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The Mill River Water Unit

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This unit focuses on water in general by studying the hydrologic cycle, maps and waterpower. It then narrows its focus to Connecticut's Mill River Basin which provides local examples of the general concepts covered and offers numerous opportunities for field trips.

The Mill River Water Unit is designed to be used in science or math classes, grades 9 through 12. One of us will be using it in a science class, the other in a technical math class. It will probably take about four weeks to cover.

The unit has four major sections. Section I, on the hydrologic cycle, stresses that we have a specific, limited amount of water on Earth and the water we have continuously moves in a cycle of precipitation and evapotranspiration. [1] Students should learn to explain the cycle in words and diagrams, including the definitions of key terms. The map study, Section II, points out the need to go beyond the political state boundaries when considering geologic features and processes such as a region's water supply and flow. Included here are knowing map locations, determining a river profile and using scales, a scale line and contour lines.

Water has been essential in the economic development of New England. Central in this was the development of water power, the topic of Section III. The main purpose here is to describe the transition from water power being used first in local mills, then in factories and finally to produce electricity. Both the mechanics and significance of this are covered.

The last part, Section IV, focuses on the Mill River. The river's history brings social, industrial and geologic aspects into play. In looking at the hydrology [2] of the Mill River Basin, the more general concepts from the first three sections are made tangible in terms of experiments and field trips.

Section I. The Hydrologic Cycle

The earth's water is used over and over in an endless cycle (figure 1). The ultimate source of energy for this cycle is the sun. The source of all water is rain—or snow, sleet, or hail. Most of the earth's surface is water, for the oceans cover about seventy-one percent of the globe. Most of our fresh water is frozen in glaciers and polar ice caps. Water is found in all living things and is integral to the making of man-made things. Luckily for us, the recycling of water insures us of a continuing supply. It is interesting to think that perhaps the water we just drank may have been the same molecules that a thirsty Brontosaurus might have tasted. This liquid is so ordinary that we often take it for granted. In New Haven each resident uses about 115 gallons a day, or about 42,000 gallons a year. For a whole year this figures adds up to about five billion gallons for all 126,000 New Haven residents. [3]

This is the way the hydrologic cycle works: Fresh water falls from the condensation of cooled water vapor in clouds. When the water falls, most of it soaks deep into the ground and flows below the surface down hills and mountains into rivers and lakes. Only during heavy storms is there surface runoff. This gathering area forms a watershed. Eventually both runoff and groundwater flow into the ocean. When the sun hits the ocean surface, the ocean water is heated and great amounts of water are evaporated (vapor), leaving the salt behind like a huge distillation apparatus. Despite the evaporation, however, the salinty of the ocean continues constant because of the balance built into the water cycle. As the vapor rises, it cools, condenses, and physically changes back to a liquid to form clouds. This is a simplified version of the cycle because not all precipitation (rain) lands in rivers or lakes.

About half of the water that reaches the ground evaporates before it can reach a lake or a river. Some of the rain may be absorbed by plant roots. Some of the rain will end up in city sewers. Not all water vapor comes from the oceans and other bodies of water. We supply some in the forms of perspiration, urine and exhaled water vapor. And of course all organisms give up tissue water when they die. It all adds up to one life-giving cycle unique to our planet.

The water which does reach the land surface either directly or indirectly (by being intercepted) may move in different ways. If a soil is porous, the water moves down into it. A well-drained soil suitable for growing plants will retain water in its small and intermediate-size pores. The water in large pores will eventually move laterally beneath the soil surface until it enters a stream that will transport it to a lake or ocean. If the soil pores are filled with water at the time of precipitation, the water moves laterally across the soil surface as surface water runoff. But most water moves below the surface. As it does, it can leach out minerals (which is how "hard water" becomes hard). When the water reaches a stream or a river, it joins the flow capable of eroding and of changing the courses of waterways and the shapes of land.

Even in nature, water is never absolutely pure as it flows through the series of physical changes in the water cycle. Water can absorb gasses, chemicals, minerals, acids, and salts. [4]

Water facts of possible interest to teachers and students are as follows:

1. Approximately 70% of our bodies is water.
2. About 30,000 cubic miles of water fall as rain and snow on the earth's land areas each year.
3. The average annual precipitation on the United States is about 30 inches. The average runoff

carried by its rivers is only about 9 inches. [5]

4. 1 cubic foot of water weighs 62.4 pounds.
    1 cubic foot of water equals 7.48 U.S. gallons.
    1 U.S. gallon of water weighs 8.33 pounds.
    1 imperial gallon of water weighs 10 pounds. [6]
5. How deep is an ocean? Up to 7 miles (Pacific), 5 miles (Atlantic). [7]
6. Long Wharf extended 3,480 feet into the New Haven Harbor because dredging would be very expensive. [8]

Section I.

Activities for the Hydrologic Cycle

1. Show the possible effects of radiation on the water cycle. (Activity Sheet is included in Unit's Teaching Packet).
2. Make a diagram or describe how you fit into the water cycle.
3. Examine further and take a field trip to the filtering plant off Whitney Avenue. (See figure 2)
    a. Have students describe what they have seen.
4. How much does your family pay for water and how often?
5. Make up an experiment to show the effects of "acid rain" or make a diagram or painting to explain acid rain to others. "One picture is worth a thousand words."
6. A field trip to the sewage disposal plant might be valuable.

The Hydrologic Cycle
(figure available in print form)

ACTIVITY: THE EFFECTS OF RADIATION ON THE WATER CYCLE AND SOIL

Put in the appropriate arrows to show the relationship of the cycle of water between lakes, rivers, land, ocean and the atmosphere. Work in groups and have one student act as the recorder to collect your answers, as agreed by the group.

