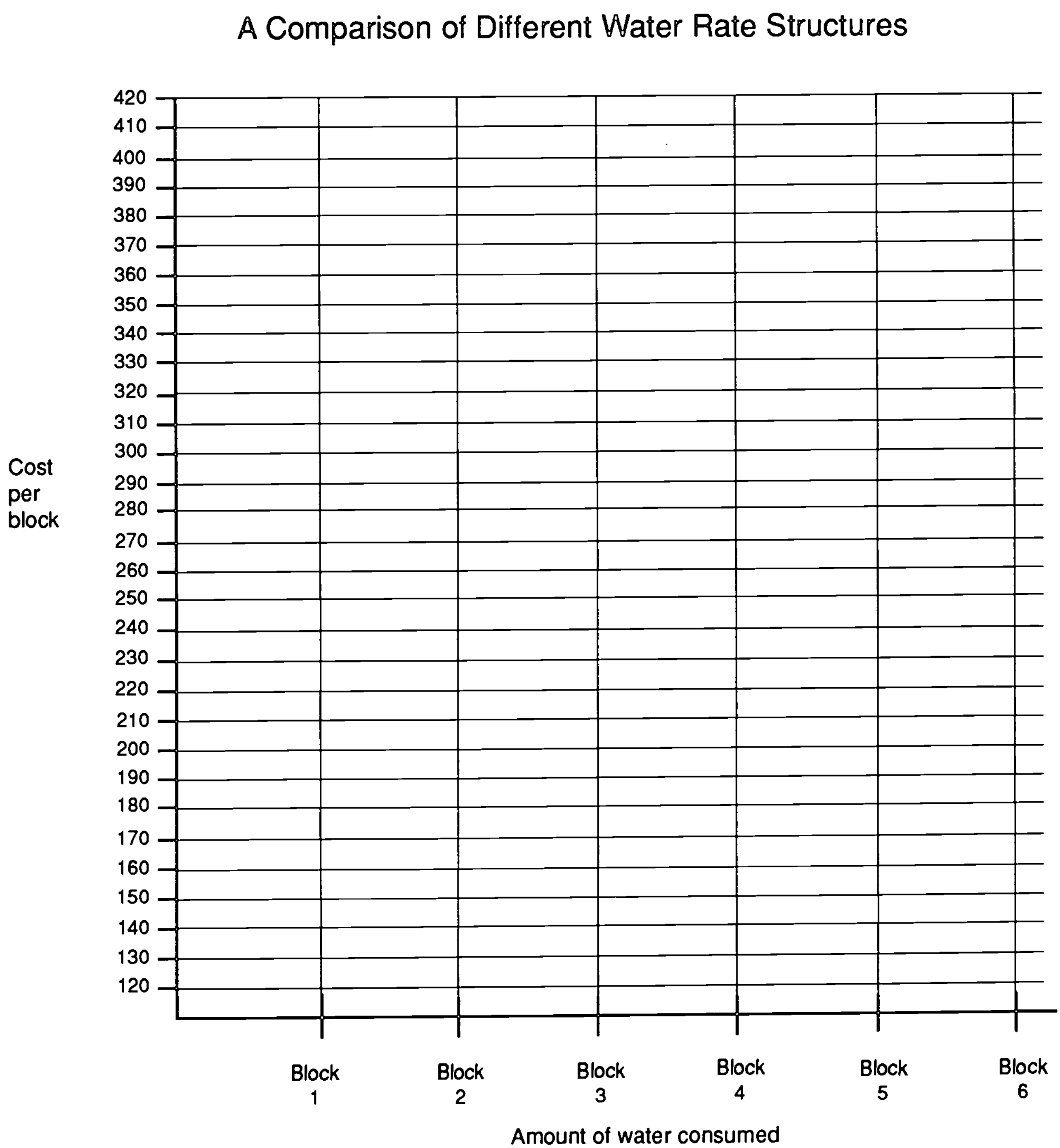
5. MATH AND CLASS DISCUSSION
   Compare the cost of bottled water versus tap water. If you had to wash and cook with bottled water, how much would you spend each year? How much more would water cost than it currently does?

6. CIVICS AND CLASS DISCUSSION
   Each community must pay a certain fixed amount of money for water regardless of how much or little they use. This money goes to such costs as water mains, meters, and public works employees. If a town implements a successful water conservation program, it may not have enough money to pay the fixed costs, and it may have to raise rates. If that happened, would the conservation program have been worthwhile?

   In the long-term (5-20 years), would the citizens of the town benefit from this successful conservation program or not?

7. MATH
   If each person uses 60 gallons of water each day, how much money would a family of four spend for water under each of the defined water rate structures? If the same family used only 40 gallons of water per person, how much would they spend on water? On a percentage basis, how much water and money would they have saved?

8. GRAPHING
Plot each of the rate structures explained in this activity (except for the flat rate). Put the amount of water used on the X axis and the cost per unit on the Y axis. Plot each of the four structures on the same piece of graph paper using a different color pen for each. Write a one paragraph description of the graphs.



#20 The Cost of Savings
Teacher's Notes

Purpose

To involve students in an activity which will help them understand both the economic and conservation benefits of retrofitting, and to analyze the true, long-term savings of domestic and/or commercial water conservation measures using *life-cycle costing*.

Activity in brief

Students calculate the costs and savings of retrofitting toilets and showerheads.

Key words and concepts

Retrofitting
Low-flush toilets
Low-flow showerheads
Life-cycle costing
Payback time

Materials

Activity sheets
Direction sheet on *Measuring the Water Consumption of Your Shower, Tub and Toilet* (attached)

Time required

One class period plus homework

Procedure

1. Discuss or demonstrate how to calculate flow rates and toilet tank capacities.
2. Provide specifications or assign students to investigate actual costs of new fixtures.
3. Assign students to measure the flow rates and capacities of the fixtures in their homes.
4. Have students use their measurements to calculate if retrofitting would pay for itself in their homes.
5. Assign practice problems as homework or do them together in class (optional).

Conclusion

Check the results of the calculations with the class and discuss those retrofitting options with the most benefit. (These are generally replacing showerheads and sink aerators, and implementing behavioral changes such as taking shorter showers and flushing less often.)

Suggest that students share their insights with parents.

Additional Activity Ideas

1. EXTENDED APPLICATIONS
   Knowing how to calculate life-cycle costing could lead to some independent or group "investigative reporting." Have students look into a business or the school's water-conservation practices, or have them examine economically viable conservation measures. They might present a proposal to the school committee showing how retrofitting could save money in the school budget.

2. ENERGY-RELATED COUNTERPARTS
   Energy conservation purchases must also be evaluated on their entire lifetime of service. Purchase price is only one of many important factors. Have students conduct life-cycle cost analyses of energy-related home improvements or appliances, such as superinsulation, energy-efficient refrigerators, and high efficiency gas or oil burners.

Sample Test and/or Discussion Questions

1. If a family's old showerhead had a flow-rate of 5 gallons per minute and their newly installed showerhead has a flow-rate of 2.5 gallons per minute, how much water would be saved in a six minute shower? ___*Fifteen gallons of water*___

2. Which of the following will save a family of four the most water in a 24-hour period? Explain.
   a. Washing dishes (in an automatic dishwasher) only once a day. (Assume 14 gallons per wash and that the family has normally washed dishes three times a day.)
   b. Putting in a low-flow showerhead that saves 2.5 gallons of water per minute. (Assume that each of the four family members takes eight-minute showers on average.)
   c. Putting in a toilet dam that holds back 1.5 gallons in the family's 5-gallon toilet tank. (Assume each member of the family flushes 4.5 times that day.)
   d. Everyone in the family shortens their showers by 3 minutes (although their shower still has a flow-rate of 5 gallons per minute).
   b. would save the most (80 gallons).
   (a. would save 28 gallons, c. would save 27 gallons; and d. would save 60 gallons.)

3. You are considering replacing your present toilet with one of the new 1.6 gallon capacity toilets. What are some of the factors you might want to consider before making a final decision to buy? List them and number them in rank order of importance to you. Explain your answer.
   a. Savings in water and sewer costs to myself.
   b. Helping to ensure adequate water for everybody.
   c. Purchase price and installation expense compared to life-expectancy to see which brand is the best buy.
   d. Possible problems in function or maintenance of the new vs. the old fixture.
   e. Finance charges for credit card or loan if my budget can't stand the purchase at this time.
   (Rank order of importance is subjective; the students should explain their decisions.)

Answer Key to the Life-Cycle Costing Practice Problems

Note: There are many correct ways to solve these problems. Reward creative approaches. Because of rounding error, the answers may differ. An exact answer is not important; the key message is that conservation measures save both money and available natural resources.

2. Calculate how long it would take the showerheads to pay for themselves.
   a. Cost of the showerheads: $30.
   b. The showerheads save 3 gpm.
   c. The Smiths shower for an average total of 34 minutes per day. (5+7+7+15)
   d. The Smiths would save 102 gallons, or 13.6 cubic feet, of water each day.
   e. Each year, the Smiths would save 37,230 gallons, or 4,964 cubic feet.
   f. 4,964 cubic feet = 49.64 ccf (hundred cubic feet).
   g. At $5.00 per hundred cubic feet, the Smiths would save $248.20 each year.
   h. $30 is 12% of $248.20.
   i. 12% of one year = 44 days.
   j. The showerheads would pay for themselves in 44 days, or about one and one-half months.

3. How much additional money did the Smiths save in fuel charges?
   a. Before installing the new showerheads, the Smiths spent $350 on water heating, and they knew that 40% of that money went toward heating their shower water, thus they spent $140 to heat the water for their showers.
   b. With the new showerheads, they used 45% of the water they had used previously (2.5÷5.5), which is the same as using 55% less water.
   c. They saved $77 each year on water heating!

4. What would happen to the Smith's annual water and fuel bills if, in addition to installing the new showerheads, Amy cut her showers to ten minutes?
   The Smiths currently shower for a total of 32 minutes each day. Amy showering for only ten minutes would cut the total to 27 minutes for an additional 15% savings. Both the water and the fuel bill would be another 15% lower.

5. How much water would the Smiths save each year with low-flow sink aerators?
   a. At 4 gallons per minute and 38 minutes of flow each day, the Smiths use 152 gallons of water each day for dishwashing, shaving and washing. At 3 gpm, they would use 114 gallons per day.
   b. With the new aerators, they would use 13,870 fewer gallons (which is 1,849 cubic feet, or 18.49 hundred cubic feet) per year.

6. With water and sewer rates at $5.00 per hundred cubic feet, how much money will they save during the first year
   a. 18.49ccf X $5.00 = $92.47.

7. How long will it take them to pay for their aerator purchase out of water savings?
   a. $15 is 16.22% of $92.47.
   b. 16.22% of a year is 59.21 days.
   c. The aerators would pay for themselves out of savings in 59 days, or two months.

8. 20% X 25% X $350 = $17.5 in additional savings on their fuel bill.

9. How much money would the Smiths save each year by installing two $10 toilet dams?
   a. The Smiths would save 20 gallons per day. (One gallon per flush at 20 flushes.)
   b. They would save 7300 gallons each year, or 973 cubic feet.
   c. 973 cubic feet = 9.73 ccf.
   d. The Smiths would save $48.67 each year. (9.73 X $5.00)

10. How long would they have to use the dam before it paid for itself in savings?
    a. Two $10 toilet dams cost $20, and save $48.67 per year.
    b. $20 is 41% of $48.67.
    c. The dams would pay for themselves in 41% of a year, or 150 days.

11. How much would the Smiths save in a year by installing two new water saving toilets?
    a. The toilets would cost $600.
    b. The present toilets consume 96 gallons each day (4.8 gallons X 20 flushes; 35,040 gallons each year (96 X 365); 4,672 cubic feet each year (35040÷7.5); or 46.72 ccf.
    c. At 1.6 gallons per flush, the new toilets would consume 32 gallons per day; 11,680 gallons per year; 1,557 cubic feet per year; or 15.57 ccf.
    d. Each year, the new toilets would save 31.15 ccf (46.72-15.57), for an annual savings of $155.75.

