Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2017 Volume II: Watershed Science

# New Haven Watershed Problems in 2017

Curriculum Unit 17.02.08
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## Introduction

The unit I am planning in YNHTI this year is for an integrated physical science class for freshmen at Cooperative Arts and Humanities Magnet High School (Co-op). The class is made up of mostly freshmen, but has a few upperclassmen who need to repeat the class for course credit. The class is a graduation requirement for students enrolled at Co-op, and is currently being revamped to accommodate the Next Generation Science Standards (NGSS) recently adopted by Connecticut. The students in this class are from the whole spectrum of demographics in New Haven and the surrounding towns. Some, but not all, are invested and engaged in their education, and some of them can read at grade level, and are proficient in 9th grade math, but many are not. Most of the school is African-American, and it is 70% female, both groups are historically underrepresented in STEM careers. Many of the students are from low income households, have unstable home lives, and do not have access to adults who have prepared them to be successful in a rigorous college preparatory school like Co-op. Most of the students plan to go on to college at the conclusion of their four years at Co-op, but all are expected to have an attainable career pathway when they graduate. The school's focus is on fine and performing arts, but it also has a heavy emphasis on academics, which include a strong AP community and college-bound culture. It is my job to demystify science, and help those that are interested to become more capable science students, so they can be informed, skeptical, conscientious voters, who take advantage of opportunities in STEM in their careers and communities.

## Content Objectives

For this unit I would like my students to investigate the problems with the watersheds in New Haven, learn about what the causes of the problems are, what the proposed solutions are, and become involved in helping contribute to one solution. They will plan and execute a project in community service, increasing social awareness, or advocating for municipal change.

The things that are the most important to me are: that my students can have some impact on the local community, and get into some real hands-on science. I want them to ask questions, develop experiments,

take measurements, make observations, write conclusions, and repeat the cycle over again.

The best way to see what a student is capable of is to give them a framework, and let them go be inquisitive. See where their natural curiosity takes them. Watch them interact with the world, and then show them how to be methodical, how to approach problems in a regimented, scientific and logical way. Doing this without crushing their natural curiosity and innate creativity is extremely difficult to do in a classroom and a lab setting. It is best achieved in the field. I can't wait to let my students actually go out into a watershed and get dirty, and get their science on!

**What is a Watershed?**

A watershed is a unit of land area. It is defined as an area of land that drains into a particular body of water, such as a stream, river, or lake. Watersheds of different bodies of water can be linked together, or subdivided. For example streams that join together and eventually meet up to a river can be combined to study the entire watershed of the river, or subdivided into the individual streams and headwaters of the river, depending upon what analysis is desired. Streams are like veins in a leaf. They are assigned consecutive numbers based on what other streams they have combined with. Lower numbers are assigned to smaller, earlier, upstream bodies, and larger numbers to bigger, later, downstream bodies. Headwater streams are given order number 1, then when two first-order streams combine they form a stream of order number 2, when two second-order streams combine, it makes a 3rd order stream. The area covered by the stream, the stream lengths, and the flux of water through them are all proportional to the stream order. Different watershed systems may have different proportions, but the ratios will be consistent within a given system. This is a really interesting application of geometry. It can be compared to fractal patterns, and as previously mentioned, veins in different types of leaves. (Wohl 2009)

**Urban vs. Wild Watersheds**

Urban watersheds are very different than undisturbed or "wild" watersheds. Urban areas are affected by many changes to the watershed. As the number of people who live in cities increase, the number of residential commercial and industrial buildings in the watershed increase. This often means more concrete structures, sometimes a relocation of a body of water, and always a decrease in vegetation and an increase in sunlight. It also means putting in piping for drinking water, wastewater, storm drainage. This decreases the natural infiltration of rainwater through vegetation and groundwater, a routes stormwater very quickly and directly into the nearby bodies of water. Fast moving stormwater also picks up larger and higher concentrations of particulates, causing an increase in sediment, dissolved chemicals, and variation as to what those chemicals are. Agricultural, pharmaceutical, industrial and household chemicals end up in the water supply in greater amounts. In some areas stormwater runoff is treated, but this is uncommon, mostly it is piped directly into a stream or river. In some areas it is combined with sewage in Combined Sewer Overflow systems (CSO). This is what New Haven had, but it is being changed. (Myers 2009)

**New Haven's Watersheds**

There are three main watersheds in New Haven, CT: the Quinnipiac River, the Mill River, and the West River. The Mill River and Quinnipiac River both flow into the same mouth of the New Haven Harbor, and all three flow into Long Island Sound. (Quinnipiac 2017), (Bass 2013) and (West River 2017)

**Quinnipiac River**

The Quinnipiac River begins at Deadwood Swamp in Farmington, CT, the river proper starts in Plainville, CT and runs mostly south through Southington, Cheshire, Meriden, Wallingford, North Haven, New Haven and empties into Long Island Sound on the east side of the Mill River. (Quinnipiac 2017)

The Quinnipiac River has had a watershed management plan in place since 2004, and it was updated in 2013. The Quinnipiac River Watershed Association is a volunteer organization located in Meriden, CT, and they oversee the watershed management. They have a small facility for educational outreach, and hold board meetings monthly. They hold cleanup days, and have office hours on Fridays from 9am-3pm. The goals of the plan are to increase capacity and awareness in the area in order to decrease nonpoint source pollution. They also work together with non-profit organizations, educational and commercial partners to reduce contamination of runoff. They seek to increase recreational use and public access to the river, and increase wildlife habitats and restore damaged wildlife habitats. They invite local teachers and students to their facility for hands-on labs, water testing and canoeing, but there are limited spots, and they book very quickly, and at least a year in advance. Their website is well done with a great deal of information on their objectives, events and resources. (Quinnipiac 2017)