Question: If a bomb dropped in a heavily populated area, what would happen?

1. What effect would this contamination have on your drinking water at the nearest reservoir? Name at least two ways.
2. How could your fish supply from the nearest lake, river or ocean or sound become contaminated? Name at least two ways.
3. How would plant growth be contaminated by the soil?
4. How would this affect our food supply of meats, grains, dairy products or produce?
5. Why is it in pollution or contamination, that all parts of the water cycle could be affected, no matter what part of the cycle was polluted or contaminated?

(figure available in print form)

Section II. Map Studies

In any region of our country, the politically determined state boundaries are useful for governing the social and economic events of everyday life (figure 3). If, however, we want to study the geologic features and processes in a region, we must look beyond the political boundaries and choose a different focus.

Since this unit focuses on water in general and the Mill River in particular, we will begin by looking at maps which show Connecticut's three major rivers (figure 4), the state's eight major drainage basins (figure 5) and the Mill River Drainage Basin (figure 6).

Figure 4 shows the Connecticut, Housatonic and Thames Rivers. Some things to notice are as follows: (1) the Connecticut and Housatonic Rivers originate outside of Connecticut. The Housatonic originates in Massachusetts and the Connecticut in Canada. (2) All three rivers flow south and empty into Long Island Sound. (3) The Connecticut River forms the boundaries between Vermont and New Hampshire and then crosses Massachusetts and Connecticut on its way to the Sound.

Figure 5 shows the major drainage basins in Connecticut. A drainage basin is an area separated from adjacent basins by a divide or ridge. All surface water originating in a basin moves to lower levels and eventually leaves the basin at the lowest point in the divide through which the main river flows. [9] Some things to notice are as follows: (1) There are eight major drainage basins in Connecticut. Six of the drainage basins are shared with other states. Only two drainage basins fall completely within state lines. (2) Drainage basin #4 is the Connecticut Valley which drains parts of Canada, Vermont, New Hampshire, Massachusetts and Connecticut before emptying into Long Island Sound. Anything that would spoil the water at any point would be carried south through Connecticut to the Sound. (3) New Haven is part of drainage basin #5. This major basin has four large sub-basins, 50, 51, 52 and 53. Located in the north and eastern part of sub-basin 53 is the Mill River System Drainage Basin. The Mill River System (figure 4) is made up of two smaller drainage basins, the Willow Brook and Mill River drainage basins. (4) Basins 7, 2 and 51 are actually composites of separate, small basins that do not always connect with each other. They are not properly drainage basins themselves, though they are considered as basins on the maps we use in this unit.

There are two maps that are needed at this point, a *State of Connecticut* relief map [10] and the *Natural Drainage Basins in Connecticut* map. [11]

Using the *State of Connecticut* relief map, follow the Housatonic and Thames rivers as they flow south through mountainous regions and the Connecticut River as it flows south through the lowlands of the Connecticut Valley then leaves the valley just above Middletown and cuts through a water gap into the eastern highlands. Notice this map's scale and what it shows particularly well.

On the *Natural Drainage Basins in Connecticut* map, locate the eight major drainage basins and the four large sub-basins 50, 51, 52 and 53. Next locate the smaller sub-basins 5301 and 5302 which are the Willow Brook and Mill River drainage basins respectively. Locate the arrow indicating where Willow Brook basin empties into Mill River. Notice its scale and the special information it gives.

These maps can serve as the data basis for several types of math lessons using map scales, making scale and time lines, constructing river profiles and determining basin contours and areas. Three example lessons follow: Lesson Plan 1 works with map scales, Lesson Plan 2 uses both scale and contour lines in constructing a river profile, and Lesson Plan 3 works with knowing the names of seven rivers and sketching the bounds of a water basin. How to make and use scale and time lines is simply and clearly explained in Dickinson's *Map and Air Photograph* . [12]

Lesson Plan 1: Using Map Scales

Objectives .

1. Given a map scale and map distance, determine the ground distance. Given a map scale and ground distance, determine map distance.
2. Using quadrangle maps of New Haven and Mount Carmel and a piece of string, determine the lengths of the Willow Brook and Mill River.

Materials Connecticut quadrangle maps of New Haven and Mount Carmel, topographic maps of the 7.5-minute series. Scale 1:24 000. size 23 x 27 inches. Price $2.00 each. Available from same source as in Footnote 10.
String and rulers.

Background A map scale expresses a comparison of ground distance and map distance. The map scale is the single most important map feature, and knowing it we can determine the ground measurement of an object if given the map measurement and determine the map measurement if given the ground measurement.
A ratio is a comparison of two numbers with the same unit of measure. Thus a map scale can be written as a ratio comparing the map distance to the ground distance using the same unit for both, for example 1 inch/63 630 inches. [13] If we invert the ratio, 63 360 inches/1 inch, we would still have a ratio or map scale, only now we would be comparing the ground distance to the map distance instead of the other way around. Consider the following:

(figure available in print form)

Notice that if you have, or are given, the map distance then the ratio you use would be the one with the map distance part in the denominator. If you have, or are given, the ground distance, the rate you use would be the one with the ground distance in the denominator. [14]

Procedure

1. Explain meaning of map scale as a ratio comparing map and ground distances. Include explaining what the reciprocal ratios mean.

2.

(figure available in print form)

(1) On a New Haven Quadrangle Map the distance from Lee High School to the corner of Church and Chapel is 1 1/4 inches. The map scale is 1: 24 000. Find the distance in feet between the two places.

(2) If the distance between New Haven and Hartford is 36 miles, what is the map distance on a state map with a scale of 1: 125 000?