12. How long would the Smiths have to use the toilets before they would pay for themselves in savings?
    a. The total cost of the toilets would be $675. ($600 purchase price + $75 interest)
    b. At an annual savings of $155.75, the toilets would pay for themselves in 4.33 years. ($675÷$155.75)

#20 The Cost of Savings
Student Activity

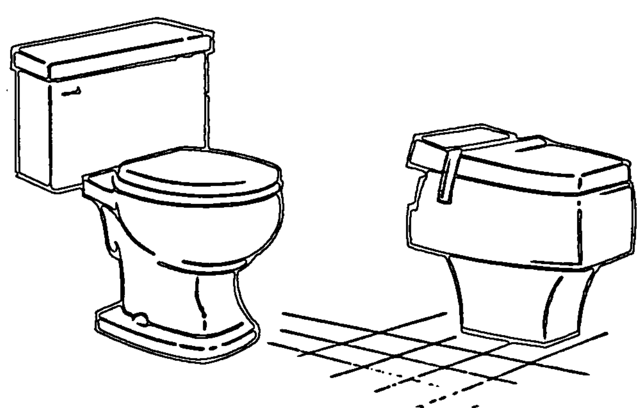
Background

In the short run, buying expensive new plumbing fixtures to save money may seem ridiculous. In the long run they may be good investments! For example, which costs more, a $550 refrigerator or a $700 refrigerator? Of course the $550 refrigerator costs less. Right? No. It may actually cost more! In fact, the $700 unit may actually be quite a bit less expensive...if you take into account such factors as operating costs, maintenance costs, and projected life spans. This is called "life-cycle costing."

The price tag of an item represents its purchase price only and does not take into account all the other potential costs. For example, two flashlights may cost $2.50 and $4.50 respectively. But, if the $4.50 model comes with $3 worth of batteries and the other one doesn't, the more expensive one actually costs less. To know the true cost of an item, therefore, you must factor the following items into the cost:

Purchase price
Finance charges (interest on a credit card or loan)
Operating costs (water and energy consumption)
Life span
Maintenance costs

You can readily discover the <u>true</u> cost of water-related items for yourself.



Purchase Price + Finance Charges + Operating Costs = True Cost

Procedure

1. Visit a local plumbing supply store or home center. Ask to see the latest low-flush toilet and showerhead designs. Ask for and read the specifications to find out how much water each one uses. (If your teacher has this information you may skip this step.)

2. Measure the flow rates of your showerhead and faucets and calculate the capacity of your present toilet tank. (Use the *Measuring the Water Consumption of Your Shower, Tub and Toilet* worksheet in this activity.)

For toilets...

1. Count the number of flushes per day in your household.

2. Multiply the number of flushes per day by the present tank volume (in gallons) and multiply that figure by 365.

3. Multiply the number of flushes per day by the tank volume of the new efficient toilet (in gallons) and multiply that number by 365.

4. Subtract the product of #3 from the product of #2 to get the number of gallons the newer model would save in one year.

   For example, if there are 5 people in the house and they average 5 flushes per day at 5 gallons per flush, they would use 125 gallons a day or 45,625 gallons per year (125 X 365). Using the same averages for a 1.6-gallon-capacity toilet, the family would use 14,600 gallons per year, saving 31,025 gallons.

5. Most cities and towns charge for water and sewage disposal at rates based on consumption in 100 cubic foot increments. To find out how many cubic feet you would use (or save), divide the number of gallons by 7.5.

6. To find out how much money you would save in one year, multiply the number of cubic feet you would save by the basic rate per cubic foot for water and sewage disposal. If you cannot find out the rate your family pays for water and sewer, assume about $5.00 per 100 cubic feet or $.05 (5¢) per cubic foot.

7. If the cost of the new toilet (including installation) is $300.00, how soon would the savings pay for the price of buying the new toilet, at present water and sewer rates?

Remember, water/sewer rates are based on the amount of water you use, and the unit you buy is ccf, or hundreds of cubic feet. Each cubic foot contains 7.5 gallons, so to find ccf, divide the gallons used by 7.5 and divide that number by 100. To find the total annual cost (or savings), multiply the total water used (or saved) by the rate per ccf.

8. Suppose water and sewer rates double in ten years. How would this price change affect the payback time of the toilet you calculated in #7? (Interestingly, as the cost of water rises, so does the amount of money you can save through conservation.)

9. If the new toilet has a life expectancy of 20-30 years, how much money would it save during its useful life (not counting maintenance cost differences)?

For showers...

1. To calculate the amount of water your family would use with a low-flow showerhead, find the published rate of flow (per minute) of a high-quality, low-flow showerhead and multiply the rate by the total number of minutes your family spends in the shower each day.

2. To find how much water your family would use for showers each year, multiply the product you obtained in #1 by 365.

3. Compare the amount of water your family uses for showers per year with your present showerhead to the savings you would realize with a low-flow showerhead. (If you already have a low-flow showerhead try to figure out how much less you are using than you would be with a 5 gpm showerhead.)

4. Calculate how fast a low-flow showerhead would pay for itself in water and sewer cost savings alone (at present water rates and at projected water rates). (If you do not know the exact cost and flow rate of a low-flow showerhead, assume they cost $15.00 and that water flows through them at the rate of 2.5 gallons per minute.)

   As an added bonus, you will also save money on fuel for water heating because you will be heating less water. In fact, to know the true *life-cycle* cost of an item, you should factor in such variables as energy savings, the cost of maintenance and finance charges.

Life-Cycle Costing Practice Problems

The Smiths are a family of four: Mom, Dad, Amy and David. Amy is 17; David, 15. Each of the Smiths takes one shower each day. Dad takes a five minute shower; David's and Mom's showers both average seven minutes; and (much to Dad's chagrin) Amy – who has thick, long hair – takes a 15 minute shower every morning. In addition, the Smiths have no dishwasher, thus they run water for 20 minutes each day while washing dishes, and Dad and David both shave with blade razors and leave the water running 5 minutes each while they shave. Each person in the family runs water for 2 minutes each day as they wash.

The Smiths live in a 50-year-old house in a suburb of Boston. While they have painted and hung new wallpaper, the sink, toilet and shower/tub are still the originals from 50 years ago. They love the house and the neighborhood and plan to stay there for many more years.

The Smiths budget their money very carefully. They examined their old water bills and found that they currently pay a constant rate for their water of $5.00 per hundred cubic feet. (This figure included their sewage disposal cost, because in most towns, sewage is billed as a portion of the total water used.) After reading that the cost of water is predicted to rise, they decided to look into whether or not they should invest in some new plumbing fixtures and water saving devices.

Furthermore, the Smiths knew from past calculations that they spent about $350 each year on fuel charges for water heating. They estimated that about 40% of that amount went into water heating for showers, about 20% went into kitchen and bathroom uses, and about 20% went into washing clothes. They had insulated their water pipes and hot water tank several years earlier, yet they still estimated that they lost the remaining 20% of the energy to system leaks and inefficiency.

Problem # 1

The Smiths' two showerheads are quite old and inefficient. Amy measured the flow rate and found each showerhead's flow rate to be 5.5 gallons per minute. Together, she and her dad went to the store and found that for a total of $30.00 they could buy two low-flow shower heads that, according to the manufacturer's claims, would deliver only 2.5 gallons per minute without lowering the quality of the shower.

Amy didn't want to buy them because she didn't think she'd be able to rinse her hair as well as she could now. Her dad made a deal with her: If the showerheads paid for themselves in one year or less, he wouldn't bother her about the length of her showers for a full month. If they wouldn't pay themselves in one year, they wouldn't buy them.

1. Before you do any calculations, do you think they did or did not buy the shower heads?

2. Calculate how long would it take the showerheads to pay for themselves through water savings? (Remember: one cubic foot contains 7.5 gallons.)

3. How much additional money did the Smiths save in fuel bills as a result of their new low-flow shower heads?

4. What would happen to the Smiths' annual water and fuel bills if, in addition to installing the new showerheads, Amy cut her showers to ten minutes?

Problem #2

As a result of dishwashing, cleaning, shaving, toothbrushing, and washing the face and hands, the Smiths estimated that they ran water from the sinks for a total of 38 minutes each day, so they decided to see if it would make sense for them to buy low-flow sink aerators to go along with the showerheads.

At present, their sinks have a flow rate of 4 gallons per minute. With the new sink aerators, the flow rate would decline to 3 gallons per minute. With two bathrooms and the kitchen, they will need to buy three of them at a cost of $5 each.

5. How much water will they save during the first year?

6. At $5.00 per hundred cubic feet, how much money will they save during the first year?

7. How long will it take them to pay for their aerator purchase out of savings?

8. If shaving and washing consumes about 20% of the Smiths' total hot water budget. How much additional money will they save through energy savings?

Problem #3

The Smiths grew so excited about their potential savings that they decided to look into other uses of their water. First they examined their two toilets. They measured the holding tanks on each of their toilets and found that each flush used about 4.8 gallons of water. They then kept a list of each flush for the next week and found that they flushed an average of 5 times per day per person, or 20 times per day.

They talked about what they could do one night, and they came up with two solutions. David had heard about putting a water dam in the back of the toilet to prevent about one gallon of water to flow out during a flush. The dam cost only $10, but David had also heard that such items sometimes interfered with the toilet's ability to flush thoroughly. He thought it might still be worthwhile to try.

For years, the Smiths had wanted to modernize their bathroom, and they thought this might be their chance. They had been reading about new toilets that used only 1.6 gallons on each flush. The next day, they called a plumber and found that buying and installing these new toilets would cost $300 each, for a total of $600. They would have to borrow that money at 12.5% simple interest during the year.

The Smiths promptly set out to calculate how much money they would save by either installing the new toilets or installing the toilet dam so they could make a wise decision about what to do.

9. How much money would the Smiths save in a year by installing two $10 toilet dams?

10. How long would they have to use the dams before they paid for themselves in savings?

11. How much money would the Smiths save in a year by installing two new water-saving toilets?

12. How long would they have to use the toilets before they would pay for themselves in savings?

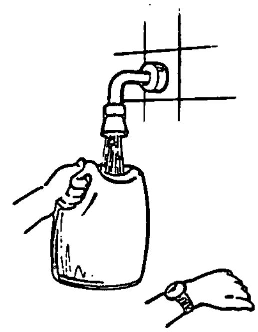
Measuring the Water Consumption of Your Shower, Tub and Toilet

To calculate the rate of flow of your showerhead or tub faucet, you will need a measured container to catch the water and an accurate way to time the number of seconds it takes to fill the container. For accuracy, you may need to measure several times and average the results. Working in teams of two, with one person just timing, may be helpful.

To measure the flow rate of your shower and faucets...

1. Open the top of a container of a known quantity such as a two-quart, plastic pitcher or a gallon jug. (You may need to cut the top off a plastic jug to get it to fit over the shower-head or faucet.)

2. Turn on the water just as you normally do and begin timing just as you start catching the water. Note exactly how long it takes to fill your container.



3. Calculate the rate of flow of your showerhead or faucet by dividing 60 (the number of seconds in a minute) by the number of seconds it would take to fill a gallon container.

   For example, if it takes five seconds to fill a two-quart pitcher it would take ten seconds to fill the pitcher twice (one gallon). In one minute you could fill the pitcher twelve times. Thus your shower has a flow rate of six gallons per minute, and a six-minute shower would use 36 gallons of water.

   If you have a tub and shower combination, an alternate way to find out how much water you use for a shower is to catch the water in the tub. Be sure the plug is tight and then measure the amount of water in the tub when you have finished showering.

To measure the volume of your tub...

1. Use a ruler, yard stick or tape to measure the length of the tub.

2. Measure the width of the tub and the depth (height) of the water.

3. Multiply length times width times height to find the volume.

   For example, if the tub is four feet, ten inches (58 inches) long by 24 inches wide, and the water is six inches deep (high). You will have filled 8352 cubic inches of space. (58 X 24 X 6 = 8352 cubic inches). To convert cubic inches to gallons divide by 231 (8352 divided by 231 = 36.15).