**Mill River**

The Mill River starts in Cheshire, CT and flows south into Hamden, through Sleeping Giant State Park, feeds Lake Whitney, and spills over a dam. Here, in the lower Mill River it becomes a tidal estuary, and flows southeast into the Long Island Sound. Just at its mouth, it passes around low lying Ball Island, which has a vacant power plant (English Station) on it, and empties into the Long Island just west of the Quinnipiac River. (Bass 2013)

The Mill River is known to be polluted, but there is no watershed management plan in place. One is supposedly being compiled, but testing must be completed first, and a watershed authority must be created. There is a Mill River watershed organization, but they do not yet have a website or an approved management plan. There are very few resources available at this time for projects in the Mill River because it does not have an approved watershed management plan on file with the state of Connecticut. However, the city has a plan to revitalize the Mill River neighborhood, which includes a riverwalk, an increase in commercial, residential, and public access for walking and parking in that area. The hope is to increase the commerce and residence in the area, increase the tax base, attract industrial buyers to some of the vacant industrial properties, and support them in cleaning up the Brownfield sites. This will help control some of the point source pollution of the lower Mill River, and the Long Island Sound. (Bass 2013)

**West River**

The West River begins in Bethany, CT, and flows south through Woodbridge and into New Haven. It provides a geographic border between New Haven and West Haven, flows through West River Memorial Park, and empties into the Winter Harbor of Long Island Sound at the western edge of New Haven. (West River 2017)

The stretch of the West River running through New Haven between the West Rock, Westville, The Hill and Newhallville neighborhoods is quite polluted. The major problems with the West River are an elevated level of bacteria. This is dangerous for swimming, and prevents fish, shellfish, and other forms of naturally occurring wildlife from surviving (let alone being safe to eat) in the riverwaters. The causes of this elevated level of bacteria are the combined sewer overflow discharges in times of heavy rain, stormwater runoff from

developed areas, flooding, and a reduction of habitat within and along the riparian zone of the river. Access to the river is limited by Ella T. Grasso Boulevard, and many industrial properties. The river has been rerouted to make room for urban and industrial development, and some of the natural habitat was compromised. Edgewood Park and West River Memorial Park are an attempt to correct some of that loss, but more should be done. (West River 2017)

The West River Watershed Coalition is a very active and enthusiastic group of people working on multiple projects in this watershed at once. They are welcoming and engaging to new members. The West River Watershed Management Plan has been approved by the state, and is comprehensive. One of the major goals is to get the river back to usability for recreation and fishing in all sections. Upstream it is used for recreation, has healthy aquatic life, and is used as a source of drinking water. Based on a survey of the participants in the watershed management plan, the main goals of the team are to increase the number of green projects in the West River watershed, increase the quality of the water, have more community awareness and engagement, and improve the habitat of the river. Some of activities they have done in 2014-2015 were to hold community events to get public input, inform the community of plans and assessments completed. They also have created partnerships with Common Ground High School, Save the Sound, and Neighborhood Housing Services. (DEEP 2017)

The river could also benefit from more frequent monitoring, remove barriers to fish passage, restore banks, and habitats. Plant natural buffers on the banks, and trees in the riparian zone. Also collaboration with players from the Quinnipiac and Mill River watersheds to work together and secure funding for similar projects. (West River 2017)

**Drinking Water**

South Central Connecticut Regional Water Authority (RWA) is a non-profit organization in charge of providing high quality drinking water for the greater New Haven region. They service Ansonia, Bethany, Branford, Cheshire, Derby, East Haven, Hamden, Milford, New Haven, North Branford, North Haven, Orange, Seymour, West Haven and Woodbridge. The mission of the RWA can be found on their website, “To provide customers with high quality water and services at a reasonable cost while promoting the preservation of watershed land and aquifers.” The website is thorough, it is an excellent resource for any information about the RWA, from billing to reservoir data to general knowledge about watersheds. They promote recreational use of their grounds, educational outreach, conservation of water, understanding your water billing, and annual water testing reports. It is a wealth of information. (SCCRWA 2017)

#### Lake Whitney

Lake Whitney is a man-made reservoir on the Mill River. It is used for drinking water, and is the oldest drinking water reservoir in the New Haven region. (Nakamura 2014)

Storm drainage from Whitney Ave drains directly into Lake Whitney, and thus sediments from Lake Whitney were used in 1978 to study the history of industrialization in New Haven, CT. At the time, Lake Saltonstall had no major thoroughfare storm drainage, but was located very close, so had comparable atmospheric and rain conditions. So, the two lakes can be compared with Saltonstall being used as the control group, and Whitney as the test group. It has some pollution but also has been the site of remediation projects, studies, and has a dedicated drinking water treatment facility on site. (Bertine 1978)

The RWA runs the water treatment facility that pulls water from Lake Whitney just before the dam on Whitney

Ave.  The facility treats water prior to putting it into the drinking water supply, and mixes it with water from other reservoirs.  There are frequent tests and an annual report published by the RWA on their website.  They test the drinking water extensively for all contaminants required by CT DEEP, in addition to several contaminants that are non-regulated, but are of concern to the RWA. (SCCRWA 2017)

The water treatment facility does not seem to have had an adverse effect on the health of the Mill River. There exists a similar diversity and make up of dissolved oxygen, pH and biological populations.  There was a noticeable shift in scraper invertebrates, and a biannual shift in some populations of other invertebrates, but this is attributed to fluctuations in flow.  As the flow varies, some dissolved nutrients and some macroinvertebrate communities are transported downstream, causing an increase in those populations downstream and a decrease in them upstream.  This is apparently expected and temporary, with a return to normalcy in 1-2 years, a reasonable amount of time for an ecosystem.  Because of this shift the RWA recommends retesting annually in August, just after the time of year when flow rates would historically vary the most. (SCCRWA 2017) and (Fisher 2009, 493)

