ENVIRONMENTAL RESEARCH METHODS WATER QUALITY REPORT FOR COZINE, GOOSENECK, AND MILL CREEKS

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INTRODUCTION

Clean water is an essential and vital part of life. It keeps rivers, lakes, groundwater, and streams safe for a variety of organisms and for human use. Fish need clean water in order to thrive, and humans require it for hydration, hygiene, irrigation, and recreation. Although clean water is essential to life, pollution frequently contaminates water and adversely affects a multitude of organisms and ecosystems. Pollution in water is primarily anthropogenic (Reddy and Lee 2012). There are two primary types of water pollution: point source and non-point source. Point source water pollution has a single identifiable source, such as a factory dumping sewage through a pipe into a river. Non-point source water pollution has a less clearly defined point of entry into waterways, such as the runoff of chemicals and soil sediments from farms, logging operations, roads, parking lots, and domestic lawns. It is the latter type of pollution that is of primary concern today because it is more difficult to regulate (EPA 2012c). Industrial and other human activities that contribute to an aquatic ecosystem's water pollution have the capacity to harm the organisms that depend on that ecosystem (Reddy and Lee 2012).

The majority of the global freshwater supply is in glaciers and ice caps. Although technology allows for the desalination of ocean water, there is a limit of freshwater available for ecosystems and human consumption because there is a relatively small amount of surface water or groundwater available for use (Perlman 2015). Examining how existing water supplies are allocated and managed can present insight into the ways water is used and misused, as well into changing water utilization practices, such as policy changes (Field 2008).

It is becoming increasingly important to keep waters safe for living organisms by developing and implementing water quality standards and clean water plans (ODEQ 2015). Many attempts have been made to improve water quality nationally. Congress took one of the first steps by enacting the Water Pollution Control Act of 1948. This act created comprehensive programs to eliminate or reduce the pollution of interstate waters and tributaries and improved sanitary conditions of surface and underground water (U.S. Fish and Wildlife Service 2015). Due to increased public awareness and concern regarding water quality and pollution, amendments were added resulting in the Clean Water Act (CWA) of 1972. This act established the National Pollutant Discharge Elimination System that required those identified as point source polluters to obtain a permit to discharge their wastes into water bodies (USGS 2015a). Point source pollution is defined as emissions that enter a water body from a single easily identified source, such as a pipe, that allows us to know who essentially "owns" the pollution. This makes it easy to regulate and control who cleans the water. Non-point source pollution includes emissions that enter water bodies in a way that makes it hard to pin-point their source and includes runoff from agricultural fields or pollutants seeping into aquifers (Hanley et al. 2013). The CWA, administered by the Environmental Protection Agency (EPA), established national water quality standards, implemented pollution control programs, maintained existing requirements to set water quality standards for the limitation of all contaminants in surface water, initiated deterrents against pollutant discharge from point sources without a permit, and funded construction of sewage treatment plants. The act also recognized the need to control non-point pollution sources. The CWA was modified in 1981 to streamline and improve wastewater treatment capabilities and was amended again in 1987 to address additional water quality needs by building on EPA-state partnerships. The CWA guidelines apply to all U.S. states, including Oregon (EPA 2015a). Oregon, through the Oregon Department of Environmental Quality (ODEQ), is required to assess water quality every two years and report to the EPA on the conditions of state's waters. The ODEQ prepares integrated reports that meet the requirements of the CWA, the Safe Drinking Water Act of 1986, and the Oregon Department of Fish and Wildlife (Department of Land Conservation and Development 2000).

Watershed conservation and management is valuable to ensure that future generations have access to clean water, healthy ecosystems, wildlife, and healthy neighborhoods. Fish are just one reason to test water quality. In the last five years it has been estimated that the Yamhill River Watershed receives roughly 4% of the winter steelhead trout returning from Willamette Falls every year (GYWC 2015a). In 2009 and 2014, researchers reported the Yamhill River watershed may contain the highest naturalized population of Coho salmon (*Oncorhynchus kisutch)* in the Upper Willamette River Watershed (GYWC 2015a).

The Yamhill County Watershed Council started in 1994 and was incorporated in 2012 as a 501(C)(3) non-profit (Westphal 2015). Current issues for the Greater Yamhill Watershed Council are high water temperature, low water levels, disconnected waterways, contaminated runoff, simplified streams, and invasive weeds (GYWC 2015a).

The Oregon Watershed Enhancement Board, established in 1995, created a state-coordinated program that provides grants to help protect Oregon wetlands, rivers, and streams. The Oregon Watershed Enhancement board only funds 60% to 70% of the councils in the state, one of which is the Greater Yamhill Watershed Council (Westphal 2015). Watershed councils are organized by local community members and membership is voluntary (Oregon Watershed Enhancement Board 2015). Watersheds are a grassroots approach to handling water quality in local areas, giving communities the ability to manage and conserve local creeks, streams, and rivers. The approach also increases opportunities to protect and cleanup local watersheds based on the community's priorities (Westphal 2015).

