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The Mill River: An Outdoor Laboratory

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INTRODUCTION:

The environment is constantly in the news these days. Most of my science students at the Cooperative High School have heard about acid rain, ozone layer depletion, and the greenhouse effect, but none of them has really experienced any of these global phenomena, much less conducted experiments on them. High school students have little notion of how environmental scientists operate in the field, how they gather samples, how they use instruments, and how they derive their findings.

This unit proposes narrowing the scope of student environmental investigation to one small stream in New Haven, namely the Mill River. This outdoor laboratory will enable my students to be real scientists. They will be able to take the tests that they have learned in the school lab, such as dissolved oxygen, pH, and conductivity, and run them on the Mill River waters. Testing will take place throughout the year and at various locations. By the end students should have a good idea of what is happening in the Mill River based on their own hands-on activities. Once they understand local conditions, they will be much more able to extrapolate their findings to global phenomena.

Another aim of this unit, besides training high school students in the techniques of environmental science, is to have them appreciate the local nature in New Haven. Too often, city students are afraid of “wilderness,” but if they are up to their knees (in boots) in the Mill River, collecting specimens, they probably will learn to enjoy their surroundings.

The next step after appreciation is activism. If the Mill River turns out to be polluted, is there anything that students can do to change the situation? At the very least they can educate themselves about the causes of the pollution. After that they should learn about Clean Water legislation and the role of the Department of Environmental Protection.

The wonderful thing about starting with a very specific project, such as surveying the Mill River, is that it will lead to all sorts of other interests, such as politics, law, history, and art. The direction taken can be determined by the students as well as the teacher. The part of the Mill River that we will study, both because it is the most interesting and also the most accessible, lies between the dam at the Eli Whitney Museum site and the tide water located under Interstate 91 where it crosses State Street. The total length of river between these two points is no more than 1.5 miles.

Students need to know that this stretch of the Mill River has had a most interesting history. Originally, before John Davenport and Theophilus Eaton and their band of Puritan settlers arrived, there was a Quinnipiac Indian camp or village where the present-day Ranger station is located (at the intersection of Orange and Cold Spring Streets). Many artifacts have been found in this area: arrowheads, chisels, and knife blades among others. There was no dam on Lake Whitney then, of course, and the Mill River was tidal along much of its length. Salt marshes of Spartina grass were washed by nutrient brackish waters twice a day, resulting in abundant ousters, crabs, and fish. In addition to these excellent food sources, the Indian tribes also had access to fresh water springs at the base of East Rock.

With the advent of the settlers. things began to change. The original Quinnipiac occupants were driven out and a low dam was built in 1640 (at the location of the present dam) by Sergeant William Fowler in order to power a grist mill. This mill burned and was rebuilt in 1665 by William Bradley and Christopher Todd. However, since the dam was quite low (no more than six feet) there was sometimes not enough water power during a drought to grind the corn. The huge mill stones from this grist mill can still be seen leaning against the present day dam on Whitney Avenue.

The next name that arises in connection with the dam on the Mill River is that of Eli Whitney. In 1798 he purchased the old Todd Mill with all the land around in order to build a factory to manufacture muskets for the government. Instead of using artisans to construct each individual musket from scratch, he proposed using water- powered specialized tools that would make interchangeable parts that could then be fitted together by unskilled help. The so-called Whitney Mill area must have been a beehive of industrial activity: rushing water, turning machines,. forges,. barges bringing materials up the Mill River, and wagons loaded with charcoal rumbling alone the east side of the river. Interestingly enough, the wooden dam that provided all this power was still only six feet high.

Even as late as 1854, the citizens of New Haven were still dependent on wells and springs for their drinking water: there was no public water supply. Fires were a real hazard. Since there were no fire hydrants, fire fighters had to form bucket brigades from the nearest well. Often the buildings burned to the ground. As a result of all of this, several concerned leaders saw the need to form a water company for their ever-expanding metropolis. These men decided that the Mill River would be an ideal location for a water supply and they approached Eli Whitney's son. Eli Whitney II, who had taken over his father's gun manufacture, with the proposal that a high dam be built on the site of the original six-foot dam. The timing was opportune: Whitney was worried about his competitor Samuel Colt in Hartford and this increased power capacity would keep him in business.

