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Cheers to Your Health: The Connection between Water Sources and Disease

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Introduction and Rationale

The consumption of contaminated water sources is one of the leading causes of death in many areas of the world. In the United States and other countries with a well-developed infrastructure, these deaths and illnesses are minimized due to water treatment. Even with this sanitization of the water that people access, there are still instances in the United States where humans have become sick due to their interactions with water from the relatively mundane such as coliform in well water to the contamination of an entire public water supply in Flint, Michigan. This unit aims to gather case studies and synthesize them into a cohesive series of lessons that is both engaging and educational.

One of the courses I teach in the health science curriculum of our school contains a unit on investigating the connections between environmental health and the health of the people who live there. Personally, I find this unit difficult to get through--- not because the material is especially difficult, but because the way it is presented is dreadfully boring. It is the weak link in an otherwise strong curriculum with the way that it is currently set up. This is a shame, since the topic is actually quite interesting-- there are numerous case studies of the impact that contaminated water can have on humans.

This unit is set up so that teachers can select the case studies based on their own needs, time frame, and course of study. Each section contains a summary of the introduction of the contaminant into the water shed, its impact on humans, and treatments that can be used to fix both the patient and remediate the water supply.

Curriculum Content

Watersheds

The watershed is the defined area of land from which the water drains into a basin. This water basin can be composed of streams, lakes and river, and groundwater sources that bubble up to intersect surface water. The watershed itself can be impacted by the terrain—for example, the type of bedrock, soil, and surrounding plants may impact the pH or minerals found in the water. Snow melts and runoff caused by other forms of precipitation erodes the terrain and carries it into the watershed. 1 In addition, runoff can carry in other compounds into the water—including pollutants. This is essential to understanding some of the ways by which water can become contaminated. Human influence the surrounding watershed greatly through daily activity and, in turn, our interactions with the watershed are themselves influenced.

The watershed is the source of much of the United States' municipal water in addition to being a source of recreation. Since we frequently interact with these water sources, it is comes without surprise that the quality of the water has an influence on human health. In order to fully understand how humans might come into contact with various detrimental agents, it is important to understand the differences between the various bodies of water in the watershed, how these water bodies operate, and how humans interact with each.

Surface Water: Streams, Rivers and Lakes

Surface water can be divided up into several major categories including streams, rivers, and lakes. Each of these types of surface water have their own characteristics and qualities and are used by humans in different manners.

Streams and rivers are common in watersheds. Streams are categorized by stream order, or the way that these running water sources are classified. First order streams are the smallest tributaries and may stem from areas where the water table—the below ground sources of water—bubble up to meet the surface or where precipitation melts and is collected into a stream bed. [1] This creates 'headwaters' that run down to connect with another first order tributaries. This joining creates a second order river. Two second order streams will converge to make a third order stream, and when three third orders converge you get a fourth. This pathway will continue as streams of similar orders join to make higher order streams until they move out of the watershed into a larger body of water or reach their terminus. [1]

Movement of rivers are an important factor for considering their implications in human health. Flow in rivers and streams is partially due to gravity as the water moves down the drainage basin elevation gradient and partially due to the input of precipitation via snowmelt and rainfall. [1] Additional water increases the velocity of rivers and streams and has the important consequence of moving terrestrially bound solutes into the river system.

Flow is one of the defining characteristics that set streams and rivers apart from lakes. There are multiple types of flow and the presence or lack of these movements in a body of water help to define to water source. One type of flow is turbulent flow. Turbulent flow is a type of flow where the waters might experience differences in velocity or in high velocity. 1 Often times this higher flow rate happens at the surface of the water body. Shear will cause lower waters to lift into the faster moving top water, creating mixing. Visually, this might cause small whirlpools or eddies as the water churns. A second type of flow is laminar flow. Laminar flow, unlike turbulent flow, is calm. The waters do not mix and stay in relatively separated layers. This lack of mixing is due to a constant velocity that keeps the waters flowing in a relatively flat layer. [1]

Since rivers have velocity, this impacts the introduction of possible pollutants and chemicals into the water source by moving possible pollutants downstream into recreational or municipal water sources. One of the macro pollutants, nitrogen that is frequently washed into and travels downstream in rivers is discussed later in this unit. Other micro pollutants, including several types of heavy metals, are also discussed.

Lakes, unlike rivers, lack significant horizontal velocity. While there are currents that run through lakes, most movement is not the turbulent flow associated with rivers and streams but more laminar flow. This mostly laminar flow allows the increased deposition of sediment increasing the storage capacity of these systems. This is important, as many macro and micro pollutants are associated with sediments and may accumulate in lakes as they deposit into the sediment [3]. These standing bodies of water are also excellent habitats for sustaining microorganisms that can have detrimental impacts on human health. Reservoirs, which may often appear like lakes in size, are manmade impoundments that are set up for various reasons including water storage for irrigation or municipal use, to control flooding, or as a way to generate electricity by channeling water over turbines [2].