To assess water quality, field tests are routinely conducted to examine the health and pollution levels of water bodies. The Environmental Science Research Methods class (ENVS 385) of spring 2011, fall 2011, 2012, 2013, and 2014 conducted water sample tests and fieldwork from creeks in the Greater Yamhill Watershed. The students' goals were to compare the water quality levels of various creeks over a period of years. Two creeks, Cozine and Gooseneck, were chosen as the first study sites (Colahan et al. 2011). Mill Creek was added in 2012. The three creeks allowed students to compare water quality differences between restored and unrestored systems, as well as in urban and rural settings (Bailey et al. 2012). The fall 2011 class found that the water in Gooseneck Creek had a higher quality than the water in Cozine Creek. Gooseneck Creek had an oxygen-rich environment that supported a variety of aquatic life, hypothesized as being partially attributable to the restoration project completed in 2009 (Weinbender and Crane 2011). The fall 2012 class concluded that Cozine Creek had a lower water quality than Mill and Gooseneck Creeks. The students hypothesized urban streams, such as Cozine Creek, have lower water quality than rural streams due to alterations in riparian zones, increased runoff from nearby roads, and the presence of invasive species. The fall 2013 class concluded that Cozine Creek had lower water quality than Gooseneck and Mill Creeks due to its urban location, whereas Gooseneck and Mill are rural streams. When compared to the past years, the students concluded the water quality for all three streams had not improved (Hollenbeck et al. 2013). The fall 2014 class also concluded that Cozine Creek had the lowest water quality among the three creeks based on its lower dissolved oxygen (DO), higher turbidity, higher nitrogen, and greater abundance of pollution-tolerant macroinvertebrates. They found Gooseneck Creek's water quality seemed to be worse than in previous years and noted the restoration project did not seem to have been effective (Fahy et al. 2014). The fall 2015 class again will test and compared the three creeks to that of past years to monitor the streams' health and determine how their water quality has changed in the past year.

The three creeks tested in this study are all located in the Yamhill Watershed in Oregon's Willamette Valley. Historically, oak prairie, deciduous forest, and grasslands dominated the locations where the three streams are currently located. The watershed encompasses approximately 529,510 acres, ranging from the crest of the Coast Range to the Willamette River (Greater Yamhill Watershed Council 2015). The area experiences cool, wet winters and warm, dry summers. The annual precipitation averages 40 inches per year, with the cooler months receiving the majority of the rain (Taylor and Bartlett 1993). The Yamhill Indians, a tribe of the Kalapooian family that lived near the Yamhill River, traditionally occupied the area. They altered the land using fire regimes and created additional oak prairies for hunting. The tribe was relocated in 1855 to the Grand Ronde Reservation in southwestern Yamhill County. In the 1800s, Europeans, many of whom arrived via the Oregon Trail in 1843 and 1844, began to settle the area. Yamhill County soon became the agricultural center of the Willamette Valley. Most of the original oak prairies were altered for human development, streams buried, and forests cleared to make way for farms and ranches (State Archives 2008).

Two of the three creeks surveyed, Mill and Gooseneck Creeks, are rural streams. Rural streams are often less polluted than urban steams; however, they have their own unique sources of pollution. Rural streams' pollutants are usually from agricultural and farming practices common in the Willamette Valley. Chemical fertilizers from surface runoff, swine and poultry waste disposal, and settling ammonia generated by swine and poultry lagoons pollute these waterways. Fecal coliform contamination also may contribute to stream pollution from wildlife, livestock waste, and septic system leaks. Agricultural land is a major source of total suspended solids and turbidity in stream waters. Septic system contamination is common due to high rates of septic systems in rural communities, leading to fecal microbial and nutrient contamination (Mallin et al. 2009). Yamhill County is host to many pollution sources typical of rural environments, including cattle, swine, poultry, dairy farms, and crop lands (Yamhill County Agri-Business 2009).

Mill and Gooseneck Creeks are located in Polk County, Oregon in a sparsely populated rural area owned by private landowners. Gooseneck Creek is a tributary of Mill Creek. Since the mid-1800s, the two creeks have been altered to facilitate agriculture and logging. Dams and dikes were built in Mill Creek but have since been removed. The Mill Creek waterway was near the location of gravel mining that plugged water channels and eliminated natural pool morphology. The alterations of the creeks increased their flow rates and depleted their gravel beds, leaving only bedrock. Due to its human-influenced past, in 2009 Gooseneck Creek was the location of a restoration project designed to decrease the amount of exposed bedrock on the creek bottom, build up gravel, and restore lost aquatic and riparian habitats. The restoration project led to the removal of a dam that blocked flow into secondary water channels and the installation of creek-spanning log weirs (Waterways Consulting, Inc. 2009).

Mill Creek was added in 2012 in order to compare a rural restored creek, Gooseneck, to a rural unrestored creek, Mill. The Mill Creek Watershed, including Gooseneck Creek, has ten Concentrated Animal Feeding Operations (CAFOs), including eight dairies, one feedlot, and one swine lot. Each dairy herd ranges from 100 to 5,000 animals; feedlot and swine operations range from 200 to 315 animals. There are four National Pollutant Discharge Elimination System (NPDES) permits in the Mill Creek Watershed, including one domestic sewage permit. CAFOs lead to high concentrations of animal manure that often contains organic matter, pathogens, sediments, hormones, and ammonia that enter nearby creeks. CAFO waste leads to an accumulation of excess nutrients, such as phosphorus and nitrogen, low levels of dissolved oxygen (DO), and decomposing organic matter that create toxic algae blooms that increase the biochemical oxygen demand and decrease the amount of DO (EPA 2015b). The NPDES permits lead to increased sewage contamination that can increase nutrients, as well as levels of bacteria including *E. coli* (EPA 2015c).