(3) Given a map scale of 1: 1 000 000, find the ground distance of a river whose map distance is 8 centimeters.

(4) Given a map scale of 1: 1 000, find the ground distance of a river whose map distance is 6.5 centimeters.

(5) Given a map scale of 1:1 000 000, find the map distance of a river whose ground length is 75 kilometers.

(6) Given a map scale of 1: 1 000 000, find the map distance of a river whose ground length is 429 kilometers.

3. Using the New Haven and Mount Carmel Quadrangle maps, do the following. Taping maps together to provide one continuous map would be helpful.

(1) State the map scale.

(2) Express the map scale as a ratio, that is using the same unit. Use inches.

(3) With a string, measure the length of Willow Brook. The part of string used = _____ inches.
(4) Using MD1 x GD/MD = GD1, determine length of Willow Brook.

4. With students working in pairs, have students repeat procedure in 3 for the Mill River.

Lesson Plan 2: Constructing a River Profile

Objective To use map scales and contour lines to construct a profile of a river's height above sea level.

Materials Maps from Lesson Plan 1 and a piece of string.

Background A river profile graphs the height of a river against the distance from its mouth. In this lesson we will graph the height of Willow Brook from its source, or head, to its mouth where it enters the Mill River.

Procedure

1. On the quadrangle maps, locate several places where contour lines cross Willow Brook. Determine the height of the river at each place. Find four or five such points.
   To do this requires locating Willow Brook, following it from its mouth to its head, carefully looking along its length to find where the contour lines cross the river and then determining the altitude at those points. The contour lines are marked in 10 feet intervals. Figure 7 shows an example of how this is done.
2. Using horizontal and vertical axes as in figure 8, graph the altitude at the mouth of Willow Brook.
3. Using a string and the maps, measure the distance from the mouth of Willow Brook to the first point. Continuing in this manner, complete the table in figure 9.
4. Graph each point according to altitude and distance from river mouth.
5. Connect points.

*Lesson Plan 3: Drainage Basins

Objective

1. Learn the names and locations of the following rivers: Housatonic, Naugatuck, Willow Brook, Mill, Quinnipiac, West and Hammonasset.
2. Draw in the boundaries of the Willow Brook and Mill River drainage basins.

Materials

1. overhead transparencies showing the maps in figures 5 and 6
2. The New Haven and Mount Carmel quadrangle topographic maps.
3. The *State of Connecticut* relief map and the *Natural Drainage Basins* in Connecticut map
4. Worksheet in figure 10

Background A drainage basin is an area separated from adjacent basins by a divide or ridge. All surface water originating in a basin moves to lower levels and eventually leaves the basin at the lowest point in the divide through which the main river flows.

Procedure

1. Using a transparency of figure 5 on the overhead projector, review the major water basins in Connecticut, the four large sub-basins of basin 5, and where in sub-basin 53 the Willow Brook and Mill River basins are located.
2. Hand out worksheets of figure 10.
3. Have students write the definition of a water basin on the back of worksheet.
4. Have students write in the names of rivers using a transparency of the worksheet to give them the names.
5. Working in pairs, each with his or her own worksheet, have them determine where they think the boundaries of these two basins would be by studying the New Haven and Mount Carmel quadrant topographic maps.
6. When completed, put up the *State of Connecticut* relief map and the *Natural Drainage Basins in Connecticut* map and carefully look at the two basins on each map. Each student should correct any errors that may be on his or her worksheet.
7. Study names and locations of rivers and the basin boundaries for homework.

8. Test: given new worksheet, fill in names of rivers and sketch boundaries of the two basins from memory.

Figure 3—Political Boundaries

(figure available in print form)

Figure 4—Major Rivers in Connecticut

(figure available in print form)

Figure 5—Major Drainage Basins in Connecticut

(figure available in print form)

Figure 6

(figure available in print form)

Figure 7—Altitude of river where arrow is pointing is 140 feet

(figure available in print form)

Figure8

(figure available in print form)

Figure 9

(figure available in print form)

Figure 10—Long Island Sound

(figure available in print form)

Water Power

In the hydrologic cycle, as water evaporates from various surfaces it increases the amount of vapor in the air. As the air and vapor circulate, some of the vapor rises, cools and forms particles of water large enough to fall to earth. When the water falls on ground higher than sea level, the water collects and begins to flow down from the higher level to sea level. *It is the force created by the flowing and falling water as it moves to sea level that forms the basis of all water power* . How part of this force has been harnessed and changed into mechanical power for our use is what this section is about.

Historically there are three levels of water power development. The first level harnessed power to run mills for local needs like grinding flour or sawing logs. The second level of development took place during the first half of the nineteenth century when there was a transition from the water mills which served local needs to those whose primary goal was the commercial conversion of raw material for the general market. [15] New England textile mills exemplified this type of development. The third level evolved with the development of hydroelectric power plants.

The grist mill is representative of the first level. I want to go into some detail on the development of the grist mill because of its interesting technological development and because the other two levels naturally followed from it.

A grist mill grinds grain into flour. Grinding grains such as wheat, barley or oats, makes them easier to digest. People have been grinding grain since ancient times. The earliest people used stones for rubbing grain (figure 11). The Egyptians used a saddlestone (figure 12). The early Greeks used a mill with a handle that swiveled and stones with carved surfaces (figure 13). Later they used a mill made of two round stones, a bottom stationary stone called the bedstone and a top rotating stone called the runner. Grain was poured into the hole at center of the runner stone and as a person turned the handle the grain would be rubbed and ground between the two stones. The millstones were carved to provide a sharp cutting surface and to lead the grain from the center of the mill to the outer edge where it would spill out as flour (figure 14).