(figure available in print form)

The thirty-eight-foot dam was completed in 1861 and is essentially the one that stands there now. A large tract of land behind the dam was flooded to become the present 139-acre Lake Whitney. New Haven had its water supple and Whitney had his power supply.

Several other companies have occupied the Whitney site in the last century including the Heany Industries who made a pink industrial ceramic that could be found in great quantities in the river. Now the Eli Whitney Museum and the Whitney Water Center run by the Regional Water Authority are the two peaceful surviving tenants of this beautiful spot.

At this point a description of the present-day Mill River would be in order, as it flows from the Whitney Dam south to the tide gates under I-91, a distance of about 1.5 miles. The obvious markers on the river are the four bridges that cross it: going from north to south, the covered bridge at the Eli Whitney Museum, the footbridge in the marsh, the East Rock Road bridge, and the Orange Street bridge. The tide gates mark the southern boundary of the section of river to be studied.

The flow of Lake Whitney water over the dam is quite variable, depending on the season, rainfall, and the needs of the Regional Water Authority. Sometimes there is no flow at all, while at other times, a raging torrent pours over the dam. This clearly affects the amount of water in the Mill River below. The stream is normally quite shallow between the dam and the covered bridge and the water flows swiftly with ripples over the rocky bottom. It's a good place to look for macroinvertebrates.

Between the covered bridge and the footbridge the stream enters East Rock Part, moving slowly between densely vegetated banks. Here one can often see great blue herons or black-crowned night herons, as well as numerous ducks. The water may be as deep as 6 to 8 feet at the footbridge and is much darker in color than by the dam. Fishing is the pastime of choice here: carp, sunfish, silversides, and even eel are commonly caught.

From the footbridge the Mill River moves slowly towards East Rock Road where a storm sewer empties under the bridge. From there it flows past a large marsh on the west bank to the Orange Street bridge. At this point the vegetation changes: much of the shore is composed of fill and Phraemites, a tall invasive reed, has taken over.

Between Orange Street and the tide gates the river seems to be more influenced by man than by natural forces. Its original meanders have been straightened out (due to highway construction in the 1960s). Phraemites lines the banks and the water looks murky. Finally the river now enclosed in a man-made channel reaches the tide gates. The ostensible reason for these sates, which were installed in the 1970s, is to prevent polluted waters from moving up into East Rock Park from the lower industrial reaches of the river and also from the New Haven Harbor. At low tide the fourteen small gates open to let the downstream flow of the river pass through. At high tide (the tides in New Haven Harbor have a mean range of 6.2 feet) the gates are forced closed by incoming seawater. This means that the fresh water backs up on the other side of the gates and floods the marshes to a certain extent. However, the tide gates don't function perfectly so that saline polluted water can move up into the marshes at high tide.

The Mill River between the dam and the tide gates is like a long mixing bowl: fresh water flows southward over the dam and salt water leaks northward through the gates and they probably mix somewhere around the Orange Street Bridge.

OBJECTIVES AND STRATEGIES:

The Mill River: An Outdoor Laboratory unit is designed to show students that science (with an emphasis on chemistry) is a tool that can be used to solve environmental problems. Students will learn to ask questions about the Mill River and then design experiments that will answer their questions.

The South Central Regional Water Authority has expressed an interest in seeing the results of our sampling: this should make students realize that their scientific work is taken seriously. Students should complete the unit with a feeling of accomplishment and empowerment.

Even though the unit is very specific — it deals with the Mill River in New Haven, Conn. — it can be used by other science teachers, with modifications, in their own local situations. One important consideration is that any teacher planning an ecological stud should have a good working relationship with local institutions. We will be able to borrow equipment from the Geology Department at Yale University and also from the Regional Water Authority. The advice of the scientists at these institutions will also be invaluable. I also hope to get graduate school volunteers from the Urban Resources Initiative at the Yale Forestry School to work with students in the field.

The unit is designed with modifications both for ninth grade Physical Science students as well as for 11-12th grade chemistry students. Obviously these classes will not be able to visit the Mill River site more than once or twice each marking period because of transportation and scheduling problems, but there will be an on-going group, namely the Science Club. which will be able to go out every Friday afternoon throughout the year, weather permitting. Science Club is a voluntary activity and attracts mostly younger. enthusiastic students who will provide the continuity that this project needs. Since there are fewer of them than in a class, they are also easier to transport and manage.