The RWA also uses their capacity to adjust the chemistry upstream, and uses the dam to adjust flow rate of the Mill River.  The water treatment facility can monitor some aspects of the water chemistry of Lake Whitney upstream to try to remediate to encourage the best environment for organisms living in the lake and the downstream sections of the Mill River.  They also encourage keeping a steady rate of flow over the dam for aesthetic reasons, and to increase the level of oxygen in the lower Mill River.  They express concern that there is not sufficient information to influence the level of dissolved oxygen (DO) and salinity in the tidal portion of the lower Mill River, which goes almost up to the plunge pool. Data from the footbridge, which is just downstream of the plunge pool, shows a high variation of DO and salinity, and shows that they are inversely proportional to each other, and appear to fluctuate with tides. (SCCRWA 2017)

#### Whitney Water Center

The Whitney Water Center is located on Whitney Ave near the bottom of Lake Whitney by the dam and plunge pool, and is dedicated to educating locals on the reservoir.  The RWA provides educational resources to share, including water science boxes you can borrow to do classroom lessons.  They also have a targeted program specifically for 6-8th graders, called Project W.A.T.E.R.  Loan boxes are available for the following topics: Liquid Assets, Waterworks, Wondering About Weather, Water Wizards, Water Wizards II, Who Sank the Boat, Community Connections, Bubbles, Water Art, Wet History of NH, Invasion of the Aliens, Troubled Waters, Discovering Density, Watersheds, The Water Cycle, Habitat of L.I.S., From the Ground Up, Weather or Not, Oozing Oobleck, Polar Opposites, Troubled Waters, and Rainsticks. (SCCRWA 2017)

### Waste Water Treatment

#### Greater New Haven Water Pollution Control Authority

Greater New Haven Water Pollution Control Authority (GNHWPCA) is a regional organization that oversees the wastewater collections, transport and treatment in New Haven, East Haven, Hamden, and Woodbridge. There are three pump stations where wastewater is delivered by gravity.  The pump stations then pump the water across the harbor to the East Shore Water Pollution Abatement Facility.  (The Greater 2017)

#### East Shore Water Pollution Abatement Facility

This is the sewage treatment facility for GNHWPCA.  Part of the 2017 CSO Long-Term Control Plan was to

increase capacity at the abatement facility.  The GNHWPCA offers tours of the East Shore Abatement Facility for students.  There are safety requirements.  They are invested in green infrastructure, and have turned their parking lot into a swale. (The Greater 2017)

#### Other Wastewater Treatment in the Area

There is a waste water treatment facility operated in West Haven very close to New Haven, only 1.4 miles from the mouth of the West River, which provides the boundary between West Haven and New Haven in that area.  Decisions the West Haven facility makes can affect New Haven residents, especially those citizens and businesses with waterfront or near waterfront property, or anyone who enjoys recreation at the West Haven marshes or beaches.

### Problems in the New Haven Watershed

#### Combined Sewer Overflow (CSO)

A combined sewer overflow is where a single set of pipes is used to deliver both sewage (grey and black water) from buildings and rainwater drainage from streets and building roofs to a water treatment facility. It works by having a large pipe with a barrier wall, also called a weir, and a pipe before the weir.  In times of little rainfall, all the water in the pipe goes down the pipe to the treatment facility (black, grey and stormwater), but in times of heavy rain the rainwater runoff and the sewage mix together, and whatever flows above the level of the weir goes into an outflow pipe and directly into a stream or river.  This dilutes the raw sewage, but still puts raw sewage into the watershed. It will of course bring raw sewage to everything downstream when there is a large rainfall event.  (EPA 2017)

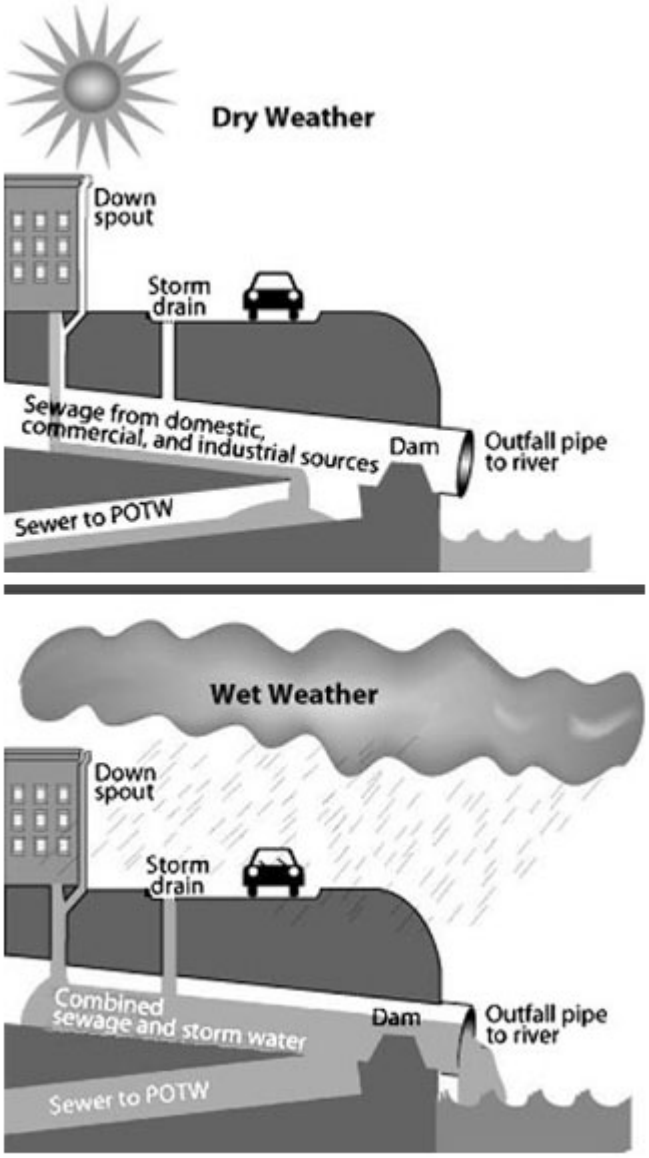


Figure 1. Photo credit: *U.S. EPA. 2004. Report to Congress: Impacts and Control of CSOs and SSOs . EPA 833-R-04-001* .