Figure 11—(Illustration sketched from The Mill p.34)
(figure available in print form)
Figure 12—(Illustration sketched from The Mill p.34)
(figure available in print form)
Figure 13—(Illustration sketched from The Mill p.34)
(figure available in print form)
Figure 14—(Illustration sketched from The Mill p.34)
(figure available in print form)

The development from rubbing stones to such a hand grist mill took thousands of years. Using a grist mill was certainly easier than doing it by rubbing stones, but even this required a great deal of time to provide the flour needed by a community.

The Greeks and Romans both used water power to run grist mills, but they were slow to develop its use. Possibly this might have been because they had slaves. The Greeks had a horizontal water wheel which was on an upright, vertical shaft. As the river turned the wheel, the shaft turned and this turned the upper stone of a small millstone above.

The Romans had a vertical water wheel which was basically boards on a shaft. As the river pushed against the boards, it turned the wheel, which turned the shaft. The shaft was connected to gears which transferred the motion to the rotating of a millstone.

The technology of a typical grist mill used in Europe and America in the seventeenth and eighteenth centuries is illustrated in figure 15. The water would fall into the buckets, descendants of the ancient wheel boards, and the force and weight of the falling water would weight it down and the wheel would turn.

The shaft or axle of the wheel would rotate as the wheel rotated. The shaft usually went through one wall of the mill to a space below the first floor. Attached to the shaft was a wooden wheel called a crown or pit wheel. The crown wheel had wooden pegs or cogs mounted near its circumference. As the water wheel shaft turned so did the crown wheel with its cogs which then meshed with and turned a gear mounted at the end of a vertical shaft. This second gear was called a wallower or latern pinion. The motion of the water wheel turned the crown wheel gear which turned the latern pinion gear that turned the vertical shaft to which it was attached. This shaft, which went up to the floor above and through the center of a pair of millstones, was attached to and turned the top millstone.

This was the basic water powered grist mill. The process was the same as that used in the small, hand-turned grist mill. Two stones were used, the bottom stationary stone was called the bedstone and a rotating top stone called the runner. Two major changes, of course, were that the runner stone was now turned by the power transferred to it from the water wheel and the millstones were much larger. In fact they generally were about four feet in diameter, a foot thick, weighed approximately a ton and turned at 120-150 revolutions per minute. If you visit the site of the Whitney Armory in Hamden, you can see two old millstones that were excavated there. If you do stop to see them, look for carved marks on their surfaces.

Figure 15

(figure available in print form)

Milling took skill. Just as with the hand mill the groves on the surface of each millstone had to be correctly carved to provide a sharp cutting surface and lead the grain from the center to the edge. The distance between the stones and the speed of rotation had to be right or the flour could become lifeless or burned. Carelessness could even cause sparks and start a fire. Mill fires were not uncommon.

This type of mill, one that did a single repetitive task and whose equipment was quite directly connected to the water wheel gradually gave way to larger mills or factories. The larger mills had many machines. As all the machines could not be run directly from the water wheel shaft, systems of gears, shafts, pulleys and belts were derived. These systems were called powertrains and they transferred the power of the moving water wheel to machines that were relatively far from it. A working example of a water power factory is Slater Mill in Pawtucket, RI. You can visit this site, see, hear and feel its great water wheel turn and watch how the power is transferred through a system of gears and shafts to an upstairs powertrain that extends the length of a *long* room. The powertrain is attached to the ceiling. The motion of the water wheel is transferred to the turning of the powertrain’s long shaft from which there are many belts that can be moved in place to cause various machines to begin moving.

The old mills were anchored at the waters edge. The water power was used right there. The larger mills and factories transferred the power from the rivers to where their various machines were located. This is a significant characteristic of the second level of water power development. Both books, *The Mill* and *Mill* , clearly describe and illustrate this development.

The third level of water power evolved with the development of hydroelectric power plants. The early horizontal type water wheel developed through the centuries into a tub wheel and then a turbine.

A turbine is a machine that has a rotor or wheel which is a shaft that has a series of blades, vanes or buckets around it. Water is lead in to strike the blades to make the wheel rotate. The shaft of the wheel, of course, rotates with it.

The rotating shaft extends from the turbine into an electric generator which is basically a spinning magnet within a structure of coiled wire. It is the motion of the water that is transferred to the revolving turbine blades and shaft which then turns the magnet within the electric generator. It is the spinning of the magnet within the coiled wire that produces electricity.

Once electricity is produced it is conducted through wires to wherever it is wanted. The power of the water was changed into the power of electricity and that power travels very far from its water source. The transfer of power from its source to locations further and further away is an important characteristic of water power development.

Why was this significant? It meant factories did not have to stay near the water power site. They could move and cause significant changes in the locations they moved from and to. The advancing technology saw new jobs created, old ones abandoned and legal issues over water rights developed. The availability of relatively abundant and inexpensive power has effected every aspect of our lives.

Some Related Math Activities

There are many ways the math inherent in this area could be used. Working with gears and river velocity and flow are described below.

1. Students can sketch the design of the technology of an early grist mill. Problems on gear ratios and the changing of speeds and direction could be part of this. Questions could be asked such as, “How can a water wheel turning 7 revolutions per minute turn a millstone that revolves at between 120 and 150 revolutions per minute?
2. A field trip to the Mill River just west of the Orange Street bridge in East Rock Park would be a good place to measure the velocity and flow of a river.

To find the velocity place markers at certain distances in the river. Go parallel to its sides. Time how long it takes a floating object to cover that distance. You’ll get X number of meters or feet per Y number of seconds. Keep it as a general rate or change it into a unitary rate. Discuss both the changing and if one form is more meaningful to them than the other.

