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Watersheds and the Cycles of Matter

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Introduction

Watersheds are areas of land that drains rain, water, or snow into one location such as a stream, lake or wetland. Watersheds consist of a number of interconnected parts that rely and function together to maintain the health of the water body. A watershed is made up with six main components including the catchment area which includes all the area within the ridgeline, the continuous ridgeline which is the boundary of the watershed, the stream network which drains and collects water for the watershed from the primary water body and tributaries, the outlet which is the lowest point of the watershed, the groundwater aquifer which is the water stored in the soil and rock units, and precipitation acting as the main water source. In order to understand watersheds and the processes there within, one must have a grasp of biology and chemistry.

This is especially true when discussing the plants and wildlife that inhabit the watersheds. Ultimately, the goal is to educate the students about the environment they live in and discuss their impact on the functions of watersheds, that effect being either positive or negative. In order for students to comprehend such ides, they first will need to be made aware of what actions sustain and hinder a watershed and the actions that can be taken to restore a watershed back to a healthy state.

In order to understand how watersheds behave and the impact they can have on the environment and how our actions affect them, one needs to understand how water, carbon, phosphorous, and nitrogen are used and recycled. We will first breakdown the idea of the watershed into the cycles that make it up. From there, we will look at the environmental impact that each cycle has and how human involvement can affect the life forms that live within the cycles. Once the students develop a basic understanding of how watersheds function, I will introduce some major watersheds, the Connecticut River and Long Island Sound watersheds, and go in-depth on how these watersheds effect our environment. Finally, we will discuss preservation of the watershed. Specifically, the laws that are in place to protect them and the actions we, as a society, can take to help ensure the long term survival of watersheds.

Introduction to watersheds

A watershed is an area of land that combines all the water running under it and draining off of it into a body of water. Watersheds combine with other watersheds to form a network of rivers and streams that progressively

drain into larger systems.

The way the natural landscape is designed or the topography determines the way and the means of the flow of water in a region. A chain of elevated land of various sizes or ridge tops determines the outer bounds of the watershed. A good example of how a watershed looks and behaves is a concave lens in the rain. Rain would hit different parts of the concave lens, but, in the end, all the rain would pool at the center of the concave lens. Any rain that didn't hit the concave lens would fall to the ground. The concave lens is like a watershed; it collects and is affected by everything that falls into it.

Streams within the watershed combine and collect into a main body of water. The main body of waters can be a river, lake, or ocean. The beginnings of a water source are called headwaters. The area where headwaters seemingly join other waterways is called the confluence, and the endpoint of the waterways that join into the main body of water is called the mouth .

The concave lens example is an over-simplification of the watershed process. The water does not simply travel from the soil to the watershed with no steps in-between. Water is lost through various natural processes like the absorption and transpiration by plants, evaporation and consumption by humans (consumption by humans does not mean it is lost from the watershed, as the humans are still a part of the watershed and will most likely expel the water as waste within the same watershed. That is to say, the water consumed is only considered lost if the humans transport the water out of the watershed). The relative importance of these factors depends on the area in which the rain falls; the desert-like environment of Arizona will react differently than the rain-heavy Washington.

One of the reasons watersheds are of great importance to scholars is that they affect the quality and amount of flow through a stream or river at a given point. For example, as the Connecticut River empties into the Long Island Sound, it is carrying water from its entire watershed, one of the largest watersheds in the Northeast region. It provides water and interacts with about 30% of the land mass of Vermont and New Hampshire. Some watersheds are highly impacted by humans. For instance, extensive agricultural development throughout the Mississippi River watershed has led to problems with its water quality. As we will discover, phosphorus and nitrogen have the potential to over stimulate plants and have adverse effects of the surrounding environment. For example, the resulting algal blooms from nitrogen and phosphorus pollution can deplete oxygen reserves dissolved in the water. As a result, this prevents aquatic life from growing. Situations like these are call dead zones and they threaten flourishing ecosystems. The United Nation estimates that there are about 150 dead zones in the world as a result of agricultural development.