According to the GNHWPCA website, “Implementation of the Greater New Haven Combined Sewer Overflow Long Term Control Plan will clearly dominate the [Pollution Control] Authority’s agenda for the foreseeable future. The goal is extremely important – to improve the water quality of the West River, the Mill River, the Quinnipiac River, New Haven Harbor and ultimately Long Island Sound.” (The Greater 2017)

**CSO Remediation**

The Greater New Haven Water Pollution Control Authority has been working to close and replace Combined Sewer Overflows (CSO’s) in the greater New Haven area they service. There are 13 active CSO’s left as of June 30 2017, and there are plans in place to change and improve the structures of several of those in the coming year. The West River Watershed Coalition was able to support GNHWPCA on three CSOs: Ella T Grasso Boulevard, Legion Ave and Fitch Street. (GNHWPCA Annual Consent Order to DEEP)

There is an argument to be made that CSOs are not all bad. Yes, when there is a large storm, sewage ends up

in the waterways causing bacterial blooms, and causes harmful contamination, anoxic conditions and strains the nutrient balance in the river. However, when there is a light storm the sewage and the stormwater overflow both go to the treatment facility and are treated. In a separated system only the sewage is treated, and stormwater is never treated, it goes into groundwater or is piped from the streets directly to the river. This can cause problems. When rain runs through the urban area it picks up whatever is on the road, big storms mean big debris gets picked up. This often results in trash, oil, fertilizer, and other harmful substances not getting removed from the stormwater at the treatment facility, and going directly into the rivers and eventually the sound. So, in New Haven, some of the CSO's will be closed, and piping separated, but for a few of the remaining CSOs, the solution is to leave them, but to make the weirs adjustable. This lets the Pollution Control Authority maximize what gets treated in a light storm, but minimize flooding and sewage overflow in a big storm. The sites that are not adjustable will be calibrated and monitored and adjusted manually as needed. Since access is a problem, designs have been created by engineers to allow GNHWPCA to park a vehicle and have access from the side rather than from through the street (in the middle of a busy intersection). In some cases, this requires removing trees. The city requires for every inch of diameter of tree removed, a replacement of an inch must be made. For example, if you remove two 6" diameter trees, you can replace them with the same size, or you can replace them with six 2" diameter trees, or 12 one-inch trees. (The Greater 2017)

"The ultimate objective is to provide measures necessary to achieve zero discharge from all CSO outfalls during the 2-year, 6-hour storm by 2040" (The Greater 2017) This means that for a large storm, one that occurs statistically every 2 years, and lasts for approximately 6 hours, there should be zero overflow from CSOs. They have used sophisticated modelling and an average of annual rain events, and have adjusted for the changing climate. The estimates for 2 year 6 hour storm as of 2016 are slightly elevated compared to their 2014 analysis. The basic plan is to raise existing weirs so they can change the height of the barrier wall inside the pipe to maximize storage capacity without causing flooding to any public or private properties. The weirs cannot be too high, or water will pressurize in the pipe, or backup into the underground pipes then back to the stormwater grates or the drains in buildings. This sort of adjustment requires access, and several of the CSO pipes are underneath roads, for example, Legion Ave, Ella T. Grasso Boulevard and Fitch Street. These pipes were originally constructed above ground, fill was put over the top of them, and then roadways. Now very busy intersections, it is inconvenient, unsafe, and expensive to routinely assess, monitor and upkeep these structures because access is so difficult. Weekly or biweekly monitoring is a safety risk to engineers, traffic cops, drivers and a significant traffic hindrance. (The Greater 2017)

#### Coastal Flooding

Problems with climate will be exacerbated on the coasts, where rising sea levels will infiltrate city infrastructure more rapidly than in non-coastal areas. New Haven already has problems with coastal flooding, and has seen massive damage during storm surges from hurricanes Irene and Sandy. Climate change models predict an increase of at least 40% of rain by 2050, and 60% of that increase is predicted to happen during more intense storms. So storm surges and flooding during storms is predicted to worsen as global temperatures rise. (US Department 2017)

### Government Organizations

#### The United States Geological Survey (USGS)

The United States Geological Survey (USGS) monitors many bodies of water at specific sites of interest. These sites are used to measure various important pieces of data about the water, like flow of water for water

budgets, to monitor the height of water bodies. Some of these sites have various measurement probes installed with the flow meters.  Data is taken automatically at regular intervals, such as optical clarity, pH, dissolved oxygen (DO), some are visited regularly by analysts and have measurements done on site by people maintaining the equipment and using the data.  Often these are government employees, or partners of the USGS, like a grad student or postdoc from a research team involved in a study with the USGS. The information from these sites is published online in raw form, and can be studied by environmentalists, researchers, and government organizations concerned with the quality of water and management of water in an area. (US Geological 2017)

There are no active USGS sites within the city of New Haven, CT.  But the following two USGS sites are the closest, and are within the range of free school buses from New Haven for classroom field trips:

- USGS 01196620 MILL RIVER NEAR HAMDEN, CT
- USGS 01196530 QUINNIPIAC RIVER AT NORTH HAVEN, CT

These three are nearby, but outside the range of free buses in 2017.