To find the flow, pick a point in the river. Determine the shape of the river and the dimensions. You will need to determine the area of the river at that point as if a plane had passed through it. See shaded area A in figure 17.

Next determine the distance the river goes in one second. That is d in figure 17. Multiply the area times the distance and get the number of cubic feet (or meters) of water that pass that point in one second. That is the river’s flow, cubic feet per second or cubic meters per second.

Trying to determine velocity and flow would certainly illustrate the difficulty of getting exact measurements. Estimating and amount of error would naturally come up.

Figure 16
(figure available in print form)

Section IV. The Mill River

Part A. History and Geology of the River [19]

The Mill River is unique in many ways, and it has played a major role in New Haven’s history from its beginning. In 1665 the town promised Christopher Todd and William Bradley land on the south side of Mill Rock for them to build and maintain a new mill. They were given extra land to house a miller and to take timber to build a dam. The town also promised that there was to be only one grist mill for the townspeople.

By 1671 Todd had become the owner of what became known as “Todd’s Mill.” Todd was plagued with problems of low water and wanted the town to help raise the height of the dam. Later his sons took over the mill, but with a new contract with the town which deliberately omitted the promise of no competition. Thus, a new grist mills started up on the river. Wilmot's Brook area was the site of a new saw mill, and in time a fulling mill (to perfect woolen cloth) was set up below Todd's Mill.

In 1733 a dam was constructed way up the swift-flowing Mill River in what is now Sleeping Giant State Park. Joel Munson was given permission to build a dam across the river if he would also build a feasible cartway across the river. This he did. He also built a grist mill and a saw mill. The Joel Munson dam is now a historic landmark.

This area became the beginning of the settlement of Mount Carmel because it became the meeting place for people to bring their grain to be ground and their logs to be cut. Bellamy's tavern, erected nearby on the northern edge of Mount Carmel Green in 1743, did not lessen the popularity of the area.

Other mills dotted the areas of the Mill River, especially after Eli Whitney took over the Todd Mill and dam and bought large amounts of land along the river as protection against any flooding resulting from building the dam higher. Whitney holdings extended from the edge of East Rock to the top of Mill Rock, a range which made it easier for Eli Whitney, Jr. to organize the New Haven Water Company many years later.

The Whitney factory was a fine working unit. Figure 11 shows the layout of the buildings and the lake formed by the dam. The original timber dam was replaced by a stone one at the same height of six feet. Unfortunately, maximum use of water power was not attained because of poor design of the water-wheel blades. In 1842 Eli Whitney, Jr. replaced the trustee authority set up by his father's estate. He got rid of the wheels and replaced them with a turbine; but a problem still existed for the armory because the flow duration was not constant. The size of the lake and the force of the waterfall were inadequate. A higher dam was needed to increase the force and consistency of flow.

Eli Whitney, Jr., like many men at this time, was quite civic minded. Realizing that New Haven would need more water in the future, and also hoping to solve some of his own financial problems in the process, he expressed willingness to share his water rights with the city, using only the surplus water for the factory. Finally a new 38-foot dam was built (at a cost to the city of about $350,000). On December 2, 1861, the New Haven Water Company began to pump water from the Mill River into a reservoir on Prospect Hill. In a short time water was being piped through seventeen miles of pipe to all parts of the city.

It later became obvious that the amount of water thought to be available was inadequate. The demands were greater than the watershed could supply. Steam power had to be used, especially when the water was low, to pump water into the supply system. A photograph showing the dam and the smokestack from the furnace is contained in the teacher's packet.

The newly formed Southern Connecticut Regional Water Authority has plans to protect other historic sites in addition to the still-standing Eli Whitney Barn, built in 1816, which is now a part of the Eli Whitney Museum, Inc. An 1824 workers' dormitory on the south side of Armory Street may become a part of the Museum complex, although it may have to be moved in the eventuality of a new filtration plant. The present filtration is quite adequate and is unique in its method of slow sand filtration with a biological layer of material at the top to help destroy bacteria.

Architect Ithiel Town's Covered Bridge is no longer standing. It had replaced an older bridge over the Mill River beside Whitney's Armory. Built in 1823, it had a 100-foot clear span and was the first truss bridge in the United States. It was itself, in turn, replaced, but because of its uniqueness, Whitney, with customary ingenuity, invented means to have it moved north to serve as the Davis Street Bridge. It "did its duty" until

1890.

Additional sites associated with the Mill River which are to be preserved include the Elam Ives House on Ives Street in Hamden, just east of bridge over the Mill River, and a nearby nineteenth century factory; a former canal and tailrace at Woodruff's Pond on Bank Street north of Ives Street whence power was supplied for the factory and where a sluice gate remains close to the road; Clark's Pond, cradled within New Road and Sherman Avenue south of Mount Carmel Avenue, where R.S. Clark had his bell factory in 1872 and a thread factory after 1875 and where the dam washed out three years ago is scheduled for reconstruction; a last, old-growth hemlock-hardwood stand south of Clark's Pond; the remains of buildings, the sluice way, and the Munson Dam at Axle Shop Pond just south of the confluence of Eaton Brook with the Mill River and near the south entrance to Sleeping Giant State Park on Mount Carmel Avenue a few yards east of Whitney Avenue; the last building of the old Augur Shop south of the Skiff Street Bridge over the Mill River and south of the confluence of Shepard Brook with the Mill River.

Marked for preservation in general are historically significant sites and structures, scenic and natural resources, and recreational facilities—and protection of both surface water supplies and the extensive groundwater aquifer underlying the Mill River.