Watersheds and the water cycle: nitrogen

Nitrogen is an essential nutrient for plants and animals as it is used in the formation of proteins and other vital molecules. Nitrogen is found in a variety of forms throughout the environment. Even though nitrogen is abundant resource with 79% of the air we breathe being nitrogen, only a few forms can be used by plants effectively. Many forms of nitrogen have the ability to move from the ground to rivers and streams because of their solubility. It should be noted that with the invention of the combustion engine and the rampant use of man-made fertilizers, nitrogen is being brought to the environment unnaturally. Although nitrogen gas makes up 79% of our air, this nitrogen cannot be used by plants. It must first be converted to a usable form through a process called nitrogen fixation—done by interacting with particular bacteria in ground, certain types of algae in water, and, most interestingly, lightning strikes.

Nitrogen has three forms that can either already be used by plants or can be converted to a useable form

easily. The first such form is nitrate (NO_3), which is the most common form of inorganic nitrogen found in water. Nitrate has the ability to move easily through the ground due to its solubility and enter different bodies of water. The second form is ammonia (NH_3), which is formed when organic nitrogen is broken down by bacteria. Plants prefer to use ammonia over nitrate, but ammonia is typically less abundant in natural waters. The third form of nitrogen is dissolved organic nitrogen. Simple forms, like amino acids, can be used directly by plants, while more complex forms require bacteria to convert it to ammonia before it can be used. Most studies on nitrogen loss from ecosystems measure only the inorganic forms of nitrogen, ignoring the dissolved organic forms.

In lakes, rivers, and streams, having too little nitrogen can hinder the growth rate of plants. When there is an excess of nitrogen introduced into the water system, however, it can over fertilize the aquatic plants in the water. When these plants die, bacteria will take up the dissolved oxygen in the water as they decompose the plant matter. As a result of the lowered oxygen levels, fish and other organisms dependent on the oxygen can die off.

They are health concerns when dealing with nitrogen and its various forms. High concentrations of some forms of inorganic nitrogen are poisonous to humans or to aquatic organisms. Nitrate can very dangerous if ingested in large amounts. Concentrations of nitrate in drinking water greater than 10 mg/liter can be harmful to babies and cause blue baby syndrome, which means the babies, will have a decreased capacity for oxygen in their blood. Nitrite can also be toxic to fish, such as rainbow trout, at concentrations of about 4 mg/liter. Ammonia may be toxic to fish and other aquatic animals at very low concentrations, especially when the water is somewhat basic (high pH) and at warm water temperatures.

Another major concern of nitrogen is its involvement in acid rain. There was a study done in Maine concerning nitrogen that illustrates the possible dangers of the over abundance of the element. For about 25 years, Maine scientists have been spreading fertilizer on a forested watershed east of the town of Aurora. Not to make the forest in the Bear Brook Watershed grow faster – though this fertilizer contains nitrogen, the most common limiting nutrient in our forests. Instead, the forest where this fertilizer spreading occurs is a research watershed where, in the late 1980s, scientists began studying the effects of acid rain. Acid rain is created by the burning of fossil fuels in a combustion engine which adds acid rain precursors to the atmosphere. These nitrogen and sulfur precursors are washed out of the atmosphere and deposited on watersheds - often watersheds remote from where the fossil fuels were burned. When acid rain brings excess sulfur and nitrogen to a watershed, lakes and streams become more acidic; and everything on the land, from the smallest soil organisms to largest trees, become stressed.

In the 1980s, scientists determined that sulfur was the major acidifying compound in acid rain and, as a result, implementation of government laws and regulations in the 1990s reduced the amount of sulfur coming from power plants, and therefore raining down on watersheds. However, nitrogen levels in acid rain have not been reduced – partly because there are more sources of nitrogen than sulfur, and partly because nitrogen was not targeted for substantial reduction by those laws and regulations. Nitrogen is usually a limiting nutrient for plants; historically this has been particularly true in Northeastern forests that have survived with very limited amounts of nitrogen. And yet, additional nitrogen in a watershed can acidify streams and lakes without being any less limiting to plant growth.