- USGS 01196561 MUDDY RIVER NEAR EAST WALLINGFORD, CT
- USGS 01196500 QUINNIPIAC RIVER AT WALLINGFORD, CT
- USGS 01208736 NAUGATUCK R AT ANSONIA, CT

These sites are monitored and checked biweekly by local researchers and volunteers, if you would like to take a class, make sure you get an analyst to go with you, the equipment should only be handled by them, as it is expensive and delicate. (US Geological 2017)

#### Other Government Organizations: Federal

There are many other government organizations at the federal, state and local levels that have a hand or a stake in the local watersheds.  Rangers from the US Fish &Wildlife Service give educational talks and host streamwalks and riverwalks in addition to monitoring use of the local recreational areas.  They have also done studies and prepared reports for remediation of the local watersheds, including a 2013 proposal to remove the Lily Pond Dam.  The Environmental Protection Agency collects and reports on the CSOs, and oversees adherence to federal Clean Water Act.  The National Science Foundation (NSF) provides funding in the form of grants that support many other organizations that study the watersheds in New Haven, including, but not limited to: local university professors, and the USGS.  National Oceanic and Atmospheric Agency (NOAA) and National Aeronautics and Space Administration (NASA) have recently combined resources and launched a joint satellite that looks only at weather and climate on the Earth.  It has many new pictures and measurements, including rainfall, and inland and coastal flooding data. (US Department 2017)

#### Other Government Organizations: State

Connecticut Department of Energy and Environmental Protection (CTDEEP) oversees state parks, recreational permits and licenses, watersheds, pollution management, energy policies, and offers outreach in conservation, climate change, recycling and clean air and water.  (DEEP 2017)

#### Other Government Organizations: Municipal

City of New Haven s Office of Sustainability, Parks and Recreation, Public Works are all involved with the watersheds in New Haven.  The Sustainability office is small but is working on several initiatives in

environmental outreach.  Their staff that are well informed as to what's going on in the city, and where resources and contacts for classroom projects, guest speakers, field trips are.  Parks and Recreation oversees all of the parks in New Haven, and is constantly looking for volunteers to help maintain the parks. Public Works doesn't take volunteers, but they oversee road salting, refuse and recycling pickup, which are vital to stormwater infrastructure, and the health of the watershed.  They also have a digital communication platform, SeeClickFix, a way citizens can report debris, dumping, pollution, and damaged stormwater infrastructure to the city, and they will take care of it.  (City 2017)

**Non-Government Organizations in New Haven**

The following organizations have invested time and resources into watersheds in the New Haven area, either through funding programs holding events, or engaging the community.  Some do educational outreach, like advocating for walking pathways by river banks, working with parks and rec by constructing parks or increasing wildlife habitats, holding festivals, providing spaces for other organizations to have meetings. These community partners are doing work in the New Haven Watershed, and have resources and contacts that may be helpful to local teachers: Save The Sound, Connecticut Land Trust (at UCONN), Urban Oases Advisory Board, Audubon Connecticut, 4-H, West River Watershed Coalition, Quinnipiac Watershed Association, Neighborhood Housing Services, Sierra Club, Yale School of Forestry, Common Ground (local agricultural charter school).

#### Save the Sound

Save the Sound has collaborated with and led partnerships with Edgewood School to make rain gardens, has been involved with planning with the New Haven City Plan Department for the Mill River Neighborhood Improvement Plan, and projects with the New Haven Engineering Department, and Neighborhood Housing Services. (CT Fund 2017)

#### Neighborhood Housing Services

This is an organization that deserves a more in depth look.  Their mission is to provide the community with resources to improve their quality of life through responsible and high quality home ownership.  They aim to increase the percentage of owner occupants in New Haven, and to encourage and help existing owners to take good care of their home and property through education, access to programs and funding.  They offer seminars on energy and water conservation, home finance, community leadership, efficient appliances, installations from windows to lighting, to insulation to rooftop gardens and rain gardens. This is a really good place for a class field trip.  They can accommodate a full class of 27 students.

## General Teaching Strategies

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**Question Formation Technique (QFT)**

One of the best ways to teach science is to have students start by asking questions.  The questions can be generated from a prompt, a news article they read, a demonstration, or their observations.  QFT is a way to hone those student questions into a product that can be used to do background research, or experimentation. Experimentation questions have to include a variable you want to test the effect of (independent variable) and

a way to measure that affect (dependent variable). Sometimes they can include a method for that measurement, or an implication of the impact. Background research questions are often open-ended and have to be split into smaller questions, phrases or keywords and names to search.

**Phenomena Based Teaching (PBT)**

Phenomena based teaching is highly effective, and works well because students are immediately engaged in an activity that is counter to what they expect. A phenomena is something interesting or unexpected that happens, and this provides an immediate response to try to explain it. The students then spend the bulk of their unit trying to tie everything they learn back to explain the original phenomena, often by way of modelling, and argumentation. Modeling helps students visualize what isn't visible, and argumentation helps because the students have to use evidence from their learning to justify their explanation. This is vital to the way science operates. Especially in today's world with ubiquitous information from nearly infinite sources, and the fake news phenomena, and ever present bias, and propaganda, sourcing credible information and data is vital.

**Problem-Based Learning (PBL)**

This is my ideal method of teaching for this unit. I want to start with a problem in the new haven watershed, and have students be inspired and driven to action to help correct the problem. Either through educating the public, advocating with a political figure, or developing and proposing a designed solution to the problem directly, or implementing a plan to change self-habits, actually solving a real problem in your immediate surroundings is an empowering thing. This is especially important for disenfranchised populations, like the bulk of the students in my school, at least when it comes to science. Since the bulk of the content in this class is tied to the human impact on climate change, it only makes sense that we should be figuring out ways to undo that impact. And starting with students in high school, who will soon be young adults, makes a lot of sense, not just for their education, and career, and opportunities to use a STEM career to get out of their economic predicament, but to help get the Earth out of its environmental predicament.