4. To determine how much water you use for a bath, estimate the depth to which you fill the tub when you take a bath or (better yet) measure the volume of water just before your next bath.

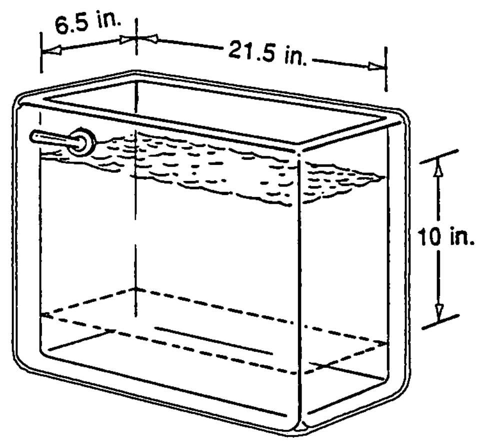
To measure the capacity of your toilet tank...

1. Very carefully remove the lid from the tank and lay it on the floor out of the way.

2. Measure the length and width of the tank's interior and the depth of the water.

3. Flush the toilet and measure the depth of the water that remains in the tank during the flush. Subtract this amount from the total depth of the water when the tank is full.

4. Multiply the tank's length by its width and multiply that product by the water level you calculated in #3. This will give you the number of cubic inches of water per flush. Divide this number by 230 to convert cubic inches into gallons. This illustration provides an example:



length = 21.5 inches
width = X 6.5 inches
1075
1290
139.75
height = X 10 inches (the water level minus one inch)
1397.5 cubic inches of water per flush

1397.5 / 231 (cubic inches per gallon) = 6.05 gallons = 6 gallons per flush

Assume this toilet belongs to a family of four who flush an average 4.5 times per person per day. If they invested in a new toilet that uses only 1.6 gallons per flush, how much water would they save per day? Per month? Per year?

If your family switched to 1.6 gallon per flush toilets, how much would you save per day? Per month? Per year?

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Part VII: Domestic Water Conservation

#21 Monitoring Your Personal Water Use
Teacher's Notes

Purpose

To help students become more aware of and more responsible for their own water use.

Activity in brief

Students first estimate their average personal water use per day, then they monitor their actual daily water use for a week and modify their estimates.

Key words and concepts

Estimation
Monitoring
Gpd (gallons per day)
Conserve / conservation

Materials

Monitoring Your Personal Water Use activity sheets (attached).
Copies of kitchen and bathroom charts for students to take home (attached).
Copies of sheet showing estimates of average daily water consumption (attached) to be handed out after students have completed the homework.

Time required

20-30 minutes during each of two class periods -- one before homework and one after homework is completed. Allow one week for students to complete the homework.

Procedure

1. Discuss the importance of estimation.
2. Have students share their guesses of how much water they think they use each day. (You may want to write the range of their answers on a chart or chalk board.)
3. Assign water use monitoring homework. You might want to suggest that students keep track of their water use and the water use of their families for at least three days.
4. Hand out estimate sheets and have students calculate their own and their family's average daily water use.

Conclusion and extensions

1. Help students check their calculations to make sure they are accurate.
2. Discuss why their original estimates may have been inaccurate.

3. Suggest that students measure their toilet tanks and bathtubs and calculate the flow rates of faucets and showers in order to make even more accurate estimates. Directions for these calculations may be found in Activity # 18, *The Cost of Savings.*

Additional Activity Ideas

1. AMERICANS ARE MAJOR WATER CONSUMERS!
The U.S. consumes more water per capita than any other nation in the world. Have students list the countries or regions of the world they think use the least water, and those that use the most. How might people use water differently and why? Have your students imagine and write about what it would be like to live with less water.

   Interestingly, in some modern European countries, many people bathe only once or twice each week, and they are amazed at the American habit of bathing every day. Have your students stage conversations between themselves and European teenagers.

2. WHAT WOULD LIFE BE LIKE WITHOUT RUNNING WATER?
Have students search out and interview someone who has lived in a home without plumbing. How did they get their water, and how did they use water differently than we do today? Have the students imagine themselves in that person's shoes and have them write about daily life in an imaginary diary. Discuss whether life without running water is simpler or more complex?

   Have students read historical stories that portray life without running water, such as *Little House on the Prairie.*

3. WHAT WOULD YOU DO WITH ONLY FIVE GALLONS OF WATER PER DAY?
Have students imagine that their water supply has been cut off and for the next six months they must live on a personal water allotment of only five gallons per day, saving at least one quart of that water for drinking. Have students list the ways they would use their water, and list the quantities. Have them prioritize their lists from most to least critical. Students could write about how it would feel to live on such a limited water supply or how their lifestyle would change. Also consider a group decision-making activity where four or five students would have to agree on how they would use the twenty-five gallons allotted to their group.

4. COMMUNITY WATER CRISIS!
Imagine that because of a severe emergency, the greater Boston area must cut its total water consumption from 250 million gallons per day (mgd) down to only 50 million gpd. What uses would have priority? (Fire fighting, residential use, commercial use, hospitals, farms, personal hygiene, car washing, hair washing, swimming pools, lawn watering?) Which uses would be easy to give up and which would be more difficult?

5. CLASS DISCUSSION: THE SOCIAL IMPACT OF DROUGHT
The summertime drought of 1988 made an extensive social/economic impact. Produce became scarcer and more expensive across the country. Because cattle did not have enough to drink, some herds had to be slaughtered early, thus beef prices dropped slightly then rose dramatically. Commerce along the Mississippi River basin came to a near halt because the river was so low that barges used for shipping ran aground.

Have students list all the effects of droughts they can think of and discuss how a lack of rainfall in one region of the country/world affects other regions.

Sample Test and/or Discussion Questions

1. What personal activity usually consumes the most water each day?
   ______*showering or toilet flushing*______

2. List at least three ways you could conserve water.
   a.____________________
   b.____________________
   c.____________________

   1. *Shut water off while brushing teeth or washing hands.*
   2. *Put drinking water in the refrigerator or add ice cubes instead of running the water to get it cold.*
   3. *Take shorter showers.*
   4. *Do not use the toilet as a waste basket or flush unnecessarily.*
   5. *Wear outer clothing more than once before putting it into the laundry.*
   6. *Only run the washer and the dishwasher when they are full.*

3. Reducing personal water consumption in the home could reduce costs other than the family water bill. List other areas of possible savings.

   1. *Energy costs for water heating.*
   2. *Sewage disposal (because it is tied to water consumption).*
   3. *Energy costs for water pumping.*
   4. *Extended life cycles of home and city water systems.*
   5. *The costs (both social and economic) of building new sewer systems.*

#21 Monitoring Your Personal Water Use
Student Activity

Background

High-quality, fresh water is in short supply in many parts of the world, including greater Boston. Although the MWRA's water-supply system can safely provide 300 million gallons per day (mgd) of some of the best drinking water in the world, its customers have used more than that for the past twenty years. Unless we all become more aware of how much water we use and start using less, there simply will not be enough water for everyone.

Think of the Quabbin and Wachusett Reservoirs as just large containers, and the people of greater Boston as the "family" using the water they contain. We never really know when rain and snow will replenish the supply so we must always be careful about how we use water, and we must always try to conserve.

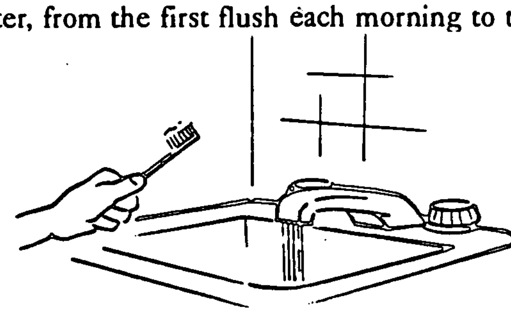
In this activity, you will examine your own daily personal water use and that of your family. By the end of the activity, you will have a reasonably accurate picture of how much water you use personally each day.

How much water do you <u>think</u> you use each day...and what do you use it for?

Take a guess. You'll be able to check your answer soon.

1. I guess I use about _______ gallons of water each day.

2. List all the things you do each day that require water, from the first flush each morning to the last tooth brushed at night.



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3. Compare your list with the lists of your classmates. Add anything you left off your list. (Did you remember laundry, cooking, or dish washing? How about the water you waste by letting it run while you brush your teeth or wash your hands?)

4. Do you want to change your guess and make a more informed estimate of your daily water use? _______ gpd

Monitoring your water use at home

Keep track of your own water use over the next week. Because you share some water uses with your whole family, such as laundry, cooking and dishwashing, ask everyone to participate in this activity with you. Your whole family will benefit from an increased awareness of water use.

1. Place record-keeping charts in each of the appropriate rooms in your home and keep a pencil nearby for recording. Note: If you use tape, be sure to attach it only to smooth surfaces such as tile or counter top for easy removal.

2. Note on the chart each time you use water.

3. At the end of the week, calculate how much water you consumed by using the quantities listed in the chart of *Estimated Average Daily Water Consumption* that your teacher will provide.

   For example, if you flushed 30 times during the weekand your toilet uses 3.5 gallons per flush, how much water did you use?
   a) multiply 30 by 3.5 to calculate the gallons per week. 30 X 3.5 = 105 gallons per week.
   b) divide 105 by 7 to calculate the average gallons per day. 105 / 7 = approximately 15 gpd.

   Important Note: The quantities listed in the chart are based on national averages. The capacities of the fixtures and appliances in your home may be very different from those listed. To make your estimate more accurate, you could measure the actual capacities and flow rates of your family's fixtures and appliances. (Activity #20, *The Cost of Savings*, contains instructions for making these measurements.)

4. Did you find that you actually used more or less water than you originally guessed? Are you at all surprised at the amount of water you use each day?

5. Did you find that any of your classmates used substantially more or less water than others? If so, try to find out why.

6. List at least three ways you think you could conserve water and write how much water you think you would save.

   a.

   b.

   c.

   d.

7. Make a commitment to change at least one or two habits that waste water. Write your commitment here.

8. Prepare a personal and family water-saving (conservation) plan.

Conclusion

Water is essential to maintaining a comfortable, healthy life. However, each of us may be able to use less water than we do now and still keep our lives comfortable and healthy. As water supplies decrease and the population increases, saving water and staying aware of water use will become increasingly important.

PLACE CHARTS IN BATHROOM AND MAKE A MARK IN THE APPROPRIATE BOX EACH TIME YOU FLUSH OR USE THE FAUCET

Family member	Flushes per day							*gpf	Total
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.		
							Total gallons		

Family member	Use of faucet for brushing teeth, washing hands or shaving							*gpu	Total
	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.		
							Total gallons		

PLACE CHARTS IN KITCHEN AND WRITE AN APPROPRIATE LETTER IN THE BOX EACH TIME YOU USE WATER

Family member	For dishwashing write "D". For clothes washing write "C". Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	*gpu	Total
							Total gallons		

Family member	Write C for cooking, D for drink, H for hand washing, etc. Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.	*gpu	Total
							Total gallons		

* gpu = gallons per use; gpf = gallons per flush

#22 Conducting a Home Water Audit
Teacher's Notes

Purpose

To involve students in the process of taking a water audit of a home or business.

Activity in brief

Students will read water bills to determine how much water their family uses each month, and they will learn about leaks and leak detection by timing drips and using their homes' water meters. Students will complete a checklist to determine their families' current water use habits.

Key words and concepts

Audit (record keeping, accounting and management)
Leak detection
Monitoring

Materials

Sample water bills
Conducting a Home Water Audit background and activity sheets
A measuring cup (for measuring the amount of water lost through drips and leaks)

Time required

One-half class period before homework assignment and one-half period the following day

Procedure

1. Preview activity sheets.
2. Encourage students to enlist their family's cooperation in conducting a home water audit.
3. Assign students to do as much of the activity as possible at their own or a friend's home.