The third stream in this study, Cozine Creek, is an urban stream running through downtown McMinnville. Urban streams in general have different sources of pollution in comparison to rural streams. Streams near urbanized areas contain pollution from landscaping, road construction, and stormwater runoff, all related to human activities. Urban waterways are often modified, such as when streams are diverted around places of development or into culverts and pipes. Urban pollution stresses stream biota due to riparian clearing and water withdrawal. Urban streams are more likely to have surfactant contamination, fecal contamination from pets, petrochemical pollution, and sediment from erosion. Nearby industrial waste and outflow pipes are major sources of urban stream pollution (Booth et al. 2004).

Cozine Creek is located in Yamhill County, Oregon and flows into the South Yamhill River on the east side of McMinnville. The creek was altered as the city of McMinnville developed around it, beginning in the late 1800s. Many areas surrounding creeks in the Lower Yamhill Watershed, including Cozine, used to have wetland qualities. These wetland habitats were filled in and cultivated for the growing agricultural industry. Petrochemical pollution and toxic heavy metals from nearby roads contaminate the creek, and runoff from storm water and fertilizer from urban gardens pollute the water. In 1989, Cozine Creek had high levels of fecal coliform and nitrogen (Yamhill Basin Council 2001). In 2009 a broken sewer pipe discharging into the creek led to higher than allowable amount of *E. coli* contamination. This pipe has been fixed and bacteria levels dropped. Trash including rusted metal and plastics are common on the banks and in the creek. Cozine Creek's pollution sources are expected to increase as the population of Yamhill County expands and the area becomes increasingly urbanized (Oregon Department of Agriculture 2013).

Each of the three creeks is monitored by the state under government regulations and guidelines. The Oregon Department of Environmental Quality (ODEQ) prepares an integrated report every two years that is sent to the EPA to meet requirements of the Clean Water Act, Sections 305b and 303d. Water quality is measured using the total maximum daily load (TMDL), the calculated amount of pollutants a water body can receive and still meet Oregon water quality standards (ODEQ 2012a). The TMDL is a good reference point to assess the pollution of particular bodies of water. ODEQ uses a system of assessment categories to describe the status of the tested water bodies. Category 1 describes a water body available for all designated uses, though the state of Oregon does not use this category. Category 2 indicates that some designated uses are supported and the water quality standard is assessed using available data and information. Category 3 means there is insufficient data to determine whether a designated use of the body of water is supported. Category 4 has three subcategories. Category 4A declares that the TMDL results in attainment of water quality standards have been met. Category 4B states other pollution control requirements are expected to address pollutants and will result in attainment of water quality standards. Category 4C states impairment is not caused by a pollutant. Finally, category 5 means data indicates a designated use is not supported or a water quality standard has not been met (ODEQ 2014).

For Cozine Creek, the latest ODEQ water quality assessment declared the creek a Category 5 with respect to its failure to meet required levels of dissolved oxygen, temperature, and bacteria. Cozine Creek and the South Yamhill River were listed as at risk for pH, nutrients, sediments, toxins, and chlorophyll (Yamhill Basin Council 2001). Overall, ODEQ data suggests Cozine Creek and the South Yamhill are severely degraded by high levels of bacterial contamination and high temperatures. Mill and Gooseneck Creeks were given Category 5 ratings in regards to salmon and trout proliferation and habitability, with insufficient levels of DO and excessive temperature levels for salmon and trout spawning. In 2010, Mill Creek was declared a TMDL for excess phosphorus levels. In 1998 and 2004, Mill and Gooseneck Creeks were given Category 3 ratings in the integrated reports due to the presence of unknown pollutants (ODEQ 2012b). Mill Creek also was listed as exceeding water quality criteria for bacteria, particularly fecal coliform, in the 1998 integrated report (ODEQ 2006).

Water Quality Variables:

When assessing water quality, certain indicators are important in determining whether water is “good” or “bad.” The definition of “good” water quality changes depending on its purpose or use. The Environmental Protection Agency (EPA) sets water quality indicators for each state to use as a guideline to assess water quality. The EPA divides water quality standards into four main categories depending on the purpose of the water body: aquatic life and wildlife, recreation, drinking water, and fish/shellfish consumption. For each category, there are recommended core indicators that are the most important for determining water quality, and lower priority supplemental indicators that represent lesser, but still important factors. Supplemental indicators include sediment toxicity, hazardous chemicals, VOCs, aesthetics, algae, and hydrophilic pesticides. Note, that in the categories focused on human consumption, “Drinking Water”, and “Fish/Shellfish Consumption,” there are less recommended indicators. The streams, like the ones we will assess in our study, fall under the “Aquatic Life and Wildlife” category. Recommended core indicators for these types of water bodies include DO, temperature, conductivity, pH, habitat assessment, flow, nutrients, and land conditions (e.g. land uses) (EPA 2003). We will be using DO, temperature, pH, flow, and nutrients from this list to assess the water quality of three different creeks. Table 1 below summarizes these water quality standards.