Ground Water and Well Water

Ground water, as the name implies, is water that is not visible on the surface of the watershed. As water percolates through the soil of the watershed, it eventually moves into a saturated zone called the water table. The water table extends down until it hits a nonporous rock. Water that rests between the soil surface and an impermeable layer can often be referred to as an unconfined aquifer. [3] These aquifers frequently intersect with surface water as soil levels dip into the saturated zone of the water table. [5] Ground water itself can move at various speeds depending on the composition of the soil. Movement can be horizontal as it flows down the topographical gradient as well as vertical as it moves through the unsaturated zone to hit the saturated zone. [3]

There are also confined aquifers, where ground water is trapped between two layers of impermeable stone. Confined aquifers move incredibly slowly and can be considered long term water storage as the water is essentially trapped between these layers and cannot easily intersect with the potentiometric surface or the level where the saturated zone is exposed. [3]

Wells tap into ground water sources as a way of providing freshwater to homeowners. There are various types of wells that take advantage of different ways of drawing water. Artesian wells access water trapped between two layers of impermeable rock. Because these aquifers are often under pressure, tapping into these wells cause water to passively flow upward under artesian pressure until it reaches the potentiometric surface where pressure becomes equalized. [3] A pumping system might be necessary to finish drawing water to the surface. Flowing artisan wells are wells where the potentiometric surface is even with the soil surface, causing water to naturally bubble up. Wells that tap into unconfined aquifers need to rely on a pumping system to draw up water, as they do not have the built-up pressure of confined aquifers to passively move water towards the surface. [3]

Understanding groundwater is important when understanding human health as this is one of the major source for potable drinking water in the United States with almost a third of the country relying on ground water as their primary source. Groundwater intersects with rivers at the hyporheic zone. The hyporheic zone is a region just below the surface of the stream where there is a mixing of groundwater and surface water. [3] This intersection between these two sources of water are important because it allows for micro and macro pollutants and biological contaminants to move into ground water sources from the surface or vice versa.

Inorganic Sources of Contamination

When water pollution is typically approached in curriculum, the traditional sources of inorganic water pollution are discussed. In addition, the introduction of pollutants are usually addressed within the watershed system itself. The impacts on human activities and health, however, is rarely addressed despite the fact that humans frequently tap into watershed sources for recreational purposes and domestic uses. For this reason it is important to discuss the implications of some of these pollutants on human health.

Pollutants enter the watershed in a variety of ways. Point sources of pollution directly enter the watershed from a clearly identifiable source. Point sources are more easily identifiable because they come from a single source. These types of pollution sources are also called plume sources because of the fanning of discharge into the water source causing a visual feather as pollutants disperse. [4] There are a variety of point sources. One of the classic visuals is the idea of a direct pipe or underground injection system stemming from a commercial or industrial district discharging toxic wastes into the surrounding water. This isn't always the case, as there are plenty of municipal sources of pollution including wastewater treatment plants. [4]

Non-point sources of pollution are more difficult than point sources to identify, manage, and control because they come from a diffuse source. As precipitation passes over the topography and travels down the drainage basin, it picks up and carries pollutants. These pollutants might dissolve in the runoff or, if insoluble, might be deposited into the water. [4] [5]

There are many possible ways that humans contribute to the pollution of the watershed. For example, in agricultural settings, runoff from many farms may contain nitrate and phosphorus rich fertilizers, pesticides, and animal wastes. Gasoline, oils, and other automotive wastes frequently wash off of roadways in urban settings and can enter the watershed through storm drains. [4] Pollution caused by the dumping of antibiotics and other medications have also impacted the overall quality of the watershed and can cause dramatic changes in the microbiota found there within. The accumulation of individual sources of pollution can have a great impact on the overall quality of the chemical and biological qualities of the watershed.

An important aspect to consider is the uptake of these chemicals by organisms when they enter into surface water. Nutrient spiraling is an important concept to understand to understand the natural interactions between nutrients that enter the watershed and the biota located within. [5] In nutrient spiraling, as essential compounds are released, they are swept down river by the velocity of the running water. This means that an organism several meters downstream may end up consuming these released nutrients rather than them being reincorporated in the immediate area where they were initially released. This cycle continues as nutrients are released again into the stream and then re-absorbed later on. [1] [5]

Nutrients are not the only compounds that can take part in this spiraling effect. One might argue that potentially harmful chemicals and compounds such as arsenic, lead, and mercury can also be passed downriver through the same mode of transportation—being taken up by and organism and then released again further downstream. The concept of spiraling may be important in aspects of bioaccumulation of materials, especially those that are entering the watershed from unknown non-point sources, as it makes them difficult to track. This is doubly important when considering the uptake of nutrient-based pollutants like nitrogen and phosphorus.

In this portion of the unit, several inorganic pollutants will be discussed. Each of these pollutants has an applicable case study that demonstrates how its entry into the watershed has affected human health. These case studies will be explained below, and can easily be modified into guided investigations for student learning or modified. For each of these sources of pollution, the methods by which they enter the watershed, their effects on the environment of the watershed, their effects on human health, and remediation of environments.

Mercury

Mercury is one of the hallmark studies used to look at the effects of chemical pollutants and bioaccumulation in food sources and humans. Students have heard about mercury poisoning in their lower grade level studies. Students may be familiar with ‘mad hatter syndrome’ or other effects from the breath of mercury vapors. Mad Hatter Syndrome, or erethism, was a common ailment among felters and hat makers. Mercury was used to help preserve the wool fibers during the felting process. Hat makers would douse fibers in mercury in order to strengthen and preserve the fibers. [6] As a result, mercury would be absorbed both through the skin and inhalation. As a result members of this occupation often suffered from the neurological symptoms of acute mercury poisoning.