Note : Many of these scenic sites have been photographed. A tape and slide presentation is being completed.

NINETEENTH-CENTURY INDUSTRIES ON THE MILL RIVER

Mr. Jefferson's Embargo of 1808 and "Mr. Madison's War" a few years later not only crippled New England shipping enterprises; they also changed the emphasis of the economy from agriculture to industry. Banks replaced merchants, and capital moved into a new ventures, notably manufactories. Connecticut was in the van of this development because of its cheap water power and its easy access to markets. Factories appeared in great numbers along rivers and streams. The Mill River is a foremost illustration of this new and growing economy.

Some of the nineteenth-century industries on the Mill River follow. They are listed to show diversity and are not listed chronologically.

(figure available in print form)
NOTE: Above information on Mill River industries is extracted from Rachel M. Hartley, *The History of Hamden* , *Connecticut* , 1786-1936. Hamden: 1943 and Rollin G. Osterweis, *Three Centuries of New Haven* , *1638-1938* . New Haven: Yale University Press, 1953.
(figure available in print form)

Geology and Nature Field Trip of the Mill River and the East Rock Area

Area A walk along the Mill River from Orange Street Bridge to Lake Whitney

Materials Map of the area (Adapted from City of New Haven Engineer's Map by Philip M. Orville); pencil, pad, protractor, hand lens, collecting bottles and a plastic bag for specimens.

Background Information Looking up at East Rock you see the main mass is a sill (an igneous rock that has

intruded between layers of sedimentary rock). This intrusive, igneous, lava rock is composed of black to dark green minerals and called dolerite, basalt or traprock (referring to the columns that resemble steps) and is very resistant to erosion. It is interesting to look at freshly broken fragments of basalt that are blackish whereas the weathered surface of the freshly broken talus fragments have a rusty orange color due to iron in its composition. Notice the large columns of dolerite that were formed when the lava contracted. Millions of years of weathering wore down these uplifted layers and the weaker sedimentary, reddish sandstone was eroded away and formed the present valleys. The degree of tilting of the dolerite can be measured. (Refer to diagram of the cross-section through the rock and notes of C. MacClintock.)
When the last glacier melted from New England (about 10,000 years ago), the big basalt outcroppings remained. Rock fragments formed a composite deposit of unsorted sand and gravel, called till. This is the upper material that forms the bed of the Mill River. Later, when the sea rose, the big river mouth was formed. Later the rains brought down sediments into the river of sand, mud and peat forming the outwash meadow and salt marshes. Looking south from the bridge, or other vantage spots, you can see the remains of this once flourishing meadow where salt hay was collected. There are pictures of this in the teacher's packet along with slides of this whole area.

There are geological clues as to the changes that have taken place with the Mill River. As a river matures and populations add problems of diverting streams, the size and direction of the river can change. Meandering is the term given when a river follows a crooked course and shows deposition of material on one side and erosion on the other forming a scarp or sharp edge (see diagram). As the water flows down the Mill River sediment is dropped. The largest rocks first and mud being deposited at the outer limits. When these deposits fan out on the valley floor it is called an alluvial fan. One can be seen on the left bank of the river near the Orange Street bridge (picture in the collection).

When you get to the dam you will notice the outcroping of traprock. There is a traprock or bedrock dike connecting Mill Rock on the west leading to the Whitney peak on the east, (see the Dana map of this dike). A dike is an igneous rock that is intruded across layers of sediments. This was a natural area for the original dam. It was here that more traprock was added to make the existing dam. Around the dam are two millstones from the days of the gristmill. There are two plates that show the profile of East Rock and the River.

Following the River to the Dam:
North by your map is looking up stream. You will find such plants as cattail, skunk cabbage, water arum, dogwood, multiflora rose, buttonbush, water shamrock, post oak and lovely plant life that adjusts to the areas many different sites.

Bird watching is a favorite of many people at East Rock all year. It is in a migratory path for many birds which stop to take a rest during their migrations. Warblers especially like this area.

The river has interesting fish life. From far up the river where trout may be caught to the flood gates where bass and killifish are caught, the Mill River provides many different kinds of places for many kinds of fish to live. Down from the Whitney Dam in the water weeds, can be found stickleback. Way downstream is a fish that prefers saltier water, the mummichog. This relative of the killifish can also live in pollution.

Mammals and reptiles thrive in the park. Look for footprints along the muddy part of the stream. Gnawed bark, clipped twigs might be clues. Most of the mammals are active at night. A turtle might easily be seen.

Other things to take note of:

1. The beauty of the footbridge.
2. The construction of the wooden covered bridge.
3. Look across Whitney Avenue to the beautiful Whitney Barn.
4. Compare the bridges with the picture of the original bridges (early map showing bridges).
5. Look for the location of the new Whitney Museum.
6. At the dam, look for the remains of the working areas of the Whitney Armory. (Photograph of this area and also slides available on loan and request.)

Remarks: This can be a most rewarding field trip and might influence some students to realize that we in New Haven have a remarkable amount of history and geology so close by and to help protect its natural beauty.

Eli Whitney Gun Factory and Dam (from Exploring East Rock Park)

(figure available in print form)

Lake Whitney

(figure available in print form)

East Rock Park

(figure available in print form)

Sill and Dike

(figure available in print form)

East Rock Park (Adapted from City of New Haven Engineer's Map by Philip M. Orville)

(figure available in print form)

Cross Section of East Rock (East Rock Association)

(figure available in print form)

Cross Section through East Rock Sill and Dike—Views looking south

(figure available in print form)

Section IV.