Table 1. Recommended water quality indicators for general designated use categories

Recommended Core and Supplemental Indicators				
	Aquatic Life & Wildlife	Recreation	Drinking Water	Fish/Shellfish Consumption
Recommended Core Indicators	*Condition of biological communities (EPA recommends the use of at least two assemblages) *Dissolved oxygen *Temperature *Conductivity *pH *Habitat assessment *Flow *Nutrients *Landscape conditions (e.g., % cover of land uses) Additional indicators for lakes: *Eutrophic condition Additional indicators for wetlands: *Wetland hydrogeomorphic settings and functions	*Pathogen indicators (*E. coli*, enterococci) *Nuisance plant Growth *Flow *Nutrients *Chlorophyll *Landscape conditions (e.g., % cover of land uses) Additional indicators for lakes: *Secchi depth Additional indicators for wetlands: *Wetland hydrogeomorphic settings and functions	*Trace metals *Pathogens *Nitrates *Salinity *Sediments/TDS *Flow *Landscape conditions (e.g., % cover of land uses)	*Pathogens *Mercury *Chlordane *DDT *PCBs *Landscape conditions (e.g., % cover of land uses)
Supplemental Indicators	*Ambient toxicity *Sediment toxicity *Other chemicals of concern in water column or sediment *Health of organisms	*Other chemicals of concern in water column or sediment *Hazardous chemicals *Aesthetics	*VOCs (in reservoirs) *Hydrophilic pesticides *Nutrients *Other chemicals of concern in water column or sediment *Algae	*Other chemicals of concern in water column or sediment

(EPA 2003)

In order to assess and monitor water quality in the three creeks, a number of water quality variables were tested. Biochemical oxygen demand (BOD), pH, dissolved oxygen (DO), temperature, depth, flow rate, turbidity, bacteria levels, nutrient concentrations, and aquatic macroinvertebrates were all measured.

pH is a measure of the acidity of a solution based on the number of hydrogen atoms. Each unit represents a 10-fold change in acidity of the water. pH is measured on a scale of 1 to 14, with acidity increasing as the scale declines. pH affects many biological and chemical processes in the water. Each aquatic organism has its own optimal pH range in which it can survive. Most inhabitants of freshwater streams prefer a pH between 6.5 and 8.0 (EPA 2012d). A pH level outside this range reduces diversity in streams because it stresses the physiological systems of most organisms and can reduce reproductive rates. Low pH can allow certain pollutants to become more mobile and available for aquatic plants and animals to absorb. pH also can affect the solubility and toxicity of chemicals and heavy metals in water. Low pH can result in conditions that are toxic to aquatic life. Many factors can change pH in freshwater streams. Photosynthesis by algae and plants lead to higher levels due to increased hydrogen ion use, whereas increased respiration and the decay of organic material can lower pH. pH can also change because of carbonate rocks, and levels can fluctuate with precipitation because of increased acidity in rainwater. Overall, pH is a good indicator of the general health of a body of water (EPA 2012d).

DO is the measure of the amount of oxygen dissolved in water. Oxygen is critical to the health of aquatic organisms because it is required for cellular respiration in aerobic aquatic organisms. When DO levels drop aquatic organisms begin to die. Different aquatic species have their own preferred ranges of DO. Oxygen enters the water in numerous ways. It can enter a stream from the atmosphere and groundwater discharge. Water can become oxygenated by wind, rapids, and waterfalls. Streams with a variety of physical features, like bends and riffles, have higher levels of DO because water is more turbulent and absorbs oxygen from the atmosphere. Fast moving water, like mountain streams, will have higher levels of DO than stagnant water. Cold water holds more DO than warmer water, which means DO levels are higher during colder seasons. DO levels also can be affected by the respiration of aquatic organisms. Bacteria in the water consume oxygen as organic matter decays, so low DO may be an indicator of higher quantities of bacteria consuming oxygen. Stagnant water contains higher levels of decaying matter because fast moving water normally washes away debris. Aquatic organisms have different levels of DO requirements. Freshwater trout need seven parts per million (ppm) DO to survive, whereas salmon require six ppm, and bacteria need only approximately one ppm to survive. Lower DO levels can lead to reduced growth rates and death in aquatic organisms (USGS 2015b).

BOD is the measure of the amount of dissolved oxygen used by aerobic organisms, like macroinvertebrates or bacteria, to break down organic matter in water. Natural sources of organic matter include leaf fall from riparian vegetation. Decay also can be unnaturally accelerated when nutrients and sunlight increase due to human influence. In urban streams, BOD levels can rise as a result of urban runoff carrying pet and wild animal waste, fertilizers, sewer and septic system leaks, and wastewater from treatment plants. Rural streams can be impacted by runoff originating from agricultural wastes and fertilizers that raise BOD. Higher temperatures and warmer water lead to faster oxygen consumption because warmer water holds less DO than cold water. Oxygen consumption in the decomposition processes robs other organisms of oxygen needed to survive (Penn et al. 2009).

Temperature also governs what kinds of organisms can live in the water. Each aquatic organism has its own optimal water temperature range. For example, steelhead trout located in the South Umpqua River in Oregon prefer temperatures from 15 to 17.8°C. Salmon species including Chinook, coho, chum, pink, and sockeye prefer temperatures between 10 and 17°C (Sauter et. al. 2001). Temperatures going above or below that range can cause species to suffer from a variety of problems including changes to metabolism, migration, abundance, feeding, spawning, and the survival rates of eggs and larvae. Temperature also affects water chemistry. Rates of chemical reactions generally increase at higher temperatures and higher levels of minerals can dissolve from the surrounding rocks in warmer waters. Certain types of dissolved minerals, like clay, can cause water to have a higher electrical conductivity, and some compounds become more toxic at higher temperatures. In addition, cold water holds more DO than warm water, affecting the types of organisms found (EPA 2012c). Temperature can change due to human alteration to the landscape including paving surfaces with impervious materials, which allows water to be warmed by the sun before running off. Water is used as a cooling agent in many power, manufacturing, and industrial plants. The warmer water, once used, is dumped back into streams raising their temperature. Water temperature can also change due to seasonal and diurnal differences, the amount of shading by vegetation, water depth, and flow rate. Increased flow rate prevents water from stagnating, preventing the water from absorbing heat from the sun (USGS 2015c).