Watersheds and the water cycle: phosphorous

Phosphorus is an important plant nutrient that occurs in different forms throughout the environment. Excess phosphorus in aquatic systems can lead to over-fertilization in a lake or stream. This over fertilization, similar

to the effects of the overabundance of nitrogen, can result in an overabundance of aquatic plants which in turn can deplete oxygen from the water through the decay process.

Phosphorus changes forms under a number of different conditions. For example, orthophosphate readily combines with different minerals and metals in the soil and in water, such as calcium or aluminum. This creates a solid form that is no longer available for plant use. Therefore, phosphorus that plants can utilize may be very scarce in natural waters. Because of this, and the high demand plants have for it, phosphorus is often the nutrient that limits plant growth in streams and lakes, even though there may be relatively high concentrations of total phosphorus in the water. Although phosphorus in natural waters is not toxic to humans or other animals, it may still have a significant impact on the living organisms in a lake or stream. With the overabundance of phosphorous comes the exaggerated growth of aquatic plants. Too many aquatic plants in a stream or lake can cause various problems. When aquatic plants die, the natural decaying process consumes oxygen that is dissolved in the water. As mentioned earlier, an overabundance of dead plants may use up oxygen faster than it can be replenished. When this occurs, oxygen concentrations may drop to dangerous levels for fish and other aquatic animals. As a result, fish deaths become increasingly more common in waters that are over-enriched with phosphorus and other nutrients. Other serious problems can occur if the phosphorous levels in a watershed or body of water are not regulated. A few examples are:

- Large attached plants in shallow areas of lakes can entangle boaters and swimmers.
- Blooms of microscopic algae can make the water cloudy and unsightly.
- Certain types of microscopic algae can be toxic if they reach high concentrations. Animals, such as wildlife and domesticated pets and livestock, can become gravely ill from consuming the water.

Reducing phosphorus concentrations in our waters requires actions by almost everyone in the watershed. Actions include reducing runoff and erosion from roads, construction sites and stream banks, lower rates of fertilizer use, proper maintenance of septic tanks, and eliminating runoff of animal wastes into water bodies. Treatment for phosphorus removal in municipal wastewater facilities may also be required in some areas.

Connecticut River watershed

The Connecticut River Watershed is the largest river ecosystem in New England at 410 miles long, encompassing approximately 11,000 square miles and spanning over four states, Vermont, New Hampshire, Massachusetts, and Connecticut. It is also the source of 70% of Long Island Sound’s fresh water. The Connecticut River drains 4.5 million acres, or 7,000 square miles, of Massachusetts, Connecticut, New Hampshire and Vermont. This amounts to 63% of the whole four-state watershed. 41% of the total area of Vermont is directly affected by the watershed, while only 33% of New Hampshire’s land is affected. The lands surrounding the Connecticut River watershed include urban areas as well as thick wilderness. In terms of people, two million people call the area around this watershed home.

The Connecticut River starts in Quebec, Canada. The river then travels through both Vermont and New Hampshire before entering Massachusetts through the Town of Northfield. Connecticut is its next stop and it enters Connecticut through the Towns of Agawam and Longmeadow. It empties into Long Island Sound at Old Saybrook, CT.

The watershed supports wildlife including black bears, bobcat, moose, beavers, trout and shad. Many endangered species also call the Connecticut Watershed home, which include the American Bald Eagle, Peregrine Falcon, and Puritan Tiger Beetle.

Before the 1972 Clean Water Act, the Connecticut River was heavily polluted by farm waste and contaminants and, at one time, was known as “the nation’s most beautifully landscaped sewer (Mullens, 2003).” The cleanup of this river resulted in less pollution being carried to The Sound and has allowed the river to again be used for recreational use.