**Inquiry Based Learning**

Inquiry based learning, doing labs, analyzing data to write conclusions, and asking questions based on data trends and discrepancies is a very effective way to teach science, it dovetails nicely with any science content. And allows students to justify taking measurement in class, and putting them into use, hopefully to change their thinking and prior knowledge.

**The 5E Model:**

Engage, Explore, Explain, Elaborate, and Evaluate. This method of teaching has been proven in research studies to break down educational barriers in underperforming demographics and to increase student engagement in science. It works really well because you start with something interesting (Engage), you dive in deep and try to get as much understanding of that thing as you can (Explore). Then you use what you've gathered to try to Explain what's going on. You then dive deeper, and get more details (Elaborate), and lastly you reflect upon the process, what you've learned, what questions you still have, and what your next steps are (Evaluate).

**Formative Assessment Probes**

Probes are a great way to elicit student understanding, prior knowledge and thinking, and help students start meaningful conversations about science.  In the absence of data, students will use anecdotes to justify their current thinking.  This allows them to begin the process of argumentation, and to start debating, and questioning each other's thinking.  It builds skepticism, and that creates an intellectual impeditive for data. Once that exists, getting students to do research or design experiment is easy, because they want to prove they are right.

## Classroom Activities

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I have decided to incorporate all of best parts of these methods.  My unit design starts by taking something that happens that is unexpected about the New Haven watershed, (unsafe for swimming signs, brown water in the sound, Man-o-war jellyfish in the sound in 2006).  I will then give the students a formative assessment probe with a handful of explanations for the phenomena, and see which one they agree with.  It will be centered on a new haven watershed problem (PBL).  We will then discuss their choices in class (Engage), give their anecdotes in a class discussion, and start asking questions.  We will then use QFT to hone the questions for background research (Explore). Students will evaluate credibility of sources, synthesize information, and share their findings with the class (Explain). We will then compare our research to our questions, and see if they are all answered.  Any that are not answered, or any pieces that don't have explanations, we will try to see if we can measure something about the river to answer those questions. We will then plan out our procedures for those measurements, research how to take and analyze those measurements, and develop a method of data organization (Elaborate). Students will write conclusions from our data, based on the trends, outliers, procedural problems, human errors and systemic errors (Evaluate).  Then they will decide what to do with this new knowledge. They have to actually try to solve the problem by community engagement, political action, or engineering a design.

**Lessons**

1. Re-evaluate & Model: Students will have to re-evaluate their original assessment of the water samples from day Students will be assigned one sample to explain, and have to draw pictures of what is in the water sample, and explain how it got there, whether it is good or bad, high or low, and justify.
2. Stream walk field trip: We will walk from a drinking water source to a tidal estuary, along a river in our city. Start: Lake Whitney, just above Eli Whitney Museum, down Whitney Ave, past the dam and plunge pool, along the river, to the canoe launch on Orange St.  May combine with sampling, if time permits. Students will take photos, and notes, and write questions.
3. Tour of a local facility: either a wastewater or drinking water treatment plant. Students will have to bring a list of questions from their research, and their question lists.
4. Water Conservation Seminar: Students will be introduced to rain barrels, swales, rain gardens, rooftop gardens, and many ways to conserve water in their home.  Combination of stations and lecture.
5. Water Testing Lab: Students will look at their water samples under a microscope, to identify macroinvertebrates, larvae, insects, and algae. Students will compile the field testing with their microscope observations, and compare to data from regional water authority testing at the same site. Enrichment & extension: students can plate samples and try to grow coliform bacteria.  Students will hand in conclusions, data and error analysis.  Students will be allowed to test and observe original samples (though because they have sat, some test may no longer be valid).

6. Sampling Field Trip: students will be taking samples from a local stream or river, in a location that is low in coliform bacteria, away from a sewer overflow site. Students will use LaMotte water quality testing in the field to do dissolved oxygen, nitrogen, pH, temp, and salinity testing.
7. Students will then be told what the other activities in the unit will be, and will be given a list of topics and projects they would like to choose from. They will have to choose one project, or design their own by the end of the unit. They should also choose a new topic they are curious about to do further research about.
8. Mini-report: students are expected to share out what they found out, and explain if their new knowledge changes what they originally thought was in the water samples.
9. Research: Students will have library time to do background research on their river. They are expected to find one problem, one proposed solution for the river they chose. They should also try to answer at least 5 of their own questions.
10. Question modifying: Students can modify or add to their question list. Then they will go through QFT to hone their questions down into research and experiment questions. They will choose one river to research from the new haven watershed.
11. Reading: Students will read an article about a local watershed, probably the Mill River since there are local newspaper articles readily available about the Mill River Plan.
12. Questions: Students will write questions about the different bodies of water and what they observe about the samples, and what others used as justifications for their choices.
13. Formative Assessment Probe: I will have them complete a formative assessment probe trying to explain what is in the water. It will have several points of view (POV), all with common misconceptions but one. Students will have to choose which POV they think is correct. The class will be polled, and students will be asked if they would like to share who they voted for and why. Students will purposefully not be told which is correct. The purpose is to get them to reflect and change their own thinking based on the data they take in the unit. Metacognition is the most effective way to build logical scientific reasoning and capacity.
14. Phenomena: Show students samples of water from various bodies of water in new haven, including drinking water from their tap, Lake Whitney, Long Island Sound, West River, Quinnipiac River, and Mill River. Ask the students to make observations of each sample then to attempt to label each sample with where it is from and justify their choices.
15. Environmental Justice Project: Students will pick one thing they can do to improve the quality of the water in New Haven. Any water: drinking, waste, ground, streams, rivers, lakes. They need to actually get involved, go to a meeting, make a poster, plant a rain garden, volunteer at a clean-up. They then need to Instagram or tweet their contribution. Selfies encouraged. Lastly, share their experience in a written reflection, optional share out in a circle in class.
16. Possible Activities for a Classroom Lesson or Student Project:
    - Plant new rain gardens
    - Maintain existing community rain gardens
    - Plant trees and plants in the riparian zones
    - Volunteer to help the NH park service on cleanup days
    - Cleanup after homeless encampments
    - Cleanup after dogs
    - Publicize and attend the west river water festival in July
    - Monitor the measurements of the river
    - Art installations that highlight watershed problems
    - Public Relations campaign on social media to raise awareness