The flow rate is the volume of water that moves over a designated point over a fixed period of time. Flow is directly related to the amount of water moving from a watershed into the stream channel. Flow rate can be affected by factors including weather, seasons, and vegetation. Flow increases with rainfall and decreases during dry periods. Oregon is currently experiencing a series of dry years; if the drought continues flow could be expected to be lower this fall as compared to that of past years. Flow decreases during the summer months as rainfall rates drop, riparian vegetation absorbs water, and evaporation rates increase. Flow can also be affected by human factors like dams that block a stream’s natural pathway. Small, slow moving streams have less capacity to dilute and degrade wastes and pollution than larger, faster moving streams. Sediment cannot accumulate as much in high flow rate water bodies (EPA 2012e). Slow flows allow water to absorb more heat and have higher temperatures. Faster streams also have higher DO levels because they are better aerated (USGS 2015b).

Turbidity is the measure of water clarity and is affected by the amount of material suspended in the water. Suspended material includes soil particles like clay or silt, microbes, algae, plankton, and pollen. The level of turbidity can affect the color of the water. Higher turbidity increases water temperature because suspended particles absorb heat, which in turn reduces DO because warm water holds less DO. Higher turbidity reduces the amount of light penetrating the water, which can reduce the rate of photosynthesis and, consequently, the amount of DO. High turbidity can affect fish by clogging their gills, lowering growth rates, reducing disease resistance, and slowing egg and larval development. Settled sediment can smother fish eggs and benthic macroinvertebrates. Sources of turbidity include soil erosion, waste discharge, eroding stream banks, urban runoff, large populations of bottom feeders that stir up debris, and excessive algal growth (USGS 2015a).

Nutrient levels (nitrate, ammonia, and phosphate) were measured at the three creeks. Nutrient levels are good indicators of stream health because they stimulate aquatic plant growth and algae blooms, leading to eutrophication. Eutrophication leads to increased aquatic plant growth. As it dies and decays, it leads to an increase in oxygen demand. The increase in organic material has led to decreased DO and increased BOD (Penn et al. 2009). Human activities have led to increases in nutrients that enter water from wastewater treatment plant discharges, synthetic fertilizer runoff, fossil fuel combustion, animal manure, urban runoff, and landfill leaching. Excess nutrient pollution is a problem in rural and urban streams. Ammonia, nitrate, and phosphate can enter water from natural sources such as animal waste (EPA 2015d). A maximum nitrate level of 2 ppm is appropriate for protecting the most sensitive freshwater species including coho salmon (Camargo et al. 2005). The recommended maximum levels of phosphate in freshwater streams and rivers is 0.1 ppm (EPA 2015d). For ammonia, sensitive freshwater fish, including trout and coho salmon, have a maximum level of 0.2 ppm (EPA 2015d).

The three creeks’ coliform bacterial levels were also measured. Bacteria are naturally found in freshwater streams but certain types of bacteria are indicators of poor water quality. *Escherichia coli* (*E. coli*) is a type of fecal coliform. *E. coli* is a natural inhabitant of the intestinal tracts of warm-blooded vertebrates. *E. coli* levels increase as a result of failing septic tanks, wastewater treatment plants, leaking sewer lines, sewer overflow, and urban stormwater runoff. High fecal coliform levels indicate the presence of vertebrate fecal matter in the water. Fecal coliform bacteria can accumulate in streams if they are near impervious surfaces, such as asphalt, that can collect the bacteria and increase the runoff concentration into the stream instead of allowing it to be naturally absorbed into the soil. *E. coli* and other fecal coliforms like *Salmonella* can pose health risks to humans who may be exposed. The EPA recommends an *E. coli* freshwater limit of 406 colonies per 100 ml for a single sample (Bruhn and Wolfson 2007). *Salmonella*, as well as *E. coli,* can be pathogenic. *Salmonella* can be found in private wells contaminated with fecal matter from sewage outflow, polluted stormwater runoff, or agricultural runoff. *Aeromonas* also was measured in the three creeks. *Aeromonas* can be found in water, food, and soil worldwide. Some species are implicated in human diseases, though most strains are not harmful. Overall, *E. coli, Salmonella, Aeromonas,* and other fecal coliform sampling is important to monitor the health of streams, as their presence can indicate potentially disease-causing bacteria in the streams (Pianetti et al. 2004).

Macroinvertebrates were monitored in the three creeks because they are useful indicators of freshwater stream health. Macroinvertebrates are organisms that are large enough to be seen with the naked eye and that lack a backbone. Macroinvertebrates live in a variety of water systems, from cold fast moving streams to stagnant pools. Macroinvertebrates include insects in adult or larval form, crawfish, clams, snails, and worms. Most live attached to rocks, logs, or aquatic vegetation (EPA 2012a). Macroinvertebrates are good indicators of stream health because their population abundances are directly related to the levels of pollution and DO in the stream. Macroinvertebrates can’t escape pollution so their population and species abundance reflects both short and long term effects of pollution, as well as the cumulative effects. Macroinvertebrates can show the impact of habitat loss not detected by normal water quality testing and can be used to determine whether a stream ecosystem is impaired. Macroinvertebrate production is related to stream alkalinity, discharge variability, and nutrients. Macroinvertebrate populations increase with higher levels of nitrogen due to an increase in the rate of decomposition of detritus that provides food for the organisms. Alkalinity increases decomposition rates of detritus. Macroinvertebrate population growth provides an increased amount of food for aquatic organisms in higher trophic levels including salmon and trout (Krueger and Waters 1983).