Part B. The Mill River Watershed

Water is collected when rain drains from higher levels to lower levels. The area drained by a stream and its tributaries is the stream's drainage basin or watershed. [20] These areas are usually natural boundaries, but in some cases man has delineated boundaries and has mapped and recorded them. We will consider the watershed of the Mill River. There is available a large map of the area given by the Southern Connecticut Regional Water Authority showing the extent of their boundary lines from the headlands in the Cheshire area and extending to the Lake Whitney Dam. The Connecticut State Geological Map (fig. 9) follows the natural boundary of the river to its mouth at the New Haven Harbor. But, since the section from the mouth to the dam is tidal and the height of the river slowed down at full tide by flood gates, the salinity and pollution would not make it useful. As it is, the Authority owns only about 3% of this large watershed, consisting of 36.4 square miles of drainage area. [21]

The Mill River watershed is unique because it is the largest in the water supply system of the Water Authority holdings, because of the degree of urbanization within its boundaries, and because it has an extensive stratified-drift aquifer. An aquifer is the name for rock or soil that contains and transmits water and is therefore a source for underground water. An aquifer may be an underground pocket of gravel or sand, a layer of sandstone or a layer of cracked rock creating a pathway. Somewhere under these aquifers is rock that is impermeable and watertight. This is called bedrock. Water is stored in the Mill River aquifer which measures thirteen miles by one mile. [22] This is a natural formation which keeps the Mill River flowing even in dry periods. This is the throughflow water that reaches the river in a few days to a week after the rains, but the water way deep in the ground, known as groundwater, may take months or years to reach the river. Very little water reaches streams by simply flowing over the ground surface.

The Mill River watershed property is quite visible. The river meanders to the right and left of Whitney Avenue from the Cheshire area down to the Whitney Dam. Lake Whitney is 2 1/2 miles long and approximately 1/2 mile wide. It has a capacity of 258 million gallons. The system derives its supply from two sources, surface water and groundwater. [23]

In highly urbanized areas, contamination of our water supply can be very serious. Problems with surface water can come from automobile exhaust emissions. Sometimes both road salt and even gasoline from leaky tanks can find their ways into groundwater. Old tires near dumpsites are a source of contamination. Noxious fumes, composed of sulfur dioxide and nitrogen dioxide, from factory smoke stacks as well as from car exhaust emissions, when combined with rainwaters, form acids which can change the chemical balance in water supplies. Ground-water problems are very serious because certain volatile organic chemicals do not dissipate readily underground. [24] So first the environment and then the aquifer must be managed carefully to protect our vital groundwater. It is not so much the quantity that should be our concern, but the quality. We seem to have enough water not to have to worry about Ben Franklin’s warning, “When the well’s dry, we know the worth of water.” Water quality problems must be constantly monitored to keep our Hydrologic Cycle as safe as we can for the generations to follow.

Activities Suggested for the Mill River Watershed Unit:

Activity 1. Using your watershed map and with the aid of the Connecticut Geological Drainage Basin Map (or with the aid of the overhead provided in the teacher’s packet) shade in the area of the Mill River Watershed, locating the Mill River and the tributaries, especially Willow Brook and Eaton Brook. Also, label the Lake Whitney Dam.

Activity 2. A short field trip to the flood gates might be of interest. Go to the beginning (North side) of the Willow Street Bridge, across from a large ball field. Head for the big recreational house and find the path on the left which leads to the flood gates.*

a. Take some specimens of water on both sides.
b. Which way is the tide flowing?
c. Are the banks of the river the same or different?
d. Notice and collect some of the plants growing along the banks of the river. Identify plants.
e. What kind of plants seem to predominate the river banks looking up stream?

f. Do you see any evidence or animal life? (People catch bass on both sides of the flood gates!)

g. Test water for salinity with a hydrometer (to measure specific gravity). One on loan upon request. Or use a little silver nitrate solution to get a precipitate (white indicates silver).

h. Test for oxygen content either with Hach material or use a simple qualitative device using colorimetry with methylene blue (directions given upon request).

i. Test for acidity with pH paper (given on request).

*Refer to Pollution Diagram.

Activity 3. A field trip to Sleeping Giant Park and to Cheshire to find the head water area for the system—also to look for historic sites in the vicinity (see History Unit).

Possibilities for an archaeological dig in one area.

Directions: In the Park, just off Mt. Carmel Avenue, is a foot path following the river north and on the right side. You will come to Axle Shop Pond and Munson's Dam. Turning around and going to the left of the river, in the same general area are the remains of either a can or a sluice way for water to be channeled to a culvert. This whole area has many interesting things to see, such as iron bars sticking up, also the remains of a wall or possible foundation. There is also the remains of what might have been a flume. Notice the quality of the water as compared to the lower river.

Activity 4. Make a diagram showing means by which "ACID RAIN" forms.

Activity 5. Make a Rain Gage and collect data for two or three months. (Find directions with diagram of Rain Gage.) Get measurement in millimeters. Make a graph for converting mm to inches.

Activity 6. Directions given for reading contour maps.

Quinnipiac River (East Rock Park Association)

(figure available in print form)

NOTES

Section I.

1. Evapotranspiration is a term that refers to the total amount of water removed from an area. It includes both evaporation, moisture removed from soil, snow and water surfaces, and transpiration, moisture removed from bodies and leaves.
2. Hydrology is the science that deals with the properties, distribution and circulation of the Earth's water.
3. *The World Almanac and Book of Facts 1984* (New York: Newspaper Enterprise Association, 1983), p. 211.
4. David R. Houston, *Understanding the Game of the Environment* (Washington, D.C.: U.S. Department of Agriculture, 1979), p. 130.
5. John S. Shelton, *Geology Illustrated* (San Francisco: W.H. Freeman and Company, 1966), p. 128.
6. *The World Almanac* , p. 765.
7. Ibid.
8. Rollin G. Osterweis, *Three Centuries of New Haven* , *1638 - 1938* (New Haven: Yale University Press, 1953), p. 193.