Conclusion and evaluation

1. Help students check their results.
2. Establish a chart on a classroom bulletin board that shows the cumulative effects of student audit and conservation efforts over several weeks or months.

Additional Activity Ideas

1. BUSINESS WATER AUDIT
   If students do not have water meters at their homes, or if they would like to do an additional activity, perhaps a small business near them would allow students to help conduct a water audit for the business.

2. WATER AWARENESS SURVEY
Have students design and conduct a water awareness survey for home, school or their community. They could ask people if they know how much water they use, or how much their family or business uses. They could ask if people are aware of their water rates or the source of their water. They could also investigate public awareness of conservation or the long-term implications of no conservation.

Sample Test and/or Discussion Questions

1. Describe a simple method for checking to see if a toilet tank leaks.
   Put food coloring in the toilet tank. If it shows up in the toilet bowl without flushing, the tank has a leak.

2. How can you use a water meter to detect leaks?
   Shut off all the water outlets in and around a building. If the meter changes, there is a leak.

3. Which of the following is <u>not</u> true:
   a. Washing dishes by hand rather than in an automatic dishwasher always saves water.
   b. Putting in a toilet dam can save a substantial amount of water with each flush.
   c. A small leak can waste up to 100 gallons of water a day.
   d. Insulating hot-water pipes can save water.
   a. While washing dishes once a day in one small basin or sink and rinsing in another can save water; letting the water run while washing the dishes by hand can use more water than a dishwasher. Thus washing dishes by hand does not <u>always</u> save water.

4. Based on what you know about conducting a home water audit, discuss how you would go about conducting a water audit for a small business.

#22 Conducting A Home Water Audit
Student Activity

Background

Water is a limited resource! Because we cannot consume more than we have available; we must use water wisely. The purpose of a home water audit is to find out where the water in your home is going and whether or not you are managing it well.

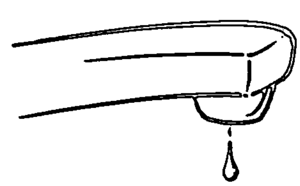
The first step in doing a home water audit is to look at records such as water bills. If you live in a single-family home you probably get a water bill; apartment dwellers often do not. If you do have water bills to examine, look at the records for the past several months and average the amounts. How much water did you use? How much did it cost? If your family does not get a water bill, you will have to estimate your family's water use. (See Activity # 21 *Monitoring Personal Water Use.)*

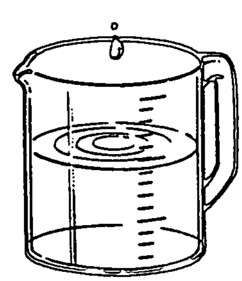
The second step in conducting a water audit is to make sure all the water coming into a building is actually being used and not being lost to leaks. This is the accounting part of the audit. The *Accounting for Leaks* activities below will help you learn how to account for water which might be lost through leaks.

The third step in the water audit process it to check how water is being managed. Use the *Home Water Audit Management Questionnaire* on pages 3 and 4 to see how well your family is managing the water that comes into your home.

Accounting for Leaks

Small drops of water add up quickly. A 1/32" diameter leak wastes twenty-five gallons of water a day. A 1/16" diameter leak wastes one hundred gallons a day. Leaks large enough to lose steady streams of water instead of drips are most insidious; they often cannot be heard. Find out how long it takes for a dripping or running leak to waste a gallon (16 cups) of water.





Procedure for measuring the flow rate of a leak

1. Open a faucet and quickly close it down to a steady drip.
2. Time how long it takes for the dripping faucet to fill a measuring cup.
3. Repeat steps 1 and 2 two more times so you measure three different rates of leaks.
4. Calculate how many gallons of water would be wasted at each rate in one day, one month, one year.

Procedure for locating water leaks

1. Turn off all the water in and around the house and read the meter. (If you do not know how to read a water meter, see Activity #20 *Reading Your Water Meter.*)
2. Keep all of the water shut off for a period of time. Fifteen minutes will enable you to find fairly large leaks. In one hour, you will discover smaller leaks. And, if you can keep everyone from using water for eight hours, you could locate even very small leaks.
3. Read the meter again after the allotted time. If the dials have changed, there is probably a leak.
4. Locate the leaks by taking an area-by-area leak detection survey
   a. Check bathrooms (a toilet tank is often the subtle culprit). Put food coloring in the tank. If color shows up in the toilet bowl within a few minutes, the toilet leaks.
   b. Check for dampness around pipes and appliances.
   c. Look for water stains on floors, ceilings and walls, and under sinks.

IF YOU FIND A LEAK DO NOT TRY TO FIX IT YOURSELF! Trying to fix plumbing-related problems can create more problems than it solves. Plumbing fixtures are often old and brittle. The job often requires special tools. Your best option is to tell the adults in your home about the problem and let them decide what to do.

In addition, according to law (Chapter 142 of the Massachusetts Legal Code), plumbing work must be performed only by a licensed plumber (in order to protect insurance coverage).

Home Water Audit Management Questionnaire

These 25 questions concern home water conservation measures. Fill them out with the help of your family.

Put a star (☆) next to those items the family is already doing properly.
Put a check mark (✓) next to those that could be improved.
Write NA next to items that do not apply to your family.

___ 1. Are toilets free of leaks?
A small leak can waste up to 100 gallons a day; larger ones waste even more.

___ 2. Do members of your family use the toilet as an ashtray or waste basket?
Every needless flush wastes 5-7 gallons of water.

___ 3. Would the toilet flush as well with less water?
Putting in a dam or displacing some of the water with plastic containers could save about half the water presently used each day for flushing.

___ 4. Is every flush necessary?
If every household in the MWRA system flushed two less times per day we would save over 5 million gallons of water each day.

___ 5. Does everyone in the family take short showers?
The wet-down, soap-up, rinse-off method of showering takes less than five minutes. Anything more than ten minutes is "recreation."

___ 6. Does the showerhead need replacing?
It does if the flow rate is more than 3 gallons per minute.

___ 7. Do people in the family take efficient tub baths by doing the following?
Closing the drain plug right away and adjusting the temperature as the tub fills.
Making sure drain plugs fit tightly.
Using no more than four inches of water in the tub.

___ 8. Does your family only run the clothes washer with full loads ?

___ 9. Could members of the family wear some clothing more than once before washing?

___ 10. Does your family wait until the dishwasher is full before using it?
Washing dishes only once a day can save 14-30 gallons of water each day.

___ 11. Does anyone leave water running when rinsing dishes by hand?
Washing and rinsing dishes in small sinks or basins only once a day can save water.

___ 12. Do you wash fruits and vegetables in small containers rather than under running water?

___ 13. Do members of your family wash their hands and faces in partially filled sinks rather than with the water running?

___ 14. Do members of your family turn water off while brushing teeth or shaving?

___ 15. Are all pipes and faucets free of leaks?

___ 16. Are hot-water pipes insulated so that hot water does not cool off in the pipe on the way to the faucet?

___ 17. Do members of your family use the outdoor water hose or sprinkler as a toy?
Filling a small pool or tub with water for summer fun is much less wasteful than a running sprinkler.

___ 18. If the lawn really must be watered, do you do it efficiently with drip hoses or sprinklers used only after sundown to minimize evaporation?

___ 19. Do you sweep hard surfaces around the house with a broom rather than cleaning with a hose?

___ 20. Do you use a hose with an automatic shut-off when you wash the car?
To save water, soap the car from a pail and only use the hose to rinse.

___ 21. If your family has a swimming pool, do you cover it when it is not in use to cut down on evaporation?

___ 22. Are trees and other lawn plantings native species of low-water-demand varieties?

___ 23. Is drip irrigation used for garden watering?
This method of watering has a slow, soaking effect and requires less water to reach roots.

___ 24. Does your family recycle water whenever possible?
For example, water used to wash vegetables and meat is very good for plants.

___ 25. Are there other ways your family could save water, inside or outside the house?

Keep track of your family's water use over the next several months. Note how it changes and try to account for those changes.

Part VIII: Auditing Your School

#23 Conducting a School Water Audit
Teacher's Notes

Purpose

To conduct a comprehensive water audit of the school's water system.

Activity in brief

Working either as a class or in independent teams of interested students, the auditors will examine water use throughout the school by carrying out the following steps:

1) Reading the school's meter(s) and water bills to determine the school's annual water use.
2) Surveying the entire school to see how water is being used.
3) Analyzing the school's water use management and recommending ways to use less water.
4) Analyzing the data and writing a formal technical report.
5) Preparing a proposal for a water conservation program and presenting it to the school administration and/or the city or town school committee.
6) Creating and implementing a school-wide conservation program.

Key words and concepts

Audit (records, accounting and management)
Data gathering and analysis
Equipment specifications (equipment standards)
Leak detection
Payback time
Preparation of public presentations
Project management and delegation of responsibility
Report writing
Retrofit
Statistics
Survey and monitoring

Materials

1. Copies of water and sewer bills (if available)
2. Instructions and data sheets included with this activity.

Time required

We think this activity may work best as an independent after-school project for a group of interested students. If it is done as an after-school project, many of the observations will have to made during school hours, thus any students who want to be involved can be, including those who work after school or are involved with extracurricular activities.

Outside Assistance and Technical Problems You May Encounter

We anticipate that you may encounter several different types of problems that you cannot readily overcome. Thus we recommend that you encourage the students to: 1) make intelligent guesses and assumptions (scientific inquiry, after all, is based on the making of assumptions) and 2) solicit the help of a technically knowledgeable person – preferably a mechanical engineer – from the community who might be willing to volunteer his/her expertise.

- Some of the water consuming systems, such as the heating and cooling system, may be too complex or inaccessible for students. If so, omit this system from the audit, and in the final report, recommend that the system be examined by a professional auditor.

- For some of the school's equipment, such as the dishwasher, you may not be able to accurately determine the water use per cycle. If such information is not available from the manufacturer and cannot be measured, simply examine the usage patterns and verify that equipment is being used efficiently. In the case of dishwashers, for example, be sure the trays are always full.

- It may be impossible to determine the true flow rate for toilets and urinals. If so, determine the approximate age of the equipment and check with a plumbing supplier to determine the approximate flow rate for equipment of that age and description.

- It will be impossible to determine the true hours of use of much of the water using equipment in the school. For example, how many times does each toilet flush and how long does each faucet run during each school day? These problems lend themselves to creative solutions on the part of your students. They may elect to do surveys, to make observations, or to make estimates. The key is to try to ensure that they are basing their guesses and research efforts on sound logic and clear thinking.

Structure of the Audit

This audit consists of two primary components. Thus we recommend two different student teams, each responsible for their portion.

One part we call "Records and Accounting," and the other we call "Management." The Records & Accounting group will obtain published information about water use, including the school's historical usage data. The Management group will examine all of the school's water using equipment to determine the actual flow rate, the actual time of use, and the total actual water consumption.

The Records and Accounting group will be responsible for:

- securing the school's water use records, including meter readings.
- securing billing information from the city or town.

- obtaining and reading manufacturer's specifications to determine an item's specified flow rate for both the existing fixtures and water saving replacement fixtures.

The Management group will be responsible for:
- calculating the flow rate of each water use item in the school.
- determining the actual time of use of each family of water use items.
- making reasonable estimates of water use in situations when real data cannot be gathered.

To ease the responsibilities on you, the teacher, we also recommend that you select three responsible students to serve as project managers. One should manage and coordinate the overall project, and the other two should manage the two work groups.

In addition to the three student managers, the audit will require the efforts of several teams of two or more students. **Using students for the work is very important!** Students are much more likely to want to help fix a problem if they are allowed to feel some ownership of the solution. Each of the tasks is such that it can be carried out by a responsible student manager and his or her team.

As a matter of note, the **Management** group's assignments are labor intensive; students must count and monitor the use of all of the water use areas in the school. **Records and Accounting's** assignments, on the other hand, require more analyses of printed information. *We recommend that three to six students serve on the Records and Accounting team, and as many as possible serve on the Management team.*

The audit itself contains four major stages:

1. Planning
   In the planning stage, the student leaders will meet with those people in the school responsible for water use areas in order to enlist their support and cooperation in scheduling and allocating time and resources for the audit.