Macroinvertebrates often are analyzed using a pollution tolerance index (PTI). The PTI measures the number of macroinvertebrate taxa in three categories. Category 1 contains pollution-sensitive macroinvertebrates; these are given three points for each taxon present. Category 2 contains macroinvertebrates that can tolerate a wide range of environments; each taxon is given two points. Category 3 includes macroinvertebrates that are pollution tolerant; each taxon is given one point. The total numbers of taxon points are summed to calculate the PTI. The quality of the stream is defined by the score, with 23 or more points considered excellent, 17 to 22 good, 11 to 16 fair, and fewer than 10 poor (Olomukoro and Dirisu 2013).

Hypotheses and Goals of the Study:

The goals of the study were to continue the research conducted by previous ENVS 385 Research Methods classes to assess stream health and water quality. Three streams, two rural and one urban, were analyzed using a variety of parameters to examine the effects urban and rural locations have on water quality, as well to compare this year's data to the data obtained by previous classes. We hypothesized the overall water quality of the three creeks would not have improved relative to past class studies because of a continued increase in the amount of point and non-point sources of pollution affecting all three sites due to the growing population in the McMinnville area (U.S. Census Bureau 2015). Cozine Creek would continue its trend of having the lowest water quality due to its urban setting. Gooseneck Creek would have better water quality than Mill or Cozine Creeks because of the semi-successful restoration efforts completed in 2011. We also planed to analyze the effects of these water quality variables on local fish populations, mainly coho salmon.

Site Selection:

The three creeks were chosen to investigate the different impacts rural and urban environments have on freshwater streams. Gooseneck Creek and Cozine Creek were chosen by the spring 2011 ENVS 385 class to represent a rural and urban stream, respectively. Gooseneck Creek was chosen with the help of the Greater Yamhill Watershed Council to help them monitor their restoration efforts. Cozine Creek was chosen because it was an urban stream that runs through the campus of Linfield College (Yamhill Basin Council 2001). The fall 2012 ENVS 385 class added Mill Creek when they decided to examine an unrestored representation of a rural stream (Weinbender and Crane 2011; Bailey et al. 2012).

Site Descriptions:

Samples were taken from Mill Creek on September 16 and 30, 2015. The weather on September 16 was overcast with a slight breeze and an air temperature of 17 ˚C. Site 1 had a width ranging from four to six meters. The creek had slow-moving water with many submerged leaves and sticks. Rocks and gravel covered the bottom. The creek banks were largely composed of gravel and vegetation that hung over the water. The creek was surrounded by alders *(Alnus rubra)*, a small cottonwood tree (*Populus trichocarpa*), Himalayan blackberries (*Rubus armeniacus*), and grass. The water was clear, and many snails were visible on the creek bottom. The width of site 2 ranged between three and four meters. The flow was slow and small boulders were interspersed with medium-sized gravel. There were fallen leaves in the creek and on the banks. The water was clear, and the creek bottom had a large population of snails. The creek banks were covered with large rocks, fallen leaves, sticks and fallen logs. Alder trees (*Alnus rubra*) were present. Site 3 also had slow-moving water, was relatively shallow, and had a width of about 14 meters. The creek bottom was covered by large rocks and medium-sized gravel. The water was clear, and the site was surrounded by small alders (*Alnus rubra*) and grass. The GPS location of each site was measured and is listed in Table 2.

Table 2: GPS Coordinates for Creek Sample Sites for fall 2015

Site	**Latitude**	**Longitude**
Mill Creek Site 1	N 45.03395	W 123.42476
Mill Creek Site 2	N 45.03373	W 123.42512
Mill Creek Site 3	N 45.03306	W 123.42548
Gooseneck Creek Site 1	N 45.03123	W 123.43076
Gooseneck Creek Site 2	N 45.03037	W 123.43042
Gooseneck Creek Site 3	N 45. 03000	W 123.19798
Cozine Creek Site 1	N 45.20297	W 123.19798
Cozine Creek Site 2	N 45.20300	W 123.19818
Cozine Creek Site 3	N 45.20343	W 123.19952

Samples were taken from Gooseneck Creek on September 23 and October 14, 2015. On September 23, the weather was partly cloudy with a slight breeze, and the air temperature was 20 ˚C. Site 1 had a width of approximately two meters. The water was clear with a low flow rate. The creek's bottom was covered by gravel with some bedrock.

Snails were abundant on the bottom and there were small pools of deep water. Both sides of the creek consisted of gravel banks with occasional patches of crumbly carbonate bedrock. Leaf litter was present on the creek banks and on the bottom of the creek. Surrounding vegetation included big leaf maple (*Acer macrophyllum*), Oregon white oak (*Quercus garryana*), Douglas-fir (*Pseudotsuga menziesii*), and densely packed alder trees (*Alnus rubra*). Site 1 was partially shaded by the surrounding vegetation. Site 2 was about three meters wide. The flow was slow with deep pools of water below a log weir spanning the width of the creek. Leaf debris gathered in the water above the weir. The bottom of the creek had patches of gravel but was mostly covered by exposed bedrock covered with many snails. The creek banks were steep and muddy with grass and riparian vegetation along the edges. Big leaf maple trees (*Acer macrophyllum*), alders (*Alnus rubra*), snowberry (*Symphoricarpos albus*), and dead trees also were present. Small patches of gravel accumulated on the banks. Site 3 was approximately one meter wide at a maximum and was shallow. The creek was more narrow and faster flowing right before the weir. The water collected in a small, deeper pool under the weir and then became more narrow and shallow again as it flowed further downstream. The site was surrounded by grass along the creek banks and densely packed alder trees (*Alnus rubra*). The GPS location of each site was measured and is listed in Table 2.