While this portion of the paper will not be dealing with Mad Hatter syndrome, the neurological symptoms are very similar and may be a good reference point for students. Instead, this portion of the paper deals mostly with the introduction of methylmercury (CH_2Hg+), a highly neurotoxic form of mercury, into the watershed where it undergoes a process of bioaccumulation in fresh and salt water fish. [7] [8]

Mercury is a naturally occurring element that can be highly toxic. [6] [8] [9] [11] It is introduced into the ecosystem naturally through atmospheric deposition as Hg (II). [9] [10] Volcanoes naturally volatize mercury when it boils out of hot magma and joins the atmosphere. Atmospheric mercury can be natural or related to industrial wastes. [6] [9] [10] [11] Traces of mercury can be found in coal and the processing of coal releases it into the watershed. [11]

Once inorganic mercury Hg (II) enters the water shed, several different pathways can occur. Mercury can be reduced to Hg (0), the gaseous form of mercury where it is able to volatilize and re-enter the atmosphere for deposition, it can also be put into storage in the sediment. [10] [11] Inorganic mercury can also undergo methylation of into methylmercury CH_3Hg+. [10] [11] The sensitivity of surface waters to mercury is highly dependent on the production of methyl mercury.

Since methyl mercury accumulates in the tissues of animals, humans are often exposed to methylmercury through their diets. Mercury tends to be more highly concentrated in fish that are of higher tropic levels. [6] Several species of salt water fish that may contain high levels of methylmercury include ahi or bigeye tuna, orange roughy, mackerel, or swordfish species. [11] Freshwater species are also able to accumulate mercury and may be more likely to contain harmful levels of mercury than saltwater fish. A study by the EPA tested various freshwater fish and determined that these species of fish include bass, walleye, trout, and pike. [12] Mercury accumulates in the kidneys, and may also accumulate in the brain. [7] [13] [14] Once methylmercury accumulates in the brain, it is easily converted back to Hg (II) and becomes fixed in the brain. [14]

Clinical signs of mercury poisoning are usually tied with neurological effects of the peripheral limbs and in cognitive impairments. For example, patients may report feeling tingling in their extremities, progressive muscle weakness, and loss of coordination. [7] [14] [15] Infants who have been exposed to a high amount of mercury in the womb due to maternal diets high in fish can include cognitive impairments in memory, attention, retarded language development, and inhibition in motor and visual spatial skills. [16]

Nitrogen

Nitrogen is introduced into the watershed many different ways. Nitrogen is one of the main components of fertilizers and is present in waste and waste disposal. [17, 19, 20] This is one of the main inputs of nitrogen into the watershed in rural areas. Nitrogen in agricultural areas becomes fixed and will be imported into urban areas as food and feed. [17] When these sources are broken down they can wash directly into the watershed or they can enter though efflux from waste water treatment plants. [17, 18, 19] As a result, nitrogen influx in the watershed is higher in areas where there is increased agricultural usage of the land due to increased fertilizer usage, the decay of plant materials from farming, and also animal wastes and also high in urban areas where there may be a lack of fertilizer due to food and feed wastage. [17, 18, 19]

It is estimated that for every 100 units of fertilizer added to an agricultural field, about 20 units leech directly into the water. [19] Some of this nitrogen is denitrified before it enters the watershed system by terrestrial microbes, however nitrates are highly mobile through water runoff and can be swept into surface water or, if there is a high amount of rain or irrigation, may even move into groundwater. [16, 7, 19, 20] Groundwater nitrate-nitrogen pollution can also occur from sewage waste treatment centers and leeching fields. These point sources can also enter surface water through sewage treatment overflow.

Atmospheric nitrogen is released by furnaces and combustion engines as nitrous nitrogen oxides and nitrogen gas (NOx and N_2) where it can combine with atmospheric ions to create nitrates (NO_3^-). [17, 19]

The maximum concentration for nitrate-nitrogen in potable water should be under 10mg/L. This permissible level is even lower for regulated public water systems—1mg/L. [20] The dangers with increased nitrate concentrations in the water have to do with the conversion of nitrates to nitrites in the body. Saliva interacts with the nitrates to complete this conversion. Infants, who also have absorption and nitrite formation take place in their GI tract, are able to convert twice as much nitrite as adults—10% as compared to 5%. [21]

Nitrites are especially dangerous because of how they interact with hemoglobin. Nitrites cause hemoglobin to convert into methemoglobin by oxidizing the iron from the ferrous state into the ferric state. [22] Methemoglobin does not carry oxygen in the same way that hemoglobin is able to, resulting in a state of hypoxia if it is in high enough concentrations. [20, 22, 23, 24]

It is important to understand that at any time, there is a small percentage of human hemoglobin which is in this form due to other oxidizing processes in the body. Adults have a system that is able to convert and maintain this percentage under 2%. [23, 24] Methemoglobinemia due to high amounts of methemoglobin is dangerous in infants because they lack sufficient quantities of NADH-dependent enzyme methemoglobin reductase (diaphorase I) which will reduce the methemoglobin back into oxohemoglobin. As a result the baby become cyanotic and may have markedly decreased pulse oximetry readings (under 72% where normal is above 95%). [23, 24]