However, I feel that it is very important for all my students to have the benefit of sampling a “real” river. Before they ever set foot in the field though, they will need to develop a good background both theoretical and practical in the classroom. They will understand and maybe also retain the knowledge if it is developed slowly and from several different angles. including a lot of hands-on activities.

The unit will start with a section on water and its properties. The physical science classes will have several simple labs on surface tension and solubility. The more hands-on activities the better since many ninth graders have not had much experience working in the lab (although more middle schools seem to be emphasizing it now). They need to learn about lab techniques, equipment, and safety. They also need to think clearly about setting up experiments: formulating questions: stating a hypothesis, controlling their variables, and reporting their results.

One simple lab on surface tension is described in the classroom activities section of this unit. It is open-ended allowing students to try their own variations. It also requires graphing the results.

Chemistry students can approach the subject of water on a slightly higher plane than physical science students. They should learn the following: the fact that the bent shape of the water molecule gives it its polar nature; hydrogen bonding and surface tension; and also the solubility of polar and nonpolar substances in water.

Now it’s time to study a hypothetical river — a river with a mysterious fish kill. The American Chemical Society has published an excellent high school text called ChemCom. The first section of the book, which was written by a team of high school chemistry teachers, presents the students with a problem: a massive fish kill has been discovered in the mythical Snake River near the town of Riverwood. Students read “newspaper articles” (they look genuine) about the fish kill and the ensuing anxiety of the townspeople who are dependent on the river for their drinking water.

Interspersed with the newspaper articles in the book are lots of labs and activities for the students so that they can help solve the mystery of the fish kill. This year I modified this unit for the ninth grade Physical Science classes who were quite enthusiastic about solving the problem. I really think that more classroom units should be presented as mysteries. because students love learning in this way.

Among other topics covered in the unit were personal water use, water purification, testing for ions, pH, and dissolved gases. (Although I didn't use the whole Snake River unit with the chemistry classes, we did do some of the labs.) Finally, the cause of the fish kill was revealed (excess air in the water under the dam had caused air bubbles in the fish gills).

Students then had a town meeting to decide who was responsible for the fish kill and who should pay for the drinking water that Riverwood had to import. They played the roles of the various interest groups in the town such as officials of the power plant at the dam, motel owners, and the Chamber of Commerce, as well as engineers and scientists. The presentations were quite passionate (everyone blamed someone else), but there were also quite a few dispassionate speeches based on the evidence.

At this point my science classes will be ready to visit the Whitney Water Center at the Lake Whitney dam (run by the South Central Regional Water Authority) and learn to sample the waters of the nonmythical Mill River. Education specialists at the Center show students how to test for pH, temperature, dissolved oxygen, turbidity, and alkalinity, using various chemical kits and instruments. For most students this will be their first opportunity to work in a real river: it should be an exciting experience for them. They will record all data on the Whitney Water Center data sheets and we will then discuss it.

The Whitney Water Center visit is an excellent introduction to the unit on the Mill River. Students have now seen a small part of the river (at the dam) and have done a little water sampling. What is needed now is to have them sort out facts from inferences. They will again form small groups and fill out a sheet labeled THE MILL RIVER that has three headings: FACTS, INFERENCES, and QUESTIONS WE WOULD LIKE TO SOLVE. Then each group will report to the rest of the class who will critique them. A fact might be. "The Mill River is shallow at the dam." A possible inference is. "The Mill River is polluted." It is important for students to learn to differentiate between facts and inferences.

Having students think about question they would like to solve helps focus them and directs their thinking. After studying the Snake River unit in ChemCom they will probably want to know if the Mill River fish are healthy and whether there is too much air in the water coming over the dam. They might also want to know what ions are dissolved in the river and whether the water is polluted.

Before we take another Mill River field trip students should learn some map skills. There will be a class set of the U.S. Geological Survey New Haven Quadrangle maps available. After they have learned some basic facts about symbols, scale, and topography, they will locate their homes, the Coop High School, and the downtown Green. Now we will look at the Harbor: how deep is it? Which rivers empty into it?