Samples were collected from Cozine Creek on October 7, 2015. The temperature at site 1 was 16 ˚C, the weather was overcast, and it had rained earlier in the day. The creek was approximately three meters wide. The site was surrounded by thick vegetation including dogwood (*Cornus stolonifera*), white ash (*Fraxinus llatifolia*), Himalayan blackberry (*Rubus armeniacus),* and grass. The banks were steep and eroded, and the water was filled with fallen leaves and trash. The creek bottom was muddy. Site 2 was approximately a meter wide. The brown, murky water of Cozine creek had an unpleasant smell and the creek bottom was slimy. The creek banks were muddy and covered with vegetation including grass, Himalayan blackberries (*Rubus* armeniacus), and other shrubs. The air temperature at site 3 was 17˚C and the creek was about four meters wide. The creek banks at site 3 were muddy, eroded, and dropped into the creek as gravel beds. Trash surrounded the site, including a mattress, a cinderblock, and bottle caps. Site 3 goes under U.S. 99 through a small tunnel slightly upstream of the site. The water in site 3 was brown in color and emitted an unpleasant odor. The primary vegetation on the banks included grass, Himalayan blackberries (*Rubus armeniacus)*, and Oregon white ash (*Fraxinus latifolia*). The GPS location of each site was measured and is listed in Table 2.

METHODS

In Field Procedures:

Water Sample Collections:

We collected two water samples at every sampling site at each creek. The first was collected in a sterile Nalgene bottle that we filled to about one-half inch from the top. The second was collected in a BOD bottle and filled to the top with no air bubbles. The BOD bottles were wrapped in foil to block light. Both water samples were immediately placed on ice in a cooler in the field. Both sample bottles were returned to Linfield College's environmental science lab. The sterile water samples were stored in the lab freezer to be analyzed later. The BOD water samples were placed in an incubator in Linfield's environmental science lab for five days at room temperature (EPA 2012b). At the time we collected the two water samples, stream depth was measured at the location of each collection site. After the water samples were collected and stream depth measured, the following other water quality parameters were measured.

pH:

Five pH measurements were taken at every sample site on each creek. The measurements were taken using two Hanna Instruments pH meters (model number H198128). Before each field day, the pH meters underwent a two-point calibration in the lab. In the field, the pH probe was submerged in water until the reading became stable, then the pH level and the temperature were recorded (Hanna Instruments, 2015a).

DO and Temperature:

Five DO measurements were taken at each sample site on each creek using two Hanna Instruments DO meters (model number HI9146). A two-point calibration was performed in the lab before the instruments were taken into the field. Before each measurement, the DO meter was calibrated to 100% oxygen before the probe was placed into the water. After the readings stabilized, the DO readings in percent, parts per million and temperature in degrees Celsius were recorded (Hanna Instruments 2010).

Flow Rate:

Flow rate was measured using two Geopacks flow meters (model number MFP51) at each sample site on each creek five times. The propeller was submerged in the water facing upstream and held until the reading stabilized. The average flow and the water temperature in degrees Celsius were then recorded (Geopacks 2013).

Macroinvertebrates:

Macroinvertebrate samples were collected at each sample site in each creek. At each collection site, three collection areas were randomly selected. Before collection, we measured the depth at each site. We also assessed the substrate of each site using a scale of one to five: one corresponded fine silt or mud, two to rocks less than one-half inch, three to rocks smaller than six inches, four to rocks six inches and larger, and five to solid bedrock. We then used two D-nets placed so that the downstream net would catch any dislodged organisms. The second net was placed one foot away and upstream, parallel to the first net. The bottom of the streambed and all large rocks were hand-scraped between the two D-nets. We then scraped the streambed with the upstream D-net such that all material flowed into the downstream net. All collected macroinvertebrates were captured and placed into jars of 70% isopropyl alcohol solution to preserve them. The jars were returned to the ENVS laboratory at Linfield to be analyzed later (EPA 2012a).

In-Lab Procedures:

In the lab, we analyzed BOD, turbidity, and nutrient levels (nitrate, ammonia, and phosphate). We also made bacterial plates and identified and counted the macroinvertebrates by species.

BOD:

After five days, DO measurements were taken again using two Hanna Instruments DO meters (model number HI9146). The water samples taken from each site at each creek was poured into five small beakers. One DO reading was collected from each beaker in percent and ppm. We did not touch the beaker while collecting the reading because the temperature of our hand would have decreased the DO level because warmer water holds less oxygen. BOD measurements were calculated by subtracting the DO measurements collected in the lab from the original DO measurements in the field (EPA 2012b).

Turbidity:

The water samples were measured for turbidity using a Hanna Instruments microprocessor turbidity meter model HI 93703. The water samples were well mixed, poured into the turbidity meter cuvette, inserted into the turbidity meter, and the turbidity in FTU units read. Each water sample was measured five times, with the cuvette being well mixed between readings (Hanna Instruments 2015b).

Nutrients:

Phosphate, ammonia, and nitrate levels were measured in each water sample. Five tests were performed on each sample site from each creek. Phosphate levels were measured with a LaMotte Low Range Phosphate Water Test Kit (model code 3121-01), following the procedure outlined in the directions (LaMotte 2015b). Ammonia levels were measured with a LaMotte Ammonia Nitrogen Kit (model code 5864-01) following the procedure outlined in the directions (LaMotte 2015a). Nitrate levels were measured with a LaMotte Nitrate Nitrogen Tablet Kit, (model code 3354) following the procedure outlined in the directions (LaMotte 2015c).