One of the risk factors behind infant methemoglobinemia is the use of nitrate contaminated well water in the preparation of baby formula. There are two cases, one in June 1998 and one in April 1999 of parents reconstituting powdered baby formula with well water. [24] In each case, the baby had been fed with the formula for several weeks, and had started to exhibit a graying of the skin (cyanosis), irritability, vomiting, and some trouble breathing [24] . In the first case, switching from well water to bottle water alleviate the symptoms of the next few days of feedings. In the second case, intraosseous (into the bone) methylene blue was administered, reducing the oxidizing effect of the nitrites. [24]

Both case studies highlight different treatments for infants that are brought in with methemoglobinemia. Supplemental oxygen may also be supplied in order to help mitigate the effects of hypoxia. [24] In both cases, levels of nitrates in the wells well above the permissible levels for municipal water supplies. However, in babies where symptoms are not quickly recognized, this condition can result in a coma or in death. [20 21 22 24]

Arsenic

Arsenic is well known for its toxic properties in its inorganic form. Exposure to arsenic can cause a number of problems including but not limited to, skin lesions, cardiovascular disease, neurotoxicity, and cancers. In small doses, arsenic is relatively harmless. It is found in several types of grains, mushrooms, and even in dairy. [25] However, once arsenic exceeds the range of 2-20mg/kg body weight/day (for a person of 90kg or about 198 lbs., this would be equivalent to 0.180 grams up to 1.80 grams per day) it becomes acutely fatal. [25]

Arsenic is found in soils and mineral deposits in several countries. These natural forms of arsenic are bound in a mineral called pyrite. Pyrite, when oxidized, releases inorganic arsenic into the surface and ground water supplies [26 27] . This arsenic is converted into arsenous acid (H_3AsO_3) or arsenic acid (H_3AsO_4) as they are leached into underground aquifers. [26 27 28]

Contaminated ground water is not used if surface water is readily available to drink, however there are cases where both surface water and aquifers are contaminated, putting regions into conundrum. [28 29 30] One particular case study what exemplifies this is the arsenic water poisoning in Bangladesh.

Bangladesh and surrounding regions were riddled with water sanitation problems. Their surface water was of exceedingly low quality because of poor water purification measures and the frequent influx of coliform bacteria and other pathogens into the water supply due to human activity surrounding the river. [28 29 30] Monsoons only intensified these problems by washing over the watershed and introducing multiple chemical and biological contaminants into the surface water. [30]

Water borne illnesses are one of the leading contributors in infant mortality rates, with Bangladesh as one of the world leaders. Deaths and disease due to waterborne illnesses were so high in Bangladesh that the United Nations Children’s Fund (UNICEF) stepped in to provide aid. UNICEF, in an attempt to alleviate the problem, dug almost 8 million wells in the region to provide citizens with access to aquifers during the 1970s. [30] While digging the wells tests were not performed to identify arsenic concentrations in the groundwater. [30]

The switch from surface water to ground water resulted in an immediate decrease in infant mortality rates over the following months. People continued to use the privatized wells. However, starting in the late 1980s to the early 1990s, doctors started to see an increase in skin lesions and other complications. [28 29 30] Typically, there is a 10 year latency period as arsenic continues to build up in the human body. This latency period, where the arsenic starts to accumulate to detrimental levels explains the lagged response time between the instillation of the wells and the first cases of arsenic-linked lesions. [29 30] Furthermore, other signs of arsenic poisoning take several years of constant exposure to develop when at levels that are less than lethal, including acute tissue damage.

Analysis of the wells dug into the area identified that as many as 77% of wells dug in the area accessed aquifer water that was over the permissible 10 ug/L arsenic concentration (ppb) recommended by the EPA. It is worth noting that Bangladesh is not as strict on their water laws and has a permissible concentration nearly 5x the EPA standard. Of all wells drilled, 42% were above 10ppb, 27% were above 50ppb and 7.5% were above 300ppb. Over 1.5 million people were exposed to above permissible levels of arsenic for a prolonged period of time with 200,000 reported cases of poisoning (skin lesions and other complications). It is likely that these numbers are under reported as the areas where the highest concentrations of arsenic are found have a population between 32-77 million people. [30]

The World Health Organization (WHO) released a statement in 2000 explaining some of the results of the poisoning. [26 30] It was estimated that over 100,000 cases of skin lesions were due to arsenic toxicity in the well water. [26 28 29 30] 10% of people who drank from wells with a concentration of over 500ug/L will likely die of arsenic-linked cancers of the pulmonary system, urinary system, and integumentary system—doubling the lifetime mortality risk of these chronic diseases. [26 28 29 30]

Once the problem was identified, an emergency action plan was put in place to help mitigate the high levels of arsenic. Chemical packets are available that are able to bind the arsenic and cause it to precipitate out of the water so it is not drawn up by the well. [29 30 32] Other treatment options include changing the depth that the tube wells are sunk to-- it appears that deeper wells (greater than 150 meters) tend to contain a lower concentration of arsenic that approaches the permissible potable water concentrations. [31]