2. Auditing
   During the audit, pairs of students from the *Management* team will examine the water use areas within the school and calculate/estimate the total amount of water used in each area. Simultaneously, students from the *Records & Accounting* team will examine available water use data.

3. Data Analysis
   In this phase of the audit, students will combine their findings to examine which areas within the school use significant amounts of water. They will also brainstorm/discuss ways in which water can be saved in each of the areas they examined.

4. Reporting/Information Dissemination
   In the final phase of the audit, students will prepare a formal report of their findings and recommendations. They may then present the information to the student body, the administration and/or the school committee. In addition, students will develop a program for implementing behavioral changes among students and staff that may save water. These efforts could include making and posting signs, monitoring water use and publishing the monthly data in the school paper, writing and producing a class skit on water conservation, or making videotapes and advertisements that address water conservation/water use issues.

Classroom suggestions

1. Define water audit and ask why a school audit is important.

2. Before the audit, have students discuss the difficulties they expect to encounter. After the audit, have them debrief and examine the true difficulties they encountered.

3. Conduct the audit entirely as a student project, perhaps in an interdisciplinary fashion with other teachers in the school. The business class, for example, could be responsible for the management/planning; the math or computer classes could be responsible for sampling procedures and data analysis.

#23 Conducting a School Water Audit
You Can Help Your School Save $$$ Through Wise Water Use!

Background

Your school, like all other public institutions, has an obligation to save money and other precious resources. Unlike businesses and industries, a school's priority is not to make or even save money; it is to educate students. This does not mean that schools are not interested in saving money -- indeed, most school systems are very short of money and are vitally interested in conserving it. However, administrators and school committees must deal with so many urgent educational and logistical concerns that saving water may not be high on their agendas.

By carrying out this *School Water Audit*, you and your fellow students can make a long-term, valuable impact on your school and your community. Your school (like most other public buildings) probably uses more water than it should. By finding how water is being wasted and stopping that waste, you will help the school save money and help ensure a reliable water supply for all of eastern Massachusetts.

This water audit will help you discover how much water is really being used and examine possible ways to use less water. Your school is not terribly different from local industries such as Gillette and Polaroid that have conducted successful water conservation programs. You have a kitchen, many restrooms, laboratories, showers, and buildings and grounds that must be maintained; some of you even have a swimming pool.

This school water audit is a long-term activity that requires teamwork, careful communication, problem solving, and creative thinking. You may come across many questions you are unable to answer, and you may need to ask for help from an expert, such as a mechanical engineer.

When your audit is complete, you will have a good idea of how much water your school could save. These savings will be possible in one of two ways: changes in the behavior of your classmates and the school employees, and changes in the plumbing equipment. In the first case, (when savings can result from behavioral changes) you can conduct a school-wide campaign to try to convince people to change their behavior in order to save water. In the second case, you might write a proposal and present it to the school committee. They are the ones who allocate the funds for equipment modifications and the ones who will realize the savings. (We recommend that you try to negotiate an agreement with the school committee similar to an agreement between the Gillette Corporation and its employees: if your recommendations save money, ask the school committee to split those savings with you, allocating money for new student resources.)

WATER AUDIT CASE STUDY: In a Successful Water Conservation Effort, Gillette Cuts Water Use By 90%.

The Gillette Corporation, headquartered in South Boston, has become an international leader in water conservation and wise water use. In 1972, their South Boston plant used 800 million gallons of water each year, and that amount was growing at the staggering rate of 25% each year.

Today, Gillette has cut its water use by more than 90% through water conservation. In their plant, they have realized these savings in two ways:

1) With the help of both their employees and hired consultants, they searched for, found and corrected places within the plant where they wasted water; and
2) They promoted water conservation among their employees, thus helping those workers change their water consuming practices. But Gillette did not stop there. To promote water conservation at home, they bought residential water-saving hardware, such as low-flow showerheads, toilet dams and sink aerators, at wholesale prices and passed the savings on to their employees.

To ensure continued savings, Gillette shrewdly relied on their employees to find conservation opportunities. For nearly two decades now, Gillette employees have submitted their water conservation ideas. When an idea is successfully implemented, Gillette pays the employee who thought of it up to 25% of the first year's savings. Gillette's business philosophy was sound: they provided special incentives to their employees and still realized substantial net savings.

Most of Gillette's savings have resulted from changes in their production processes and changes in the heating/cooling system. Within the manufacturing process, they concentrated on reusing and recirculating water. While your school may not have equivalent processes or equipment to change, there are plenty of opportunities for schools to conserve water.

> *We evaluate the capital costs of water saving steps differently than we do investments in a product. An investment in water savings, unlike an investment in a new product with a shelf life of two to five years, will continue to pay for itself over time.*
> Gillette's Manager of Capital Operations

Gillette is not the only local company that has benefitted from wise water use. Other companies and institutions save water and money as well. Polaroid, Boston Edison, Massachusetts General Hospital and Harvard University have all audited their physical facilities and water use practices. They are not only profiting from their savings but are also contributing to the greater good of the community.

The Components of the School Water Audit

To conduct this school-wide audit, you will be divided into two groups: **Records and Accounting** and **Management.** Each group will have a student manager, and a third student manager will oversee the entire audit. Smaller groups of two or more students will carry out the necessary research. The audit itself contains four discrete steps: planning, auditing, data analysis and reporting.

Step 1: Planning

A. In the planning phase, the key student managers and the faculty advisor will meet with the primary water users from throughout the school to enlist support and cooperation. This group may include (but not be limited to):

- heads of departments that use water, such as science, home economics and industrial arts.
- the principal or headmaster.
- the buildings and grounds supervisor.
- the food service supervisor.
- the head custodian.
- representatives of other water-using groups.
- the school's business manager.

In this meeting, explain what you are doing and ask them to help by providing access to their equipment and, whenever possible, printed information, such as copies of water bills for the past two years, meter readings and manufacturer's specifications for water use equipment.

B. *Scheduling*
Establish (and stick to) target dates for the entire project. Depending on the level of detail, you could complete the audit in as little as two weeks or as much as one semester.

C. *Personnel planning*
Teams of at least two students each should audit each water use area. Some audit areas, such as restrooms and shower rooms, will require separate teams of males and females, and if your school has many restrooms, you may need several teams.

Step 2: Auditing

The audit will be conducted by two separate teams: **Records & Accounting** and **Management.** (Use the attached forms for listing team members and recording your data.)

The **Records & Accounting** Team will obtain published information about water use, including the school's historical usage data. They will be responsible for:

- securing the school's water use records, including meter readings.
- securing billing information from the city or town.
- obtaining and reading manufacturer's specifications to determine an item's specified flow rate for both the existing fixtures and water saving replacement fixtures.

The **Management Team** will examine all of the school's water using equipment to determine the actual flow rate, the actual time of use, and the total water consumption. They will be responsible for:

- calculating the flow rate of each plumbing fixture or appliance in the school.
- determining the actual time of use of each group of water use items.
- making reasonable estimates of water use in situations when real data cannot be gathered. (For directions on calculating flow rates, see Activity #22 *Conducting a Home Water Audit.)*

Without doubt, both teams will encounter unforeseen problems. For example, the management team may calculate the flow rate of an average faucet to be 2.5 gallons per minute, and they may count a total of 60 sinks with similar faucets in the school. Calculating how long each sink is actually in use, however, may be more difficult, thus they will have to make a reasonable guess, perhaps by observing several sinks or questioning other students about their sink use habits.

Audit Procedure

Records & Accounting Team

1. Obtain water meter readings and billing information from the past one to two years.
   - The school may have several meters, and it may receive several different bills. You should try to locate all of them.
   - The school might be billed for water monthly, semi-annually or annually. Take note of the billing schedule.
   - Your school may be metered but not billed. In that case, the town offices should have the meter-reading history.
   - You may find that your school is not metered. In that case, your school is part of your community's *unaccounted for* water budget, and your audit will have to rely entirely on the data collected by the management team.

2. Calculate the total water used by the school during four continuous three-month periods. (NOTE: keep records of this for data analysis --- if water consumption is higher in a certain season, such as the fall, see what's different. Perhaps it is football season.)

3. Calculate the combined water rate and sewer rate. (If your town charges the school on a block rate system (see Activity #19 *Can Water Rates Promote Conservation?*), take the blocks into account when you calculate the cost of savings. Using less water will undoubtedly save the school water and money, but the amount of the savings will depend on the rate structure.)

4. Find out if the town's water rates will be rising in the foreseeable future. If so,

how much? When you calculate future savings, use future costs as your basis.

5. Whenever possible, obtain the manufacturer's specifications for the different pieces of water using equipment. If the specifications contain water use data, record that data for future reference on *Data Collection Sheet* #2 (on page 13 of this activity).

Management Team
(Use the *Management Team Data Collection Sheet* on page 14 for recording your observations.)

1. Assign team members to specific audit areas.

2. Count the different types of fixtures/water users in your audit area.

3. Count the number of each type of fixture/water user in your audit area.

4. Calculate or estimate the flow rate of each type of equipment in your audit area.

5. Calculate or estimate the total time of use of each type of equipment in your audit area.

Step 3: Data Analysis

The data analysis phase of the audit has two main components: 1) examining which areas within the school use significant amounts of water, and 2) determining how water can be saved in each of these areas. Your job is to examine the available data to discover where water is being used or wasted and to recommend ways to minimize waste.

Someone who is adept with computers could help set up a spreadsheet and data base for the analytical calculations. Otherwise, you should carry out the calculations by hand. You will be analyzing two types of data -- that which pertains to *structural facilities (hardware)* and that which pertains to *people's behavior*. Each type of data represents a potential source of savings.

To begin, examine and discuss the data collected by the two teams to determine what useful information it contains.

Example I: To determine water use on an *average* school day, compensate for the summer and other long vacation periods. If the school receives only one meter reading for the entire year, divide the annual water usage by 200 rather than the usual 365 days per year. This would include the 180 days school is in session plus 20 extra days for cleaning and maintenance. This kind of *estimating* is essential, especially when exact figures do not exist.

Example II: The Management team may have determined that the school has a total of 62 toilets, each with a flow rate of 5.5 gallons per flush, while the Records and Accounting team determined that flushometer valve disc retrofit kits could reduce the flow to only 3 gallons per flush and that the kits could be installed at a cost of $ 55 each. You could then determine how much the school would save and how long the payback time would be for the retrofitting of the valves.

IMPORTANT NOTE: *Be sure the data you are using are internally consistent. For example, water use units must all be the same. You cannot directly compare a flow rate of cubic feet per year with a flow rate of gallons per minute. Likewise, you cannot calculate savings from a structural change if the savings are expressed in gallons and the billing rate is expressed per ccf (hundred cubic feet). You must convert to one consistent unit. Use the conversion chart at the end of Activity #13* ***How Much Water do You Really Use?***

To calculate the savings from these examples, calculate 1) the average amount of water the 62 toilets use each year, 2) the percentage of the water that would be saved and 3) the costs for water and sewage disposal. Then compare the purchase-plus-installation costs with the savings in order to determine how long it would take for the savings to pay for the cost of the changes (payback time).

Professional auditors determined that the flushometer kits described above would save 30% of the water normally used for flushing in a college dormitory with 62 toilet units. The valves would conserve 695,250 gallons of water per year (92,700 cubic feet or 927 ccf) for a total annual savings of $2,040. Installing the 62 flushometers cost $3,410, so the payback time was 1.7 years.

Sample Problem for Calculating the Savings:

For this example, imagine that you measured the flow rates of the 20 showers in your school to be 4 gallons per minute, and you found that replacement low-flow showerheads have flow rates of 2.5 gallons per minute (for a savings of 1.5 gpm).