Long Island Sound watershed

The Long Island Sound watershed comprises all the land and water area that feeds into the Sound from Connecticut, New York, Massachusetts, Rhode Island, Vermont, New Hampshire, and Canada. The Long Island Sound watershed is comprised of nine major watersheds and numerous smaller ones.

The largest of these major watersheds is the Connecticut River watershed, which was discussed earlier. The Housatonic, East and Thames River watersheds add over 3,500 square miles of watershed. A good number of creeks and small streams and rivers empty into the Sound. Also, there is an area between the coast and the moraine of the North Shore that flows into the Sound. This adds another 210 square miles to the Sound watershed.

Long Island Sound was originally formed during the Ice Age through a series of events during the last Ice Age. Geologists estimate that the last Ice Age began 85,000 years ago and lasted for more than 60,000 years. Glaciers which originated in northern Canada moved south to what is now Connecticut and Long Island Sound. The advancing ice radically altered the landscape. The sea levels were approximately 450 feet lower than they are today due to the water frozen in the ice sheet. Dry land extended several hundred miles east of the present shoreline.

Today Long Island Sound is a body of salt water bounded on the north by Connecticut and the south by Long Island, New York. The eastern end of the sound is connected with the Atlantic Ocean by Block Island Sound and Gardiners Bay. On the western end the East River connects the sound with New York Bay. Long Island Sound is 110 miles long, 21 miles wide and covers 1299 square miles. In addition, about 9 million people live in the Long Island Sound watershed. These people are affected by the amount of waste water and material from the connecting watersheds and river, the Connecticut and East River.

There is a complex system of bays, estuaries and marshland that contribute to the quality of water in the Sound. This delicate balance is often upset by human activity due to commercial, recreational, and individual usage.

The coastal environments represent a highly productive and unique ecosystem with a diverse array of living creatures. Many types of wildlife live on shores and in the watershed. Wetlands are breeding areas for wildlife and help to filter pollutants from land runoff.

Watershed impact on environment and humans

Watersheds have the ability to sustain a high quality of life. According to the Environmental Protection Agency, more than $ 450 billion in foods, fiber, manufactured goods and tourism depend on clean, healthy watersheds. For this reason, that is why it is so important to protect and conserve our watersheds.

Protecting the watersheds entails protecting a lake, river, or stream by managing the entire watershed that drains into it. In order to have a clean and healthy watershed, it is required to have a well-informed public and environmentally conscious political leaders to make the right decisions and preserve the health of the

environment, the economy, and the people.

- Human Health: A healthy watershed provides safe drinking water, provides food, enables us to adapt to the impacts of climate change more easily by cooling the air and absorbing greenhouse gas emissions, and provides natural areas for people to keep active and recharge our batteries.
- Ecological Health: A healthy watershed conserves water, promotes stream flow, supports sustainable streams, rivers, lakes, and groundwater sources, enables healthy soil for crops and livestock, and also provides habitat for wildlife and plants.
- Economic Health: A healthy watershed produces energy and supplies water for agriculture, industry and households. Forests and wetlands help to prevent or reduce costly climate change and flooding impacts, manages drought, contributes to tourism, fisheries, forestry, agriculture and mining industries.

The pollution and pitfalls of watersheds

Earth is covered in 70% water and, unfortunately for us, 40-50% of our nation's waters are impaired. In this case, "Impaired" means that the water body cannot support one or more of its desired uses. This could mean that the water is not suitable to drink, swim in or to consume the fish that was caught there. Doing so can result in illness or, in more serious cases, death.

The leading causes of pollution in our waterways are sediments, bacteria (such as E. coli) and excess nutrients (such as nitrogen and phosphorus). As we have discussed earlier in the nitrogen and phosphorous sections, even though the nutrients have a great deal of good associated with them, the overabundance and miss use of them can result in an unhealthy watershed. For example, sediment can interfere with a fish’s ability to breathe and the presence of bacteria can be an indicator of an even larger problem in the works.