Then students will focus on the Mill River on the map. Between the Harbor and the dam. how long is it in miles? Which roads cross it? How high are the tides and would salt water move into the river at high tide? Are there marshes? What are meanders? Finally they will make a sketch of the river between the dam and the State Street tide gates, labeling all the parts. The art teacher at the Coop High School will show them how to enlarge a drawing using graph paper. Students also need to know the difference between QUALITATIVE and QUANTITATIVE experiments at this point. Up to now when testing for dissolved ions (such as chloride and iron) in the lab we have only stated whether they were present or absent — in other words, the results were qualitative. However when we test in the field we will be using instruments which measure results in parts per million (ppm). In water solutions this is the same as milligrams per liter (mg/L). In order to understand the magnitude of these numbers, I will do a dilution series beforehand using food color on the overhead projector, showing that even though the eve can't detect one ppm. the chemical is present.

Which factors are we going to measure in the Mill River? The following would seem to be the most pertinent (and are also the easiest to detect: dissolved oxygen, temperature, pH, and conductivity. The Geology Department at Yale University will lend us a dissolved oxygen meter; a conductivity meter will come from the Regional Water Authority.

Dissolved oxygen (DO) is probably the most important parameter in measuring the health of river waters. Most fish need a minimum of 4 to 5 ppm of dissolved oxygen to survive, while some fish like trout need about 9 ppm. There is usually more oxygen in a swiftly moving stream than a slowly moving stream because the water mixes with the air. The Mill River below the dam flows rapidly over the cobbles. and, as expected, there is more DO than farther south where it slows down.

So that they will be comfortable doing the DO testing in the field, students will first need to learn how to sample dissolved oxygen in different waters in the lab using both chemical tests and an oxygen meter. Does fresh tap water contain more DO than boiled water? Do the chemical tests correlate with the DO meter results? They should also understand how a dissolved oxygen meter works and how to take care of it (keeping the probe moist).

The dissolved oxygen meter also measures the water temperature in degrees Celsius. Students can then figure out the percent saturation of oxygen if they know the temperature and the DO in ppm. 90 percent dissolved oxygen saturation or better means that the stream is probably healthy. Since students are much more familiar with the Fahrenheit scale than the Celsius scale we will always take the Fahrenheit reading first and let them estimate what it would be in Celsius.

The Snake River unit allowed students to stud the pH of various substances, but this is a good time to go more deeply into the subject. Students should understand that the scale is logarithmic so that each number on the scale represents a ten-fold change in the hydrogen ion concentration. For instance, pH 5 is 10 times more acid than pH 6 and it's 100 times more acid than pH 7. Normal rain has a pH of 5.0— 5.6 but the average reading for acid rain in the northeastern United States is about 4.3 (Mitchell and Stapp, 1992).

The pH in streams can vary greatly depending on several factors including the bedrock in the watershed. (A limestone bedrock can buffer the acid rain, making it less acid) But the Mill River runs through primarily sandstone and traprock which have less buffering capacity. Will we find that the pH of the river is toward the acid side? Fish and invertebrates have quite specific pH requirements but any river water that has a pH more than 9 or less than 4 will not have a lot of living things.

Students will have already learned to use Universal Indicator paper to test substances, but for the Mill River we will use a portable pH meter which they will quickly discover is much more accurate.

A conductivity meter measures the total amount of dissolved ions in water. The more ions, the greater the flow of electricity and the higher the reading. Distilled water has no dissolved ions and therefore the meter will register 0 ppm because there is no flow of electricity. Seawater, on the other hand, contains a high percent of dissolved sodium chloride as well as other ions so that the conductivity meter readings will be very high. The average salinity of ocean water is about 35 parts per thousand (or 35.000 parts per million).

Long Island Sound is an estuary with many rivers emptying into it: therefore the salinity is not as high as in the open sea. We will first test the conductivity of the New Haven Harbor waters and then move on to the Mill River which is a tidal stream whose lower reaches are flooded twice a day by waters of the Sound. The tide gates at the intersection of State Street and I-91 keep much of the saline water out but some still flows north into the river by East Rock Park. How far does it go? To the Orange Street bridge? Or farther? Students should be able to make predictions based on the tides before they use the conductivity meter at various locations.