<u>Present costs of existing showerheads</u>

- Each showerhead uses 240 gallons per hour (4 gallons per minute times 60 minutes = 240 gph).
- On average, each shower runs for one hour per day; therefore each showerhead uses 240 gallons per day (240 gph times 1, the number of hours the showerhead is used each day).
- Each showerhead uses 43,200 gallons per year (240 gpd times the number of days in use, 180 school days per year).
- Each showerhead uses 5,760 cubic feet of water each year (43,200 gpy divided by 7.5, the number of gallons per cubic foot).
- Each showerhead uses 57.6 hundred cubic feet of water each year (5,760 divided by 100 = the number of hundred-cubic-feet of water used per unit).

- Assume your town charges $6.00 for water and sewage disposal per hundred cubic feet of water used. Thus the water and sewage disposal cost per showerhead is $345.60 (57.6 ccf times the cost of water and sewage disposal).

- The total cost for water and sewage disposal for all 20 shower units is $6,912 ($345.60 times the number of units, 20).

Potential savings

Replacing 4 gpm showerheads with 2.5 gpm showerheads would cut water consumption by 37.5% (2.5 divided by 4 = 37.5 X 100 = 37.5 %).

The potential savings, therefore, would be $2,592 per year. (37.5% of the present costs of $6912.)

Payback time

To calculate payback time, divide the savings per year by the cost of retrofitting. (Assume that the cost of retrofitting would be $25 per showerhead for hardware and labor.) In this case, then, the total retrofit would cost $500, and total savings are $2,592. By dividing the cost of retrofitting by the savings per year, you find the payback time to be about .2 years (just over two months). What is more, this figure represents simple payback. It does not take additional savings into account, such as energy savings from using less hot water, and it does not include the rising cost of water. Make similar calculations for each structural conservation change to determine if you think the change should be recommended.

Savings from behavioral changes may be more difficult to calculate. Implementing behavioral changes costs nothing and the amount of water saved will not stay constant, thus you must estimate savings.

STEP 4: Reporting

The audit report should summarize the analyzed data. You may want to present portions of the report to the student body, the school's administration, and/or the school committee.

The report should contain the following information:

1. An overview of the areas you examined and the results of your investigations. (For example, how much water does the school currently use and what percentage of that water could be saved through conservation measures?)

2. A summary of specific water conservation recommendations with the cost of installation, the amount (number of gallons or ccf) of water that could be saved, and the dollar savings.

3. A discussion of each recommendation.

You may want to summarize your findings by using a chart such as this one:

Summary of Water Conservation Recommendations

Measure	Cost	Water saved	Dollars saved	Payback
Low-flow showerheads	$500	432 ccf	$2,592.00	.2 years
Flushometer retrofitting	______	______	______	______
Lavatory aerators	______	______	______	______
Repairing leaks	______	______	______	______
Other	______	______	______	______

Recommendation: Install Reduced-flow Showerheads

Discussion

From samples taken, the average flow rate of showers in the locker rooms (boys and girls) was 4 gpm. The showerheads were estimated to be operating approximately 1 hour per day for 180 days per year.

Recommendation

We recommend replacing all existing showerheads with reduced-flow showerheads that have flow rates of not more than 2.5 gpm.

Implementation

The existing 20 showerheads can be replaced with low-flow showerheads at an estimated cost of $25 each (installed), for a total cost of $2,592.00. The flow reduction would save about 37% of the water now being used for showering in the school.

Conclusion and Follow-up

After all this work on your *School Water Audit*, you will want to see your recommendations implemented. You will have to convince other students, faculty and staff to change their water wasting habits. You will have to convince administrators and the school committee to make the necessary structural changes. Getting everyone involved in saving our precious water supply is the most important part of your job. Use your imagination to think of ways to promote water conservation in your school.

We have a few suggestions for you...

- Publish the results of the audit in both your school newspaper and your local community newspaper.
- Create and implement a public education campaign in the school with advertisements, a bulletin board display, public announcements and a video tape.
- Offer prizes and recognition for the most creative water conserving ideas.
- Set a water savings goal for your school and post the weekly or monthly usage readings near the main entrance.
- Create and wear buttons with water conservation slogans on them.
- Write letters to members of the school committee outlining possible water and monetary savings.

Job Assignment Sheet

Project Manager ________________________

Manager of the *Records & Accounting Team* ________________________

Manager of the *Management Team* ________________________

Records & Accounting Team:

Records & Accounting Analyzers ________________________

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Management Team:

Kitchen and food service examiners--------- ________________________

____

____

____

Restroom examiners---------------------------- ________________________

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____

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Shower examiners------------------------------ ________________________

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____

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Classroom examiners (sinks, etc.)----------- ________________________

____

____

____

Grounds and athletic field examiners------- ________________________

____

Building maintenance/janitorial examiners-------- ________________________________

____

____

Drinking fountain examiners--------------------------- ________________________________

____

Swimming pool examiners------------------------------- ________________________________

____

Greenhouse examiners---------------------------------- ________________________________

____

Teacher's lounge examiner (should be a teacher)-- ________________________________

____

Other water use areas----------------------------------

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Records and Accounting
Data Collection Worksheet #1

Directions for understanding water-meter readings may be found in Activity #20 *Reading Your Water Meter.*

Date	Meter #	Meter Reading	Rate paid (water+sewer)	TOTAL $$ PAID
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________
______	________	____________	$ ________	$ __________

Units of measurement (cubic feet, hundreds of cubic (ccf) or gallons)? ____________

Rate structure (inclining block, declining block, constant, flat)? ______________

Total cubic feet of water used each year? __________________

Total cubic feet of water used September - November? ______________

Total cubic feet of water used December - February? ______________

Total cubic feet of water used March - May? __________________

Total cubic feet of water used June - August? ____________________

Average monthly cost of water? ______________

Records and Accounting
Data Collection Worksheet #2

Use copies of this form for both existing and water saving replacement equipment specifications.

Type of Equipment	Manufacturer's Specified Water Consumption	Unit of Measure (cycle, flush, minute of use, etc.)
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______
______	______	______

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Management Team
Data Collection Sheet

For directions on measuring and calculating flow rates and capacities and calculating savings, see Activities #18 and #22 *The Cost of Savings* and *Conducting a Home Water Audit.*

Audit Area ________________________________

Fixture #1: ________________________________

Total # of fixtures in your area	Total # of fixtures in school	Flow rate of fixture	Average time of daily use	Total daily consumption	Total annual consumption

Fixture #2: ________________________________

Total # of fixtures in your area	Total # of fixtures in school	Flow rate of fixture	Average time of daily use	Total daily consumption	Total annual consumption

Fixture #3: ________________________________

Total # of fixtures in your area	Total # of fixtures in school	Flow rate of fixture	Average time of daily use	Total daily consumption	Total annual consumption

Fixture #4: ________________________________

Total # of fixtures in your area	Total # of fixtures in school	Flow rate of fixture	Average time of daily use	Total daily consumption	Total annual consumption

Appendices

Water in Literature

Murky Water Problems

Glossary

Resource List and Bibliography

Appendix #1: Water in Literature

Water has long been an important theme in literature. It is central to Biblical tales, children's stories, mythology, poetry, short stories, and many novels. *The Grapes of Wrath*, for example, is set in the middle of one of America's worst-ever droughts. We recommend that you examine water as a theme in literature with your students. This annotated bibliography will help you get started. If you come up with other good examples, please submit them to the MWRA Education Department, and we will add them to this bibliography.

You may be surprised at how much you find. Many people, for example, are familiar with Sisyphus, the character of Greek mythology who was doomed to an eternity of pushing a boulder to the top of a hill only to have it roll back down again. But how did Sisyphus meet with such a fate? Water!

Sisyphus: He tricked the gods to get water for his kingdom

Sisyphus was the king of Corinth and known for being clever. His people needed water to prosper and multiply, but their available supply was inadequate. One day Sisyphus encountered Asopus, the river god, who was searching for his lost daughter, Aegina. Sisyphus agreed to help Asopus find his daughter if he would give Corinth a spring, and Asopus reluctantly agreed. He struck the ground and a clear spring began to flow.

Sisyphus told Asopus that it was Zeus himself, the king of the gods, who had taken Aegina, and he told him where to find Zeus. Asopus caught Zeus unprepared, with no thunderbolt with which to slay the furious Asopus. Thus Zeus temporarily changed himself into a rock and Aegina into an island.

Asopus had lost his daughter and Sisyphus had unleashed the wrath of Zeus. Zeus asked his brother Hades to take Sisyphus to the underworld and punish him severely. But when clever Sisyphus saw Hades coming to get him, he pretended to be honored. It was the messenger Hermes, after all, not Hades himself who guided dead souls to the underworld. Why, asked Sisyphus, would Hades come for him personally? Hades had no answer and in the moment he paused to think, Sisyphus chained him to a post.

With Hades imprisoned by Sisyphus, no one on earth could die. Confusion reigned. All of the gods became increasingly angry at Sisyphus and threatened to make his life unbearably miserable. Sisyphus finally relented to the pressure of the gods, and when he released Hades, the first soul to be taken was his own.

But Sisyphus again tricked Hades. He expected his soul to be taken, so he instructed his wife not to put a gold coin under his tongue after he died. Such a coin designated a person's place in life and paid for the final passage across the River Styx. Because Sisyphus was a king, entitled to a funeral feast and a trip across the River Styx, his wife had committed an act against Hades. So Hades instructed Sisyphus to return to Corinth to teach his wife a lesson. Instead of teaching her a lesson though, he lived to old age with her.

When Sisyphus finally died, Hades felt compelled to give him a task that would keep him out of any more mischief: Hades condemned Sisyphus to his fate of pushing the rock up the hill only to have it roll down again. All on account of needing water for his kingdom.

Water in Literature
An Annotated Bibliography

NOVELS and BOOKS

The Grapes of Wrath, John Steinbeck. The Joad family is forced to move because of a severe drought in the American midwest. Their journey to find work is filled with struggle and pain.

Keepers of the Earth. Native American tales and literature, many of which address isses related to water. Michael J. Caduto and Joseph Bruchac.

The Milagra Beanfield War. A small-town farmer decides to divert a real estate development's water supply to irrigate his bean field, and the townspeople rally in his support.

The Sea Around Us, Rachel Carson. The story of the ocean and the ways it affects our lives.

Silent Spring, Rachel Carson. An account of the way in which humanity's use of poisons to control insects, pests and weeds is changing the balance of nature.

Toad is the Uncle of Heaven, A Vietnamese Folk Tale. In the time of a terrible drought, a toad enlists the help of all the animals to get the King of Heaven to send rain.

Walden, Henry David Thoreau. Thoreau's naturalistic, humanistic description of daily activities in the 1840s at his cabin on the shore of Concord's Walden Pond.

Water and Life, Lorus J. Milne. A discussion of humanity's crucial need to conserve, produce and carefully use water to ensure an adequate supply for the future.

Water for People, Sarah K. Rudman. A description of the importance of water to human life.

What Made Tiddalik Laugh, An Australian/Aborigine Folk Tale. The Tiddalik is a giant toad who drinks all the water in the land. The only way to get the water back is to get the Tiddalik to laugh. The duckbill platypus finally succeeds and from then on, all toads have been small.

POETRY

"Rime of the Ancient Mariner," Samuel Taylor Coleridge.
"Neither Out Far, Not in Deep," Robert Frost.
"Dover Beach," Matthew Arnold.

FILMS

Jean de Fleuret and its sequel, *Manon of the Spring.* (1988 - French with subtitles. Based on novels by Marcel Pagnol.) In the first film, a romantic idealist in the late 19th century returns to his ancestral country estate determined to live off the land, unaware that his neighbors have plugged up the natural spring on his property. His plants and animals die, and he himself is killed in his frantic search for water. In the second film, his neighbors have unplugged the spring and diverted it to their property to create a thriving carnation farm, while the idealist's daughter, Manon, lives as an impoverished shepardess on the family estate. She eventually discovers the neighbors' deceit and takes a chilling revenge. (Available from some libraries and video rental stores with a good selection of foreign films.)