As mentioned earlier, watersheds are vitally important to our communities. Watersheds provide many of us with our drinking water supply, plus recreational opportunities and aesthetic beauty. Unfortunately, the replacement of vegetation by impervious surfaces like roads, parking lots and rooftops has a negative impact on watersheds. This increases the velocity and amount of runoff flowing into surface waters and causes erosion, turbidity and degraded wildlife habitats. Not only that, but this runoff carries pollutants such as oil, bacteria, nutrients, sediment and metals into surface waters along with it.

Watersheds directly affect water quality, whether it's for drinking or recreational use. For example, algae blooms from fertilizer runoff draining into water harm watershed health, as do mercury and lead seeping into the water supply due to pollution. As states and cities try to find new sources of uncontaminated drinking water, keeping watersheds healthy becomes increasingly vital to finding clean water.

Furthermore, unhealthy watersheds affect wildlife negatively. The polluted water supply can also harm the health of the humans that partake in the affected watershed. Unhealthy watersheds can create a snowballing effect for the aquatic species. Aquatic life quickly suffers the effects of watershed pollution, while new pollutants introduced into ecosystems alter wildlife habitats. This reduces biodiversity by eliminating some species and introducing new, invasive ones that replace the native species. That, in turn, can affect the food chain, from organisms that feed birds and animals to fish that feed humans.

According to the EPA paper "Sustaining Healthy Freshwater Ecosystems," one freshwater ecosystem can be greatly affected by another: "Far from being isolated bodies or conduits, freshwater ecosystems are tightly linked to the watersheds or catchments of which each is a part, and they are greatly influenced by human

uses or modifications of land as well as water".

The drastic increase in development around the world may be the cause of some of the problems affecting watersheds today. Development in the Amazon Basin has threatened the Amazon River dolphin with extinction. Development usually requires the removal and the altering of the natural makeup of the environment. These factors and many more affect an area's watershed dramatically. In addition, the manmade structures of building and roads have caused, what the United States Geological Survey has called, a fast lane for rainfall. Under normal circumstances, rainwater would fall and be absorbed slowly into the soil and neighboring plants. Instead, the water is streamed directly into the rivers and streams. This has a result of increasing the chances for flooding and any impurities in the rainwater will be directly added to the watershed without the natural filter of the soil.

Pollution can be divided into two categories based on its source: point-source pollution, which is pollution that can be traced to a single source, such as industrial waste, and nonpoint-source pollution, which is pollution that comes from many sources and cannot be traced to a single source such as run-off from crop land, failing septic systems, construction sites, and drainage systems. This includes pollution created in residential areas from chemicals used for lawn treatment, soaps used to wash vehicles, and yard waste, pet waste, and garbage that get into the storm sewer system.

The prevention and conservation of watersheds (watershed management)

Everyone lives in a watershed. Regardless of where you decide to live or will live, your life will be affected by watersheds. Watersheds come in a variety of sizes and shapes and can span for miles. A resident of Maine can affect a river in New York as their actions will be carried downstream to other watersheds and the coastal ocean. Therefore, pollution occurring at any part of the watershed has the potential to negatively affect the conditions and lifestyles of those farther downstream and through coastal connections.

In preserving the health of a watershed, nature plays a key role. The leaves that surround the watershed and other various plant life help absorb moisture and keep the soil structurally sound. Root masses are available to stabilize the soil and allow the moisture that comes in to be stored properly. As a result, the water can be properly filtered and released slowly into the watershed at large.

Along with nature itself, we have come up with ways to prevent watersheds from deteriorating. Several laws exist to protect watersheds. The first such law was the Watershed Protection and Flood Prevention Act in 1954. This law helped coordinate federal and state flood prevention efforts. The Act was then amended in 1972 to add the conservation of watersheds. There has been a world wide effort to protect watersheds and install programs for their conservation by The World Bank, the United Nations and other world organizations.