There are also other options for treating the water in Bangladesh. There was a challenge issued in 2007 by the Grainger Foundation and National Academy of Engineering to create a system to adequately strip the arsenic from the water. Three different filtration units were created including a SONO filtration system with an iron matrix, a community water system that uses alumina, and a final system that, through ferric-sulfate flocculation-precipitation, are all able to adequately remove arsenic. [32]

The SONO filter has two buckets—the top bucket containing a composite iron matrix between two layers of fine sand. This matrix attracts arsenic as water is poured through the system. The second bucket contains a standard charcoal filter which can remove any iron from the initial filtration and other impurities. [32] This filter, which costs around $40 to produce, is able to filter between 20-60 liters/hour for up to 5 years. [32]

Lead

Lead is another heavy metal, like arsenic, that has an impact on human health. Many students may be familiar with exposure to lead in domestic situations—lead paint in homes was identified several years ago as having an impact on the proper mental and physical developments in children.

Lead can enter the water system in a number of ways. Leaded gasoline, smelting and combustion, lead containing paints, and pipes or structures containing lead can all be sources of point and non-point pollution in the water source as lead leaches out of these sources readily. Unlike arsenic, there is no level of lead in the body that would be considered benign. [33]

There are two major classifications of lead poisoning that are recognized, mostly dealing with duration of exposure and concentration of lead in the blood (BLLs). Chronic poisoning is usually classified as low-level exposure (between 40-60 ug/dL BLL) over a prolonged period of time. [33] Acute poisoning is an intense exposure (100-120 ug/dL BLL) for a short period of time. [33] Each presents with different clinical symptoms and may be treated differently.

Lead toxicity impacts the majority of the major body systems, each with various effects depending on the level of lead in the system and the exposure length. Lead is stored readily in the bones—adults storing up to 85-95% of the lead in their body as opposed to children who only store about 70% of lead in their bones and the remainder in the soft tissues. [33] Even when the patient has reduced their environmental exposure of lead, it can continue to leach out into the blood over time.

Some of the most dramatic impacts of lead are on the nervous system as it is both the most sensitive and the most easily noticeable of the impacted systems. Encephalopathy starts to occur with frequent low level exposure and may cause changes in behavior or attention span, headaches, problems focusing, and other cognitive impairments. [33] Higher exposures of lead, even for a short period of time, can lead to problems with delirium, ataxia, convulsions, and paralysis. [33]

The last major system that is most dramatically impacted by lead poisoning is the hematopoietic system. This system deals mostly with the formation of red blood cells and the ability of erythrocytes to carry oxygen. [33] High amounts of led can cause both hemolytic anemia in acute poisoning and frank anemia—a type of anemia caused by iron deficiency—during chronic lead poisoning. [33]

The CDC estimates that over 4 million households in the United States are living in conditions where children are exposed to significant levels of lead (more than 5ug/dL BLL). [33] Lead poisoning from drinking contaminated water is more common in areas where housing still has lead pipes as hot water corrosion slowly causes the lead to leech out into domestic water supplies. [33]

One ongoing case study from 2001 involves the District of Columbia. In 2001, Mark Edwards, a civil engineering professor at Virginia Tech, was working with the DC Water and Sewer Authority (WASA) to identify the cause of premature pipe corrosion in copper piping of their municipal water system. At first, drought conditions were thought to have increased the alkalinity of the Potomac River which would increase corrosion of the copper pipes, causing the pinhole leaks. [39] While Edwards was testing the local water supplies, he noticed that lead levels were exceptionally high—nearly 1250ppb or 83 times the permissible potable levels stipulated by the EPA. [34] [35] [36] [39]

A wider survey was conducted by fall of 2003, and nearly 66% of the over 6000 homes they tested in DC contained levels of lead that were at or above 15 ppb. [36] [37] [38] 2287 of the homes tested had lead concentrations over 50ppb. [37] 157 homes had levels that were over 300 ppb. [36] [37]

WASA concealed the extent of the contamination. It failed to properly notify any of its customers until late November 2003 and, even then, failed to include any specific warnings. [35] [35] [37] [38] [41] They notified customers on a byline on their water bill that there was lead found in the area but neglected to tell their consumers that this lead was in extremely elevated amounts and in their drinking water. [38]

In January of 2004, local news stations started to investigated the case and found that the mayor of DC, members of the Committee on Public Works and the Environment, and members of the council were not notified about the contamination. [39] [41] Edwards, who originally identified the problem, continued to work to notify homeowners of the danger. WASA contacted Edwards on January 2 [nd], 2004, notifying him that they were discontinuing their partnership and cut off his access to their data. [39]

As news of the water contamination continued to grow following an article by the *Post in* 2004 and the subsequent formation of an investigative team, the EBA finally stepped in by June 2004, citing WASA for breaching the law and withholding test results. At that point, several homes in DC were reporting lead levels over 6000 ppb. [40]

A report was released indicating that the 2001 switch of chlorine in municipal treatment plants to chloramine was responsible for the aggressive corrosion of lead and copper pipes in the city. [41] This change was originally made because the EPA was concerned that the use of chlorine created harmful byproducts when mixed with organic wastes in treatment plants. By August of 2004, orthophosphates were added to the municipal water supplies with the hope of preventing further leeching and homeowners were told that repairs to the pipes (an estimated $300 million) would cost homeowners around $7 a month. [41]

Biological Contaminants

In addition to the different inorganic exposures that are related to disease, there are several pathogens that are transmitted to human hosts via interactions with the local watershed. These interactions may come in a variety of formats—through direct contact during recreation, through contaminated city water obtained from local water reservoirs, or contaminated well water. There are multiple pathogens that are linked to gastrointestinal and other pathologies that humans can come into contact with through the watershed, however, the focus will be on three particular pathogens. These pathogens were chosen because of the size of their outbreak, the severity of their virulence, or the frequency with which they are encountered. For additional pathogens of interest, see the table located under additional resources.