Malagra Bean Field Wars. (1987, R rated.) A delightful film directed by Robert Redford about deceitful developers in a small southwestern town. A farmer decides to divert the development's water supply in order to irrigate his bean field, and the townspeople, who were fatalistic at first, eventually rally in his support.

Appendix #2: Murky Water Problems: Water-related Dilemmas

For classroom discussions, term paper ideas, group activities, etc.

1. **To Salt or Not To Salt.**
   Many open reservoirs are very close to roadways. During the winter months, those roads must be salted to prevent icy conditions that may make driving hazardous. But the salt can contaminate these local water reservoirs and regional agriculture, especially cranberry bogs. What should be done?

   Salt itself is inexpensive; the Commonwealth currently pays about $31.50 per ton for road salt. Each year the Massachusetts Highway Department applies about 260,000 tons of it to the roads. On the one hand, this salt will contaminate the water and destroy some of the crops. On the other hand, it keeps the roads safer.

   One possible solution is available. A non-corrosive salt replacement substance called CMA (calcium magnesium acetate) is commercially available that effectively de-ices the roadways while not polluting any water sources. But CMA costs $950 per ton, 30 times more than conventional road salt.

   What should be done? Should we continue to save money while we pollute our waters? Should we use no salt and hope that people will drive carefully in icy areas? Or should we spend 30 times more money to protect people, water, and agriculture?

2. **Where Does all the Water Go?**
   According to government figures, the average person consumes 60 gallons of water per day. But if that is the case, something must be wrong. The MWRA uses about 250 million gallons per day and serves two million people. Two million people using 60 gallons each would consume only 120 million gallons, less than half of what is really used. What happens to the remaining 130 million gallons per day? Is it fair to say that each person uses an average of 60 gallons per day, or would it be more accurate to say that each person really uses 125 gallons per day?

3. You are a town manager and have $1,000,000 to spend. You have five miles of leaky water main that needs to be replaced, and you have 1000 elderly citizens who need a new service center and a reliable food service program. Both the water main replacement and the elderly care program would cost $1,000,000. What will you do?

4. A town launches an aggressive and successful water conservation program. The citizens use 25% less water, and as a result, the income of the water department drops by 25% leaving them unable to cover their expenses. Now the water department must raise the water rates. Was the water conservation program a good idea in the first place? Would your response change if you found out that as a result of the conservation campaign, the town was not going to build a new reservoir and the rates would remain relatively stable for the next 15 years?

5. The company you work for is planning to develop five acres of land alongside the main building for the benefit of the employees. What would you like to see them do? Install a water fountain and garden in the middle of a grassy area? Plant low water demand plants and install picnic tables? Put in a running track and fitness area, and install new showers in the basement of the building? Which of these improvements would be the most water wise? Which would be the most water foolish?

6. As you walk in to the school building one morning, you notice that one of the lawn sprinklers has broken and is spraying water across the sidewalk and into the street? What would you do? What should you do?

7. As a result of a severe water shortage, your town has ordered a 50% reduction in all water use, including industrial, public and private uses. Should any groups or services be exempt from such a ruling?

   How about the fire department? A hospital with a hydro-therapy department? A large commercial water user that has already undertaken a very successful water conservation program and is using as little water as is possible to stay in business?

8. Your community has been suffering a drought for the past five years and your water supplies are becoming alarmingly low. You have been appointed by the mayor to a committee to help decide what restrictions to place on the public to help ensure that you will not run out of water. What restrictions will you place on whom?

9. As you finish washing your hands in a public restroom, you realize that you cannot turn the water off completely. What would you do? What should you do?

10. You have five gallons of water to last you for one week. What will you use it for? What would you normally do with water that you will not be able to do?

11. Each morning on your way to school, you notice a leaking fire hydrant on a busy street. After seeing it for a few days, you call the fire department. They say they will take care of if, but a week goes by and it still leaks. So you call the public works department for your town. They too say they will take care of it, but again, after a week nothing has changed. As a responsible citizen, what could you do?

Appendix #3:
Water Wisdom GLOSSARY

Accessible fresh water Water that can be tapped from above-ground and below-ground sources and that is fit for human consumption (drinking/washing/gardening). Three percent of all the water on earth is fresh (the rest is sea water), and ten percent of that is accessible. Thus only about 0.3% of all water is accessible fresh water.

Aqueduct A large pipe, *conduit*, or other channel (open or enclosed) for conveying water, especially for transporting the water supply of a city.

Aquifer Subsurface water trapped in rock or stratum, also called the *saturated zone*.

Artesian well A well that is drilled at a point lower than the surrounding water table, so water rises to the surface due to its own underground pressure.

Audit The examination of usage patterns, hardware and management practices within a system.

CCF Hundred cubic feet, the common measurement of delivered water. One cubic foot is 7.5 gallons; one hundred cubic feet, or 1 ccf, is 750 gallons.

Capillary action Movement of underground water through soil and rock.

Cellulose A complex chemical compound found in the cell walls of most plants.

Cellulytic bacteria Organisms that live on the *cellulose* build-up in bodies of fresh water and degrade it into simpler compounds. This process accelerates the growth of algae that threatens the water's quality (see *eutrophication*).

Condensation The change of a substance to a denser form, as in *vapor* to water, or gas to liquid.

Conduit A pipe, canal or passageway for conveying water.

Conservation The act of preserving, guarding or protecting a natural resource from loss, decay or violation, as in protecting water supplies from overuse or contamination. Water conservation means using less water through structural and behavioral changes while maintaining a comfortable lifestyle.

Contaminate To make impure, unclean; to pollute.

Contour lines The lines connecting all points of the same elevation on a part of the earth's surface as shown on *topographic maps*.

Deciduous trees Trees that grow new leaves in the spring and shed them in the fall.

Declining block rate structure A *rate structure* that charges more for the first unit of water than for each subsequent unit. The more water used, the less expensive it is, thus this rate structure provides no *incentive* or motivation for the water consumer to conserve water. (See *inclining block rate structure* and *flat rate structure*.)

Deforestation The removal of large amounts of forested areas. Deforestation affects an area's temperature and humidity, *water-holding capacity* and *runoff* rates, and also interferes with the process of *transpiration* in the *hydrologic cycle*.

Demand management Controlling the demand for a resource, such as water, primarily through conservation and careful use.

Dispersion The process by which substances, such as minerals or pollutants, are widely distributed throughout the air or underground water zones. Different chemicals/ pollutants may disperse at different rates.

Distillation A method of *water purification* that involves heating water to separate out the water *vapor* from the particles suspended or dissolved in the liquid, and then cooling and condensing the resulting vapor to produce a pure form of water. Distillation is one method of deriving drinking water from sea water.

Distribution sytem The system that divides and delivers goods or services in proper allotments to the people and places that require them. The water delivery system includes reservoirs, aqueducts, pumps and water mains. (See *infrastructure.*)

Divide A *ridge* of hills or mountains that separates *watersheds.* On one side of the divide, water drains in one direction; on the other side of the divide, water drains in another direction to a different watershed.

Elevation The height, or altitude, of any land surface above sea level.

Environmental impact statement A document that analyzes the anticipated effects of a development, such as increased traffic, new paved areas or dredging, on the surrounding natural habitat, including the holding capacity of the watershed, the purity of the water, and the integrity of the wildlife and plant life.

Estimation An approximate calculation that one arrives at without actually measuring or conducting an experiment.

Eutrophication The process of *cellulose* accumulation in ponds, lakes and reservoirs. If not checked, it can cause excessive plant growth and deplete the oxygen supply of the water, thus killing animal life and making the water unfit for human consumption.

Evaporation The process of converting a solid or liquid state into gas or *vapor,* as in water changing into vapor. The evaporation rate of reservoirs is determined by the air and water temperature, relative humidity, wind and the exposed surface area.

Filtration The act of passing water through a porous substance, such as sand, charcoal or natural materials to separate out solid particles and impurities. (See *water purification.*)

Flat rate A *rate structure* that charges the same amount per unit of water no matter how much or how little is used. The first unit costs the same as the last. (See *declining block rate structure* and *inclining block rate structure*.)

Flow restrictor A device installed on showerheads or faucets that reduces the water flow.

Hard water Water that contains a high concentration of dissolved minerals, usually originating in deep *wells* or *aquifers*. Hard water requires using more soap for cleaning, and it often leaves stains or calcium deposits in containers and tubs. On the other hand, it is often relatively free of metals that leach into soft water, such as lead.

Hydrologic cycle The repeating changes water undergoes in nature as it moves through the environment, including *evaporation*, *transpiration*, *condensation*, *runoff*, *precipitation*, *infiltration* and *percolation*.

Incentive That which encourages or motivates. A water *conservation* incentive, for example, is a condition that makes it worthwhile to use less water or to invest in water-saving devices.

Inclining block rate structure A *rate structure* that charges more per unit for each unit of water used. The first unit of water is less expensive than subsequent units. This structure encourages water conservation. (See *declining block rate structure* and *flat rate structure.*)

Infrastructure A society's system of basic services, including roads, bridges, public transportation, electric cables, utility poles, telephone lines, street and traffic lighting, and municipal buildings. The water delivery infrastructure includes *reservoirs, wells, aqueducts,* pumps, water mains, sewer lines and waste disposal plants.

Leak detection Locating and repairing leaks in any water system in order to reduce water waste and to assure that a higher proportion of available water reaches its destination.

Life-cycle costing A method of analyzing the cost of an item not just in terms of its initial purchase price, but in terms of the ongoing cost of operation, maintenance and repair over its expected life. An item that costs more initially may save money over the long run because it uses less energy or water, or it lasts longer.

Limited resource An asset, such as *accessible fresh water,* wood or fossil fuel, that has a finite supply, that is not endlessly renewable, and that can be depleted through overuse. (See *renewable resource.*)

Low-flow showerhead A device installed on the shower that reduces the actual amount of water used but increases the pressure so the user does not notice reduced volume.

Low-flow toilets Toilets that use only 1.5 gallons of water per flush, about 1/4th the amount of water that standard toilets use (4-7 gallons). Because toilets account for about 30% of an average household's water use, replacing older toilets with low-flow toilets can dramatically reduce the household's consumption of water.

Monitoring To keep a close watch; to check or regulate the use or progress of something, such as keeping track of one's water use and the family's conservation efforts.

Operating costs The expenses involved in using an item, such as the electricity used to operate an appliance, the gas needed to drive a car, or the water used by toilets, washing machines and dishwashers. Other operating costs might include maintenance and repair charges.

Payback time The length of time needed for a conservation device or high-efficiency appliance to pay for itself in terms of the money saved on *operating costs* (by consuming less water or energy and thereby paying lower utility bills).

Particulate matter Minute pieces of substances; particles of rock, earth and organic material that are suspended in water. Particulate matter makes water turbid: it is generally separated out from water through *sedimentation* or *filtration*.

Parts-per-million (parts-per-billion) A way of expressing the concentration of chemical pollutants and other substances in water or other liquid solutions. It usually refers to one part of dissolved material per 1 million or 1 billion parts of a solvent.

Peak use period The time when consumers demand more service than average. The peak use period for water is afternoons on hot days. This high demand for water during a few hours can create a short-term water shortage that can be resolved if people reschedule some of their activities (washing, watering lawns, etc.) to earlier or later hours of the day.

Per capita The number of an item that each person in the population has or uses. For instance, the average person uses 60 gallons of water a day, which is 60 gallons per capita.

Percolation The downward movement of water into underground *wells* and *aquifers*. The farther down water percolates, the more it is filtered through rock and soil. Therefore, deep wells often contain purer (although harder) water than shallow wells.

Precipitation Falling rain, sleet or snow.

Projected life span The length of time an item, appliance or organism is expected to function or live. For example, the average refrigerator will need to be replaced after ten years, thus its projected life span is ten years.

Pore space The tiny, sometimes microscopic, openings or passages in a substance that allows fluids to pass or be absorbed. In the *hydrologic cycle*, the pore space of rock and soil determines the *water holding capacity* of the earth. When the pore space is filled, it is called the *saturated zone* or an *aquifer*.