Students should also learn to ask themselves about the methodology of sampling: is it better to sample water on the banks of the river or from a bridge? How many samples should we take in each location?

The final question to be asked is "Is the Mill River a healthy river or is it polluted?" To answer this we will look at the animals that live in the water. The absence or presence of these animals, called macroinvertebrates, indicates the environmental quality of any stream. The Izaak Walton League of America, which is dedicated to sports fishing and the improvement of stream quality, has started a program called Save Our Streams (SOS). This program shows volunteers how to survey the biota in a stream in order to rate the water quality. For instance, if stonefly and caddisfly larvae are plentiful the stream is probably healthy: on the other hand, worms and midge larvae indicate polluted conditions.

The students will get to use kick seine nets in the river: they will dislodge bottom dwellers for a distance of three feet upstream. Then we will spread the net on the bank and, using magnifying glasses and tweezers, we will sort the "critters" into groups, using the SOS identification card. This procedure will be repeated at different points along the river.

All this data — dissolved oxygen, temperature, pH, conductivity, and invertebrate populations — needs to be combined into one report. Students can work in groups on this. They should also write down their recommendations and further questions that they have. We will then present the reports to the Regional Water Authority

Student Activities for the Mill River Unit:

Activity 1: Surface Tension of water

This is the first water lab for the ninth grade physical science class.

Materials needed: plastic cups, pennies (lots), water, and Ivory liquid detergent.

Procedure:
Fill a cup to the very top with water, ask the class how many pennies they can slide in before the *meniscus* breaks. They can work in pairs. Have them do the lab three times and then average. Why?

Now ask them what would happen if they added 5 drops of Ivory liquid to a full cup of water and then dropped in the pennies. (The soap reduces the *surface tension* of the water so that only a few pennies can be dropped in before the meniscus breaks.

Results:
Have them make a chart of their results. and then a bar graph.

Questions:
1. Why do we repeat the experiment and then average the results?

2. Is this a *qualitative* or a *quantitative* experiment? Why?

3. What does it mean in this lab by controlling the *variables* ?

Activity 2: Measuring direction and velocity of the Mill River flow

This activity will correlate the tides in New Haven Harbor with the direction and velocity of the water flow in the Mill River. We will use the Orange Street bridge as our reference point.

Finding the *direction* will be easy: just throw a stick in the river and see whether it floats upstream or down. Then check the New Haven Register for the daily tide schedule.

Finding the *velocity* will give students a chance to use some math. Students will mark off a length along the river bank with string — at least 20 meters. Then they will drop in an orange and take the time in seconds that it takes to float from one end of the string to the other. The answer will be in meters/second. This should be run three times and the answers averaged.

Activity 3: Student Survey Sheet of the Mill River.

NAME _____ SURVEY STATION _____
DATE _____ TIME OF DAY _____
WEATHER _____
DEPTH OF RIVER (in meters) _____
VELOCITY OF RIVER FLOW (in meters/second) _____ (do three times and average) _____
DOES THE RIVER FLOW UPSTREAM OR DOWNSTREAM _____
TIDES (check the New Haven Register) Time of nearest HIGH TIDE _____ Time of nearest LOW TIDE _____
DESCRIPTION OF WATER (color, odor, objects floating?) _____
WATER TESTS (sample from bridges if possible)
DISSOLVED OXYGEN (ppm) _____
TEMPERATURE (°C) _____
SATURATION OF OXYGEN (percent) _____
pH _____
CONDUCTIVITY (ppm) _____
COMMENTS _____

List of Materials for Classroom Use

1. U.S. Geological Survey Quadrangle maps of the New Haven Quadrangle (order from the Department of Environmental Protection in Hartford). There should be 24 of these maps so that each person in a class can have their own.
2. Water sampling bottle. (Can be made or ordered).
3. Kick-seine net. (Can be made or ordered).
4. Dissolved oxygen meter. Borrow from the Geology Department at Yale .
5. Conductivity meter. Borrow from the Regional Water Authority.
6. pH meter. Borrow from the Coop High School.
7. Clip boards (for student surveys in the field). Borrow from the Art Department at the Coop High School.
8. Magnifying glasses. To identify the invertebrates in the river.

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