Background information for each of the particular pathogens are provided below. These sections can be used as direct reading for students, with guided questions, or can be used to inform the teacher about the nature of these cases. Depending on the nature of the class, casefiles can be created providing pertinent information and allowing students to diagnose the pathogen in question. If diagnosis is not the focus of the class, these case studies can be used as the foundation for any number of problem based learning projects, some examples of which are provided in the 'Sample Learning Activities' portion of this document.

Coliform Bacteria

Coliform bacteria are one of the most common biotic organisms that are tested for in local water sources. They can be found in any area of the watershed, the riparian zone, and may even infiltrate into municipal water supplies. [42] [43] [44] [45] Coliform bacteria are Gram negative bacillus species.

While not all members of the coliform subspecies are considered to be pathogenic, presences of coliform bacteria are an indicator species for the cleanliness of the water source as they are typically associated with fecal contamination of humans or other animals. [42] [43] [44] [45] Since members of the coliform bacteria grouping are relatively easy to culture *in vitro* , testing for the presence of these bacteria in suspected contaminated water sources is common and relatively inexpensive, thus providing ecologists and pathologists with a quick profile of local water sources. [42] [43]

There are three main subgroups of coliform bacteria. The total coliform is composed of all of the common forms of coliform that are in the local watershed. [43] [44] As previously mentioned there are several species of bacteria that are included in the coliform grouping. The majority of these species are relatively harmless, even if ingested, and will not cause any sort of illness. Within the total coliform, there is a smaller subgroup called fecal coliform. Fecal coliform species can be pathogenic in nature depending on the specific strain of the bacteria and can including *Citrobacter, Enterobacter, Klebsiella,* and *Escherichia* species. [43 44 45]

The last subgroup of coliform bacteria deals specifically with E. coli bacteria. Again, not all strains of E. coli are pathogenic. E. coli O157:H7 is most typically associated with outbreaks in municipal water supplies or in produce recalls. [43 44 45] This serotype of E. coli is shigatoxigenic (STEC) and can cause multiple gastro-intestinal diseases including gastroenteritis, hemorrhagic diarrhea, and severe cramping. [43 44 45] Severe infections have also been liked to renal failure and even death—especially in the young, elderly, and immunocompromised.

Diagnosis of this bacteria in water is relatively easy and many do-it-yourself kits are available online for purchase. It is, however, recommended that homeowners who are reliant on well-water for their drinking water supplies not rely solely on these purchasable kits and instead have their water tested by professionals.

There is a three part water quality testing lab created by Edvotek (951, 952, and 953) which allow for testing of coliform species. The first test uses coliform detection broth to identify the presence of coliform from a water sample. Students can then use indole reagent to identify the presence of *E. coli* . These kits progress through RFLP analysis of bacteria and further diagnostic techniques. Depending on the extent that the material is being covered, students can progress through all three kits or can end with the first kit.

Cryptosporidium sp.

Cryptosporidiosis is a common gastrointestinal water borne illness caused by the parasite cryptosporidium. [43 44 45] Cases of cryptosporidiosis can be caused by coming into contact with infected fecal matter from animals, humans, or water sources that have been polluted with fecal runoff. In water, cryptosporidium exists as a thick walled oocyst that, upon consumption, awakens and embeds itself into the wall of the small intestine. This parasite will continue to propagate within the small intestine causing watery diarrhea, cramping, and other common gastrointestinal symptoms. These symptoms usually persist as the infection runs its course—up to and as long as five weeks. In the meantime, the host can be incredibly infectious, passing out oocysts with their stool which can cause others to become sick through enteric infections. [42 44 45]

Two infamous cryptosporidium outbreaks occurred in 1987 Carroll County and in 1993 Milwaukee. In the 1987 case of Carroll County, Georgia, it is likely that the parasite entered the public water supply in one of several ways. Hayes, who was the lead epidemiologist at the time, suspected that the oocyte was introduced by infected cattle using the river that supplied the districts water or through a sewage overflow from a local treatment plant. [46 47 48] In this particular outbreak, around 13,000 citizens in the county were suspected to have come into contact with the parasite. [48]

The 1993 Milwaukee cryptosporidium outbreak is very similar to the outbreak in Carroll County. This particular outbreak is one of the largest waterborne disease outbreaks recorded in the United States with over 400,000 of the city’s residents becoming ill and at least 100 deaths due to severe dehydration in the elderly or immunocompromised. [49] In this particular case, there were two possible water-treatment plants where the infection could have originated from—a southern and a northern plant. [48 49]