Rate structure The way in which customers are charged for using a certain resource. In water consumption, rates may be structured so that each unit of water used costs the same (*flat rate*), so that the first unit costs the most and subsequent units cost less (*declining block rate*), or so that each additional unit costs more than the last (*inclining block rate*). These different rate structures have different impacts on consumers' *incentives* to conserve water.

Relative humidity The amount of water vapor in the air at a certain temperature compared to amount the air can hold at that temperature. The higher the relative humidity, the slower the evaporation rate of water.

Renewable resource A supply of something that can be replenished over time and will not be depleted or used up. Energy from sunlight is a completely renewable resource because we can never deplete it no matter how much we use. Water and trees are renewable resources because the natural cycles will replenish their supply, but they are also limited resources because they can be depleted if we use them up at a faster rate than nature can replenish them. Fossil fuels are essentially non-renewable because of the extraordinarily long period of time it takes nature to produce them from decayed organic matter. (See *limited resource.*)

Reservoir A natural or human-made lake where water is collected and stored in large quantities before being supplied to a community.

Retrofitting Making structural changes to a building or system, such as replacing hardware or appliances with new parts or models, usually because they are more efficient or consume less water. In water conservation, retrofitting showerheads, faucets and toilets means changing or replacing them with types that use less water.

Ridges In geology and geography, a long, narrow chain of hills or mountains. In the *hydrologic cycle*, a ridge or *divide* determines the direction of water flow into *watersheds*, rivers and lakes.

Runoff The water that is not absorbed into the ground following rain or snow fall and therefore moves above ground into streams and lakes.

Safe yield The amount of water that a reservoir can provide and still maintain safe delivery levels. Engineers determine safe yield by taking into account the expected rainfall, the size and absorbing capacity of the watershed, the capacity of the *reservoir*, and the amount lost through *evaporation*. The safe yield of the MWRA system is 300 million gallons per day.

Saturated zone The underground area that has absorbed as much water as possible into its *pore space;* an *aquifer*. The surface of the saturated zone is the *water table*.

Sedimentation The depositing of particles of earth, stones and organic matter (*particulate matter*). Water is partially purified by sedimentation. *Reservoir* systems should allow water to stand long enough for sedimentation to occur, thereby naturally purifying the water. (When reservoirs are overused, water moves through the system too quickly and thus contains less sediment and higher levels of particulates.)

Solar still A mechanism for collecting or distilling water. This method uses the heat of the sun to cause water to evaporate quickly from the soil and then collects the condensate in a reservoir. As such, it is a replica of a simplified *hydrologic cycle*. (Because water *vapor* contains no particulate matter, this process can effectively purify dirty or contaminated water, or it can desalinate sea water for drinking water.)

Specific heat The number of calories of heat required to raise the temperature of one gram of a substance by one degree celsius. The specific heat of water is one. (One calorie raises one gram one degree celsius.) Water's specific heat is relatively high, which gives it the ability to absorb and store great quantities of heat without undergoing drastic temperature changes.

Supply and demand The relationship between the need for a resource and the availability of that resource. In a water distribution system, the customers' need to use water (demand) may outstrip the amount of water available (supply) when the population grows or lifestyles change, and during periods of drought or peak use periods.

Toilet dams Structures, either makeshift or commercial, that take up volume or hold back water in the toilet tank in order to reduce the amount of water consumed with each flush.

Topographic maps Maps that show the elevations and positions of hills, rivers, lakes and roads.

Transpiration The release of water through a membrane or surface, such as the *evaporation* of water moisture through the leaves of growing plants.

Turbidity The amount of cloudiness or opaqueness of a normally clear liquid due to the suspension of solid particles. The federal government has established turbity standards for drinking water.

Ultra-violet light High energy light that has a shorter wavelength than the visible light rays at the violet end of the spectrum. Ultra-violet light is invisible to the human eye, but can harm both eyesight and cause skin cancer. It also destroys the surface bacteria in water and thus helps purify water.

Universal solvent Water is termed the universal solvent because it dissolves so many other substances. (A solvent is a liquid in which another substance is dissolved to form a solution.)

Vapor The gaseous form of any substance that is also liquid or solid. In the *hydrologic cycle*, vapor is atmospheric water and is usually invisible. Water vapor also refers to the steamlike mist that rises into the air, or evaporates, from water or damp objects. It appears as visible particles of moisture floating in the air, fog, mist, steam and clouds.

Visual analogy An analogy is a way of explaining something by comparing it with something else. A visual analogy illustrates a fairly abstract concept by comparing it graphically to objects that have a more concrete, or day-to-day, significance to people.

Volumetric measurement Measuring the amount of space occupied in three dimensions: height, length and width. To measure the cubic contents of a container of water, multiply length times width times depth.

Water budget The relationship between rainfall that recharges a groundwater or surface water supply (water "income") and the demand for water use that depletes the water supply (water "expenses"). Water managers must assure that a town's water income can "pay" for the water needs of a community and still keep water in the "savings bank" (supply reservoir).

Water-holding capacity The amount of *pore space* in the earth that absorbs water.

Water purification The act of removing sediment and contaminants (hazardous chemicals and bacteria) from the water supply. Water is purified in nature by stops in the hydrologic cycle – evaporation, precipitation, infiltration, percolation and sedimentation. Humans also purify water by adding chemicals (to control bacteria and algae) and performing additional steps such as filtration.

Water table The surface of the *saturated zone* of the earth, below which the ground is saturated with water. The level of the water table will rise and fall depending on rainfall and dry periods. When the water table rises above the adjoining land, such as on a slope, water escapes as natural springs. Marshes or lakes develop where the water table is higher than a valley floor.

Watershed The land area that drains into a stream, river system or reservoir, usually determined by the ridges and lowlands in the watershed area.

Well A deep hole or shaft dug or drilled into the earth to tap an underground supply of water.

Yield rate The amount of water that a *watershed*, *reservoir* or *well* produces that is safe for consumption.

Appendix #4: Resources

Books

Brown, Lester R. et. al., *State of the World: A Worldwatch Institute Report on Progress Toward a Sustainable Society.* New York, NY: W.W. Norton and Co. Annual editions since 1984 contain chapters concerning water-related issues. For example, the 1996 edition has chapters entitled "Forging a Sustainable Water Strategy" and "Sustaining Freshwater Ecosystems."

Conuel, Thomas, *Quabbin, the Accidental Wilderness.* Brattleboro, VT: Stephen Greene Press. The 1981 volume of the *Man and Nature* series, produced by the Massachusetts Audubon Society (Lincoln, MA.) A study of the wildlife around the Quabbin.

Greene, J.R., *An Atlas of the Quabbin Valley.* Athol, MA: The Transcript Press, Revised Edition 1983. An overview of the creation of the Quabbin Reservoir, with maps and brief histories of the towns and villages detroyed by the construction of the reservoir, and with a guide to fishing and hiking opportunities at the reservoir.

Greene, J.R., *The Creation of Quabbin Reservoir, The Death of the Swift River Valley.* Athol, MA: The Transcript Press, Second Edition, 1987. A complete history of the building of the Quabbin Reservoir that analyzes the political and social events leading to the construction of the reservoir, including the court hearings and investigations that were part of the "water fight." (Available from the author and publisher, J.R. Greene, Athol, MA.)

Greene, J.R., *The Day Four Quabbin Towns Died.* Athol, MA: The Transcript Press, 1985. A look at the human side of the issues surrounding the Quabbin Reservoir. It recreates the atmosphere of the four towns destroyed by the Quabbin from the time the decision was made in 1929 to create a reservoir in the Swift River Valley to April 27, 1938, the day the towns officially passed out of existence.

Hillel, Daniel, *Rivers of Eden: The Struggle for Water and the Quest for Peace in the Middle East*Oxford University Press, New York, 1994

Nesson, Fern, *Great Waters: A History of Boston's Water Supply.* Hanover, NH: University Press of New England, 1983. An examination of the Quabbin Reservoir and the water supply system.

Outwater, Alice, *Water: A Natural History*Powledge, Fred, *Water: The Nature, Uses, and Future of Our Most Precious and Abused Resource.* New York, NY: Farrar Straus Giroux, 1982.

Pringle, Laurence, *Water: The Next Great Resource Battle.* New York, NY: Macmillan Publishing Co., Inc., 1982.

Reisner, Marc, *Cadillac Desert: The American West and Its Disappearing Water.* Penguin Books, New York, 1986. A highly readable and engaging treatment of water in the American west.

Curriculum Materials

Environemental Education in Massachusetts: A Resource Guide, available from the Executive Office of Environmental Affairs, 100 Cambridge Street, Boston, MA 02210.

For a comprehensive annotated listing of water-related curriculum materials from across the nation, refer to "*Environmental Education: Compensium for Water Resources,*" available from the California Department of Water Resources, Office of Water Education, 1416 Ninth Street, Room 1104-1, Sacramento, CA 95814. (916) 653-6192 FAX (916) 653-4684. http://www.dwr.water.ca.gov/

Water Quality. MWRA. A field kit of water quality chemistry testing materials. Available from MWRA's School Programs, 100 First Avenue, Bldg. 39, Boston, MA 02129, (617) 241-4662.

Water Watchers: Water Conservation Curriculum for Junior High School Science and Social Studies. Boston, MA: The Massachusetts Water Resources Authority, 1987. The field-tested junior-high water conservation curriculum distributed by the MWRA containing activities on the water cycle, the water delivery system and water conservation. Copy available for free from the MWRA.*

Maps

USGS maps are available from the Government Printing Office, Region 1. John F. Kennedy Building, Boston, MA 02203, (617) 565-2488.

Maps may also be purchased at map stores and some outdoor recreation supply stores.

Kits

Water quality test kits can be ordered from the LaMotte Company, P.O. Box 329, Chestertown, MD, (800) 344-3100, or the Hach Company, P.O. Box 389, Loveland, CO 80539.

Agencies and Organizations

Massachusetts Water Resources Authority, Charlestown Navy Yard, 100 First Ave., Charlestown, MA 02129. For information or materials call (617) 242-7110 or 242-SAVE. The MWRA provides posters, brochures, water-system maps, portable exhibits, video tapes and other curriculum material. Field trips and speakers can also be arranged.

Massachusetts Department of Environmental Protection 1 Winter Street, Boston, MA 02108, Public Affairs Office: (617) 292-5515. Information on water quality issues, brochures and slide shows available.

Environmental Protection Agency, Region 1, John F. Kennedy Building, Boston, MA 02203, Public Affairs Office: (617) 565-3420. Publications and films (free loan): 565-3187.

Metropolitan District Commission, 20 Somerset Street, Boston, MA 02108, (617) 727-5033. Information about watersheds and reservoirs. Tours or field trips to reservoirs can be arranged.

League of Women Voters of Massachusetts, 133 Portland St., Boston, 02109. Position papers on water, report on road salt contamination of water supplies. Speakers may be available.

Massachusetts Audubon Society, South Great Road, Lincoln, MA 01773. Hatheway Conservation Education Library in Lincoln. (617) 259-9500. Open M-F, 9-5. Special requests and evening hours can be arranged.

New England Aquarium, Central Wharf, Boston, MA 02110, (617) 973-5200. Ongoing exhibits on water quality.

Boston Museum of Science, Science Park, Boston, MA 02114, (617) 723-2511. BMS welcomes school-group visits to its permanent water exhibit.

Watershed Associations

Charles River Watershed Association, 2391 Commonwealth Ave., Auburndale, MA 02166, (617) 527-2799.

Merrimack River Watershed Council, 694 Main St., West Newbury, MA 01985, (508) 363-5777.

Mystic River Watershed Association, 276 Massachusetts Ave., Arlington, MA 02174, (617) 643-2157.

Nashua River Watershed Association, 348 Lunneberg St., Fitchburg, MA 01420, (508) 342-3624 or 342-3506.

SUASCO Watershed Association, (Sudbury-Assabet-Concord), C/O Ms. Barbara Mudd, Chairperson, 89 Wilson Road, Concord, MA 01742, (508) 369-6978.

Consult your local phone book for additional local resources.

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