- Attend and speak up at a city council meeting.
- Write a letter to the editor of a local paper concerning CSOs
- Start a phone call campaign or a letter writing campaign to a political representative
- Write a letter to NOAA, NASA, the EPA, or the NSF asking them not to cut funding to programs for watersheds and watershed educational outreach.

## Classroom Materials

- LaMotte test kits: dissolved oxygen, nitrogen-nitrates
- pH test strips, thermocouples, sampling bottles/syringes, bins, gloves
- big paper and markers for modelling
- microscopes, slides, pipettes, magnifying glasses
- petri dishes, agar, fridge, wire loop, Bunsen burner, incubator, autoclave or bleach
- library computer time, websites, sample questions
- Formative Assessment Probe to model from
- Question Formation Technique framework
- map for local stream walk, transportation to stream walk, chaperones
- local facility to tour, more chaperones
- community partners for help/resources/guest speakers

## Readings for Students

Bass, Paul. "Mill River Revival Mapped Out." New Haven Independent. December 04, 2013. Accessed July 5, 2017. http://www.newhavenindependent.org/index.php/archives/entry/mill_river_revival_mapped_out/.

Overview of the plan to revitalize the Mill River neighborhood. Purpose is to change the land use in that area, to attract new businesses which will increase taxes, promote cleanup of Brownfield sites, and improve the area. An appropriate read for high school students in civics or science.

Gellman, Lucy. "Mill River District Plan Moves Forward." New Haven Independent. July 02, 2014. Accessed July 15, 2017. http://www.newhavenindependent.org/index.php/archives/entry/mill_river_district_initiative_moves_forward/.

Local paper reports on the update of the Mill River Plan as presented during a city council meeting. An appropriate read for high school students in Science or History classes.

O'Leary, Mary. "Grant will help develop trail along Mill River in New Haven." New Haven Register. June 29, 2016. Accessed July 5, 2017. http://www.nhregister.com/environment-and-nature/20160628/grant-will-help-develop-trail-along-mill-river-in-new-haven.

Overview of improvements to the Mill River bank including a walkway and potential birding sites. Appropriate read for high school students in civics and science.

Nakamura, Jacqueline, Mary Nguyen, and Christopher Zappi. "A People's Guide to Infrastructure in New Haven." A Peoples Guide to

Infrastructure in New Haven. 2014. Accessed June 15, 2017. https://campuspress.yale.edu/infrastructurenewhaven/waste-and-water/.

An overview of infrastructure in New Haven.  Includes a historical perspective, but is still current enough to be relevant in 2017. All sources cited for follow-up research. Text is written at a high level for high school students, but graphics help.  Appropriate for high school students in history, civics, and science classes to do background research on New Haven infrastructure.

US Department of Commerce, National Oceanic and Atmospheric Administration. "North Carolina Sentinel Site Cooperative." Oceans and Coasts. July 25, 2017. Accessed July 25, 2017. https://oceanservice.noaa.gov/sentinelsites/north-carolina/welcome.html.

Overview of potential coastal flooding due to climate change. Has a model of coastal flooding that satisfies one of the NGSS standards for computer simulations.

## Annotated Bibliography for Teachers

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Bertine, K. K., and M. F. Mendeck. "Industrialization of New Haven, Conn., as recorded in reservoir sediments." *Environ. Sci. Technol.* 12, no. 2 (February 1978): 201-07. Accessed July 22, 2017. Doi: 10.1021/es60138a002.

Explains how cores of anoxic sediment from local lakes can be used to study the history of industrialization in New Haven, CT based on the types, amounts and location of pollutants found. Compares two lakes for Ag, Cd, C, Cu, Ni, Pb, V and Zn, but especially C, Cu and Pb.

Bukaveckas, P. A. “Rivers." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 721-731

Nutrient cycling, Floodplains, macroinvertebrate populations.

Caraco, N. “Phosphorus." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 73-78

Phosphorus as a limiting reagent to photosynthesis, and usefulness as a control mechanism for eutrophication, anoxic conditions, increasing dissolved oxygen and biota. Sources of phosphorus, soaps, detergents, industry point source control.

City of New Haven. "New Haven Mill River Planning Initiative." City of New Haven Economic Development. Accessed July 5, 2017. http://www.cityofnewhaven.com/economicdevelopment/Projects/readmore.asp?ID=%7B12624DBD-6339-4117-959D-EA76A63765B5%7D.

Links to the meeting notes, reports, and planning documents to the Mill River improvements endorsed by the city.

"Coasts Region | NOAA Climate.Gov". 2017. *Climate.Gov* . https://www.climate.gov/teaching/national-climate-assessment-resources-educators/coasts-region.

"CT Fund for the Environment & Save the Sound." CT Fund for the Environment & Save the Sound. Accessed July 25, 2017. http://www.ctenvironment.org/.

Department of Energy and Environmental Protection. DEEP: Watershed Management Plans and Documents. June 7, 2017. Accessed July 3, 2017. http://www.ct.gov/deep/cwp/view.asp?a=2719&q=379296&deepNav_GID=1654.

List of current watershed management plans approved for implementation in the state of CT.

EPA. July 25, 2017. Accessed July 25, 2017. https://www.epa.gov/.