Milwaukee Water Works (MWW) obtained water from Lake Michigan and treated it with chlorine and polyaluminum chloride. [46 47 50] Chlorine was used to kill any parasitic agents that could be living in the water and the polyaluminum chloride acted as a coagulant to help large particles of debris precipitate out of the water so they may be filtered. [50] Water was also treated using flocculation and sand filtration to help clean out large clumps of particulates. [50] Unfortunately, cryptosporidium spores are highly resistant to chlorine treatment and so were unaffected by the plants processing. [50]

Similarly to the Carroll County outbreak, the exact cause of the contamination is unknown, but scientists suspect that cryptosporidium were introduced into Lake Michigan from infected cows or from human sewage carried by snow runoff. The exact reason why the plant failed to adequately remove the oocysts is also unknown—there were no mechanical breakdowns of any of the filtration devices. In order to more adequately filter the water, turbidity monitors were introduced and measure are taken when the water becomes too turbid. Also, backwashing of filter water was ceased, as this can cause a buildup of oocysts in the water. [46,50]

Naegleria fowleri

Naegleria fowleri is an amoeboflagellate, known colloquially as the “brain eating amoeba”. It is a naturally occurring species that prefers freshwater hot springs and warm lakes and rivers. It is thermophilic and will grow best in waters that reach 46 ^{o}C. [51,52] In cooler temperatures, it is often found in the sediment of rivers and lakes. There are also cases where *N. fowleri* has been found in unchlorinated pools and contaminated tap water inhaled through the nose (commonly used in Nettie pots). [51,53] Because of its preference for warm water, infections of *N. fowleri* were most commonly associated with the southern United States during summer months when water temperatures increase. [51,52]

When someone swims in a water source where there is a population of *N. fowleri* , there is a risk of infection. The trophozoite (pathogenic form of the organism) is activated by warmer waters. [51,52] This parasite enters through the nasal cavity. Swallowing contaminated water will not cause an infection—the water must enter through the nasal passage, which is why submersion in warm lakes can be so dangerous. [53] The amoeba then penetrates through the cribriform plate into the brain causing fulminate (rapid) brain degeneration. [51,53]

Symptoms of primary amoebic meningoencephalitis (PAM) caused by an *N. fowleri* infection in early stages are very similar to those of bacterial meningitis. [51,53] They can include nausea, vomiting, headaches, stiff neck, and photophobia. These symptoms usually occur between around five days after the amoeba has burrowed through the cribriform plate. The patient then begins to rapidly degenerate and may experience a loss of balance, seizures, and coma. Death typically occurs within a week to a week and a half after infection due to intracranial edema and destruction of brain tissues. Of the 143 known cases of PAM, only 4 people have survived. [51,53]

As previously mentioned, *N. fowleri* infections were most commonly associated with southern states due to their increased temperatures. However, there have been cases in more northern states including 1 case in Indiana, and 2 cases in Minnesota. [51,52,53] All three of these cases were linked with either thermophilic pollution due to industrial efflux waters or unusually warm summers causing water to heat up, activating dormant *N. fowleri* found in the sediments of those water bodies.

Additional Learning Activities

The following section outlines some sample activities that can be used in the classroom in order to facilitate learning. This section provides a brief overview of some of the possible activity and some strategies for helping students progress through the content. Several of these labs can be run through kits. Kit names are listed below along with an item number and company, current as of 2017.

Nutrient Inputs and Outputs

Many of the inorganic pollutants that were mentioned previously enter the watershed from several different sources. Understanding the sources for each of these nutrients is important because learning how to limit their access to the watershed will ultimately help to reduce human exposure.

It is recommended that an initial cycle is modeled before having students look on their own. Mercury is a good example of a nutrient cycle that can be used to demonstrate how to set up a cycle as it contains both natural and anthropogenic sources. In an early cycle, teachers may want to include a list of terms to be used or a picture that has already been generated. Students can add arrows and numbers to represent the budget of that particular cycle. As students become familiar with this cycle, teachers can have student generate their own pictures showing the nutrient cycle. An extension for this activity is to have students look at different types of watersheds and compare inputs between them. For example, although nitrogen inputs may be very similar between agricultural and urban settings, the sources for these inputs may vary.

Testing Water for Pollutants

This section will outline testing procedures for both inorganic and organic contaminants. Students can obtain water from their tap, local rivers and streams, or lakes. It is recommended that students do not collect alone if they are obtaining water from outdoor sources for safety reasons. Students should also not collect samples from the surface of lakes and streams but rather from deeper in the water column for a better reading.

Once students have collected their water samples, they can be tested for a variety of chemicals. LabAids Kit #19: Qualitative Introduction to Water Pollution contains an entire array of possible pollutants that students can test their own water for. Once students have finished profiling their water sample, students can compare samples to one another.

An extension for this lab is to have a field trip where samples are collected along the length of a watershed. Samples can be refrigerated in a bag with ice to keep them until testing can occur at the lab. Students should mark the location along the watershed where they collected theses samples. After testing the samples, students can create a ‘profile card’ along the watershed, noting pollutants of interest. This map can be expanded further to have students look at adjacent lands and figure out what possible inputs of pollution might stem from.

Impact of Pollutants on Human Health

Only a small portion of the possible contaminants found in a watershed are listed above. Once students have tested their water, the next logical step is to look at the effects of these pollutants in the water source. If it is suspected that all water shed samples will read within allowed tolerances, the impacts of these chemicals can be assigned before testing.