Section II.

9. Ray K. Linsley, *Water-Resources Engineering* (New York: McGraw Hill, 1979), Chapter 1.
10. The *State of Connecticut* shaded-relief map, scale 1: 125 000. Size 45 x 56 inches. Cost $3.25. Available from U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202.
11. *Natural Drainage Basins in Connecticut* colored map with topographic base. 1:125 state map scale. Cost $5.00. Available from the Natural Resources Division, 450 Main Street, Hartford, CT 06103.
12. Gordon C. Dickinson, *Map and Air Photography* , (New York: Wiley, 1979), pp. 134-149.

13. In a ratio the quantity named first is put in the numerator, the quantity named second is put in the denominator: i.e., map distance to ground distance is *map distance* . Further, a ratio such as 1 ground distance 63 360 is often written as 1: 63 360. It is a matter of convenience since the two forms are equivalent.
14. This uses the general rate rule method of solving rate problems. It is from the method presented in Goodstein's *Sci-Math* .

Section III.

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15. Louis C. Hunter, *A History of Industrial Power in the United States* , *1780-1930* , *Volume one* : *Waterpower* (Charlottesville: University Press of Virginia, 1979), xix-xxiv.
16. David Macaulay, *Mill* (Boston: Houghton Mifflin Co., 1983). Illustrates the development of waterpower at a particular site. Very simply and clearly done.
17. The use of direct wheel power can be seen in Ledyard, CT, at the Up-Down Sawmill and in New London at the Olde Town Mill.
18. Slater Mill restoration in Pawtucket, R.I. provides an authentic, working factory which clearly illustrates elaborate millwork which transfers power from a water wheel to a large number of machines.
Section IV. Part A.
19. The history and the geology of the Mill River is organized from information in Hartley, *The History of Hamden* ; Osterweis, *Three Centuries of New Haven* ; Atwater, *History of the City of New Haven* ; East Rock Park Association; interviews with Mrs. C. Hunt, Curator of the Eli Whitney Museum; Mrs. Martha Brewster of the Hamden Historical Society; Mr. Otto Schaefer of the New Haven Water Authority; Dr. Copeland MacClintock of the Peabody Museum; Mrs. Lise Orville; and personnel of the Map Department of Sterling Library of Yale University and of other libraries.

Section IV. Part 2.

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20. C.W. Wolfe *et al* ., *Earth and Space Science* (Boston: D.C. Heath and Company, 1966), p. 166.
21. *Land Use Plan* , S. Central Regional Water Authority (New Haven, 1983), p. 35.
22. Ibid., p. 36.
23. Ibid.
24. Ibid.

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Interesting history.

Dana, James D. *The Four Rocks* : *with Walks and Drives about New Haven* . New Haven: Tuttle, Morehouse, & Taylor, 1891. Excellent maps and geological information.

Dickinson, Gordon C. *Map and Air Photography* . New York: John Wiley, 1979, pp. 134-149.

Goodstein, Madeline P. *Sci-Math* : *Module One* , Menlo Park: Addison-Wesley Publishing Co., 1983.

Sci-Math presents a method of solving rate problems. It was originally designed as a course to help high school students to better handle the math in college science courses. I've found this method helpful, but the concepts could be presented in a simpler, clearer manner.

Gordon, Robert B. "Hydrological Science and the Development of Water Power for Manufacturing," *Technology and Culture* , in press. (36 pp. +).

Interesting background for understanding hydro power. Strong on Whitney Armory and the water works.

Hartley, Rachel M. *The History of Hamden* , *Connecticut* , *1786-1936* . Hamden, Conn., 1943.

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Houston, David R. *Understanding the Game of the Environment* . Agriculture Information Bulletin No. 426. Washington, D.C.: United States Department of Agriculture, Forest Service, 1979.

An excellent approach to conceptualizing the environment.

Hunter, Louis C. *A History of Industrial Power in the United States* , 1780-1930. Charlottesville, Va.: University Press of Virginia, 1979. Vol. I, pp. xix-xxiv.

A very thorough book. It is a detailed development of waterpower clearly written and easy to understand.

Land Use Plan . New Haven: South Central Regional Water Authority, 1983.

A most informative book with excellent land-use maps. Book suggested by Otto Schaefer of the Water Authority.

Leopold, Luna B. *Water* , *A Primer* . San Francisco: W.H. Freeman and Company, 1974.

A very good introduction to hydrology.

Linsley, Ray K. *Water-Resources Engineering* . New York: McGraw-Hill Co., 1979, chapter 1.

Macaulay, David. *Mill* . Boston: Houghton Mifflin Co., 1983.

A wonderful book for teachers and students. Very clear and detailed illustrations and text. It takes into account the lives of the people involved. A fictional work which parallels closely historical developments.

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Helpful and informative. A good reference book.

Shumway, Flyod and Richard Hegel (Editors). *New Haven* : *An Illustrated History* . Woodland Hills, Calif.: Windsor Publications, Inc., 1981. Sponsored by New Haven Colony Historical Society.

Every New Havener should read this book.

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States, 1800-1932," *Technology and Culture* , Vol. 25, No. 2, April 1984, pp. 226263).

Interesting treatise on sewer technology.

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F. Fox W., Brooks, B., Tyrwhitt, J. *The Mill* . Boston: New York Graphic Society, 1976.

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