Evans, John, and Howard Perlman. "The Water Cycle." Chart. The Water Cycle - USGS Water Science School. December 15, 2016. Accessed July 22, 2017. https://water.usgs.gov/edu/watercycle.html.

Best Water cycle chart on the internet. Website has several versions appropriate for all ages, and in many languages, interactive and static. Other resources on this website are extremely useful for learning about and teaching the water cycle.

Fisher, S.G. and R.A. Sponseller “Streams and Rivers as Ecosystems." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 491-498

Boundaries of streams and rivers, Riparian zones, justification for planting trees in riparian zone on West River Memorial Park.

Gilmour, C. and G. Reidel. “Biogeochemistry of Trace Metals and Metalloids." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009.7-15

Mercury pollution, pollutants from coal-fired power plants, point source and non-point source pollution.

"The Greater New Haven Water Pollution Control Authority." Home. 2017. Accessed July 25, 2017. http://gnhwpca.com/.

Comprehensive website for the wastewater treatment facility, and sewer system in the New Haven area. Has information about ordinances, policies, bill payment, emergency contact info, educational outreach, community outreach, services, data, and reports.

Lewis, W.M. “Lakes as Ecosystems." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 431-440

Lake ecosystems, abiotic and biotic factors, lake management.

Meybeck, M. “Fluvial Export.” In *Encyclopedia of Inland Waters.* Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 668-680.

Stream and river flux, dissolved substrate transport, sediment transport, flow rate.

Myers, J.L. “Urban Aquatic Ecosystems." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 367-377

Urban stressors to watersheds: human population, vegetation, concrete structures, sediment, pollutants, runoff, floods, wastewater, infiltration, wastewater treatment chemicals, increase nitrogen, increase phosphorus, increase coliform bacteria, ions, dissolved oxygen, pharmaceuticals, birds, amphibians, non-native species, light algae.

Narasimhan, T.N. “Hydrological cycle and Water Budgets." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 714-720

Water cycle, accounting for all the inflow and outflow and storage for a body of water.  Explains and is an excellent example of NGSS standard on coevolution of life and environment (HS-ESS2-7). Excellent water cycle diagram of an individual river.

NGSS Lead States.  Next Generation Science Standards: For States, By States (High School Physical Science).  2013.

Prarie, Y.T. and J.J. Cole. “Carbon Unifying Currency." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009.743-746

Redfield Ratio, Carbon cycle and water cycle link.

"Quinnipiac River Watershed Association (QRWA) in Connecticut (CT)." Quinnipiac River Watershed Association QRWA News. 2017. Accessed July 25, 2017. http://www.qrwa.org/.

"Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows." EPA. August 2004. Accessed June 20, 2017. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30006O5F.TXT.

A comprehensive report of all the sewer overflows in the USA as of 2004. A thorough report by the EPA to Congress. It includes sewer overflow permits in all states, technologies, impacts, stakeholders, monitoring and approaches to change. Includes a record of all outbreaks of pathogens from exposure to contaminated drinking water, recreational water, shellfish and fish, and a list of states and sites where sewer overflow is a mile upstream or less from a drinking water intake site (affected states: ME, NY, PA, WV, KY, IN, OH- see table on page F-7 for more info).

SCCRWA. "Education at the Regional Water Authority." Education. Accessed July 25, 2017. http://www.rwater.com/products-services/education.

An overview of teaching resources offered by RWA Whitney Water Center, including a registration form for loan boxes and contact info.

SCCRWA. "Studies and Reports." Studies and Reports. Accessed June 20, 2017. http://www.rwater.com/conservation-stewardship/whitney-environmental-management-plan/studies-and-reports.

RWA Comprehensive list of the water quality studies they have done of Upper Lake Whitney, and the Mill River downstream of Lake Whitney. Purpose is to monitor the effects of the Whitney Water Treatment Facility. It includes 10 years (5 pre, and 5 post) of bioassessments, vegetation, and continued water quality monitoring. Annual reports include raw data as well as reports with discussions, graphs, conclusions and some include presentation materials.

"U.S. Geological Survey." USGS.gov | Science for a changing world. Accessed July 10, 2017. https://www.usgs.gov/.

"The Watershed Fund." The Watershed Fund. 2017. Accessed July 14, 2017. http://thewatershedfund.org/.

RWA document. Details about how the watershed fund works, who runs it, where funding comes from, and how to donate.

*West River Watershed Management Plan* . 2017. Ebook. New Haven, CT: Fuss & O'Neill. http://www.ct.gov/deep/lib/deep/water/watershed_management/wm_plans/west/westriver_wbplan.pdf.

Detailed explanation of West River Watershed Coalition Goals and objectives including building community capacity, outreach to businesses, homeowners, pollution remediation, funding, and future projects. (Education and Youth opportunities are on page 79)

Wohl, E. "Streams." In *Encyclopedia of Inland Waters* . Edited by G. E. Likens. 1st ed. Millbrook, NY: Elsevier Inc., 2009. 756-765.

Stream Order, Turbidity, Flow Rate.

# Appendix

New Haven District Standards: (state, national & proposed national): New Haven Public Schools requires science teachers to use Next Generation Science Standards which have been recently approved by the state, with a special emphasis on inquiry, and the 5E model

All Earth Science Standards Applicable to This Unit

- HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
- HS-ESS2-2 Earth's Systems: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
- HS-ESS2-4 Earth's Systems: Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- HS-ESS2-5 Earth's Systems: Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.
- HS-ESS2-6 Earth's Systems: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- HS-ESS2-7 Earth's Systems: Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
- HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- HS-ESS3-3 Earth and Human Activity: Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
- HS-ESS3-4 Earth and Human Activity: Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.
- HS-ESS3-5 Earth and Human Activity: Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- HS-ESS3-6 Earth and Human Activity: Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. ( NGSS 2013)