Students should look for the common inputs of this source of pollution, both natural and anthropogenic, in addition to their short term and long term impacts on the major body systems and how to treat this On a large drawing of a human, students can color code the organs and tissues affected by these organs and list their long term effects. The collection of these posters can be displayed in a hallway or can be scanned and shrunk down to create a classroom set of notes.

Case Files Lessons

All of the examples of chemical and biological pollutants can be presented to students in a variety of case-study formats. I have presented several casefile formats that can be altered with any of the types of cases.

Case Study Format A—Traditional Case File

A traditional casefile would be excellent for pollutants like mercury, nitrates, or even some of the biological contaminant like *N. fowleri* . In a traditional case file, patients come in complaining of initial symptoms. Casefiles should include important patient history in addition to their blood temperature, respiration rates, blood pressure, and other important intake information.

Students should begin by reading through the patient file and text coding. A recommended method for reading through the casefile is as follows. Initially have students read the file and box any terms that they do not understand. Students can then take time to look up those words to create a class vocabulary list for the patient. This is an excellent opportunity to introduce medical terminology and help students learn prefixes and roots that are commonly used in medicine.

Once students have completed this initial read through, they should complete a second pass through where they underline any symptoms that the patient is experiencing. These symptoms can be listed on small white boards as a group assignment or on the class white board if the case file is being worked through as an entire class. Students can then begin the third and final reading where they identify any other important information about the patient that can be helpful in identifying what is wrong with their patient. In all of these samples, I would recommend that particular emphasis is given to locations that the patient may have been before becoming ill.

Students can then brainstorm illnesses that could be causing the symptoms. If students have participated in other medical classes before this unit, students may have background knowledge in the effects of some of these nutrients on the body already and may not need to use the internet. Otherwise, students can use reliable source to identify the cause of the illness. Students should always complete a written analysis of the symptoms that their patient has presented with and how those symptoms are directly tied in with the suspected illness. Furthermore, since many illnesses may present with similar symptoms, it is crucial that students identify alternative diagnoses and justify their decision to dismiss them.

An alternative method for presenting an individual casefile to either make it more interesting and challenging for students is to have an initial casefile where the patient is admitted to the hospital with some of the initial symptoms. The patient's stats can change in 'real time' and crises can be included after certain periods of time. For example, for someone suffering from *N. fowleri* infection, neurological symptoms and coma can easily be introduced as 'updates' to the initial case file. Using this format, teachers can create a sense of urgency as their patient becomes sicker and sicker. In some case files, it might be interesting to have the patient pass and provide the final update in the format of an autopsy report for students to analyze.

Case Study Format B—Epidemiological Case File

Similarly to the presentation of a single case file as outlined in format a, there is also an opportunity for multiple casefiles to be introduced at a single time in the form of an epidemiological outbreak. This format might work especially well for instance of coliform, *Crypto* , or even lead. Individual casefiles can be presented, one to each group, and students can each create a map for their patient and draw connections if the casefile will be addressed as a full class. Or, if students are working in individual groups, each group can receive all of the casefiles and create their own concept map of the infection.

In an epidemiological case file, not all patients need to present with the same symptoms, at the same time, or even with the same severity. Cases can be complicated by including patients with similar presenting illnesses that do not fit in with the profile or by presenting updates to patients based on clinical testing.

Case Study Format C—Timelines and Trials

The creation of timelines are best served for complex examples that might benefit from students having prior knowledge about a case and how the particular pathogen works. For example, this type of casefile is strongly recommended for the Washington lead case file, the Bangladesh arsenic case file, and the outbreaks of cryptosporidium. While all three of these casefiles can be presented in the traditional or epidemiological file, doing so will strip them of the important ethical situations that make these cases so intriguing.

In all of these cases, student can be presented with small bits of information at a time. For example, in the lead casefile, students can start looking at the research being conducted in 2001 and progress through the case by receiving primary and secondary articles, tracing the testing, concealment, and eventually public exposure of the incident and into the remediation. Students can do embedded tasks, including testing water for lead and mapping the location of the most severe contamination.

A similar progression can be done with the arsenic case file, where students look at some of the surface water results and propose solutions. Students can be introduced to the concept of drilling wells as part of the remediation effort, and then look at the introduction of casefiles resulting for acute arsenic poisoning and end with remediation efforts.

After students have finished looking at the background of these cases, a further extension might include students having a mock trial where they take on the roles of various parties involved and conduct a trial to determine fault and damages to be paid out by those affected. This can also be presented as a debate, again with students taking on various roles within each of these casefiles.

Appendix—Standards

Material in this unit can be used to cover several aspects of the Next Generation Science Standard for high school regarding chemistry, the water cycle, and the interactions of humans with the environment. In addition, activities are aimed at helping to develop student's proficiencies in the Common Core State Standards for English Language. This unit can also be used to fulfil learning objectives related to the transition of disease related agents and epidemiology.

A few of these standards are listed below.

Next Generation Science Standards

HS-ESS2-2: Analyze geoscience data to make the claim that one change to the Earth's surface can create feedbacks that can cause change to other Earth's surfaces.

HS-ESS2-5: Plan and conduct an investigation of the properties of water and its effect on Earth materials and surface processes.

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.11-12.2: Determine the central ideals or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

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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