The Environmental Protection Agency or EPA also developed a program to help watersheds in 1996.
The watershed approach is an environmental management program that was designed to address the ever growing contamination issues that have sprung up resulting in the dwindling welfare of our watersheds. Groups in particular areas are encouraged to team up and combat the pollution and improve the environment in and around the watershed.

The previously stated laws and the efforts of government and world groups are all a part of watershed management. Watershed management refers to the process of creating and implementing plans, programs, and projects to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary. The primary purpose of watershed management is to protect,

maintain, and restore the water quality in watersheds, through community and government-funded efforts.

There are many ways the average person can prevent the pollution of local watersheds and they are as follows:

- Conserve water every day. Take shorter showers, fix leaks & turn off the water when not in use.
- Don’t pour toxic household chemicals down the drain; take them to a hazardous waste center.
- Use hardy plants that require little or no watering, fertilizers or pesticides in your yard.
- Do not over apply fertilizers. Consider using organic or slow release fertilizers instead.
- Recycle yard waste in a compost pile & use a mulching mower.
- Never pour used oil or antifreeze into the storm drain or the street.
- Pick up after your dog, and dispose of the waste in the toilet or the trash.
- Drive less—walk or bike; many pollutants in our waters come from car exhaust and car leaks.

Sample Learning Activities

The following section outlines some sample activities that can be used in the classroom during the section on watersheds and the various cycles involved. This section provides a brief overview of the activity and resources needed that are useful for supporting student learning in the topics brought out in the section.

Research a Watershed

Students when they come into the class seldom have knowledge of watersheds. Even after learning about the uses of watersheds and the overall benefits, it can still be hard for a student grasp the importance without experiencing it for themselves. For this project, the students will research local watersheds in their area. They will first use a website to locate the watershed for their place of residence. From there, they will document the wildlife that inhabit the area, the different plant life that live in the watershed, and how the houses and surrounding businesses use the watershed.

The students will get the opportunity to explore their local areas and experience how watersheds are connected to their lives.

Building your own watershed

This would be the final project for the unit on watersheds. Over the course of the unit, students would have learned a good number of vocabulary words and important concepts. In addition, they would have seen several examples of watersheds and should be able to identify parts of a watershed. The task has the students designing their own watershed, from the boundaries to the local wildlife. Along with the physical model of the watershed, the students will also be tasked with using 10 or so vocabulary terms to incorporate into their watershed and write a presentation using said words. While a large number of vocabulary words may be available, the students will only need to use a set number of the words. This will increase the likelihood of different projects.

Clean-up a Watershed

As with all of the major units in PhyChem, we aim to improve our environment by learning about the various strategies that have been implemented in the past regarding the subject matter. During the last few sections of my unit, I discussed the environmental impact of our misuse of watersheds; this includes pollution and general mismanagement. For this task, the students will be investigating in depth the different pollutants and human actions that have an adverse effect on our watersheds. They will also be researching methods to reverse the effects of their pollutants or human activity and incorporate those into their final clean up report. The students will be grouped into teams of three or four as they use the internet and other resources for their research. In addition, they will be using their model watershed to illustrate how the pollutants and human activity travel through watershed and the show how their solutions will ultimately improve the health of their watershed.

Appendix: Standards

Material in this unit can be used to cover aspects of the Next Generation Science Standard for high school regarding ecosystems and energy. Included also are standards from the English Common Core that deal with investigation, research, and the use of sources.

A few of these standards are listed below.

Next Generation Science Standards

HS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics

Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

HS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics

Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics

Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-LS2-6 Ecosystems: Interactions, Energy, and Dynamics

Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem

Common Core State Standards

ELA-Literacy.RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

ELA-Literacy.RST.11-12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

ELA-Literacy.RST.11-12.7: Integrate and evaluate multiple sources of information presented in different formats as well as in words in order to address or solve a problem.

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