Bacteria:

Five plates for each water sample site at each creek were prepared using Easy Gel Kits, following the included procedure outlined in the directions. We used 5 ml of water from Mill Creek, 5 ml from Cozine Creek, and 3 ml from Gooseneck Creek. The plates were placed in an incubator at 35^{o}C. After 24 to 48 hours the plates were removed and the number of bacterial colonies were counted using a colony counter. Dark blue colonies were identified as *E. coli*, teal colonies were counted as *Salmonella*, pink colonies were identified as *Aeromonas*, and small blue colonies were identified as other coliform bacteria (Micrology 2008).

Macroinvertebrates:

Macroinvertebrates were identified to the most specific taxa and counted under a dissecting microscope. Each jar was counted twice, except for the jars collected at Cozine site three due to the excessive amount of sediment collected with the macroinvertebrates at this site. The taxa of macroinvertebrate, along with how many were caught at each site were entered. After each jar was counted twice, sheets were compared to verify that the same number and type of macroinvertebrates were identified in each jar.

Statistics

JMP 11 statistics software was used to statistically analyze each water quality and macroinvertebrate variable measured among the creeks this year, and at each creek among previous years starting from 2011. For all tests, we assumed normal distribution and used parametric tests. We compared the water quality variables among the creeks using ANOVA because we were comparing the means at more than two locations. Variables that were significant (p-value <0.05), were examined using an All Pairs Tukey-Kramer post-hoc test to determine which creeks were significantly different from one another.

RESULTS:

We found significantly lower pH and DO at Cozine than Gooseneck or Mill Creeks (Table 3). We also found significant higher temperature, BOD, turbidity, phosphate, *Aeromonas*, and other coliforms at Cozine than at either Gooseneck or Mill Creeks.

Table 3: Mean (standard deviation) for water quality variables at Gooseneck, Cozine, and Mill Creeks in 2015. Means with different letters are significantly different from one another.

	Gooseneck: mean (standard deviation)	**Cozine: mean (standard deviation)**	**Mill: mean (standard deviation)**	**P-value**
pH	7.52 (0.10) A	7.18 (0.04) C	7.38 (0.22) B	<.0001
Flow (cm/s)	0 (0) B	3 (4) A	2 (2) A B	0.0231
Temperature (°C)	15.4 (0.679) B	16.6 (0.687) A	15.2 (0.303) B	<.0001
DO(%)	94.7 (2.11) A	58.8 (2.86) B	94.7 (2.01) A	<.0001
BOD(%)	-0.66 (6.80) B	24.8 (14.2) A	0.5 (1.00) B	<.0001
Turbidity (FTUs)	3.04 (0.648) B	9.49 (0.648) A	2.07 (0.648) B	<.0001
Ammonia (ppm)	0.15 (0.023)	0.15 (0.023)	0.09 (0.02)	0.1154
Nitrate (ppm)	4.0 (0.77)	2.6 (0.77)	5.1 (0.77)	0.0868
Phosphate (ppm)	0.0 (0.059) B	0.3 (0.03) A	0.0 (0.029) B	<.0001
E. coli (# per 100ml)	7.4 (9.8) AB	15.0 (40.4) A	0.0 (0.0) B	0.0239
Aeromonas (# per 100 ml)	16.3 (103) B	126.7 (257.7) A	2.2 (7.6) B	<0.0001
Salmonella (# per 100ml)	2.2 (1.4)	30.0 (136)	0.0 (0.0)	0.1343
Other Coliforms (# per 100ml)	5.9 (8.6) B	25.0 (43.7) A	0.0 (0.0) B	<0.0001
Macro Depth (cm)	22.0 (11.6) A	13.7 (6.95) A	21.0 (12.5) A	0.2361
Water sample depth (cm)	36.5 (17.3) A	20.0 (8.48) A	15.8 (8.22) A	0.2086
Substrate	3.2 (0.40)	2.6 (0.38)	3.3 (0.38)	0.3301

When we compared this year's data from Cozine Creek to the previous years of study from 2011 to 2015, we found pH, temperature, temperature, turbidity, and phosphate was significantly higher in 2015 than the previous year (Table 4).

Table 4: Mean (standard deviation) for water quality variables at Cozine Creek each year from 2011 to 2015. Means with different letters are significantly different from one another.

	2011	**2012**	**2013**	**2014**	**2015**	**P-VALUE**
pH	6.84 (0.09) B	6.49 (0.09) BC	6.28 (0.09) C	6.30 (0.09) C	7.18 (0.07) A	<.0001
Flow (cm/s)	45 (11) A	11 (11) AB	1 (11) B		3 (9) B	0.0255
Temperature (°C)	12.3 (0.292) BC	9.56 (0.292) D	11.5 (0.292) C	13.5 (0.292) B	16.6 (0.226) A	<.0001
DO(%)		58.2 (1.93)	58.5 (1.93)	52.4 (1.93)	58.8 (2.86)	0.0596
BOD(%)	22.1 (3.78) AB	3.68 (3.78) C	9.84 (3.78) BC	16.2 (3.78) ABC	24.8 (2.93) A	0.0004
Turbidity (FTUs)			5.95 (1.01) B	5.04 (1.01) B	9.49 (0.788) A	0.0027
Ammonia (ppm)			0.23 (0.035)	0.15 (0.035)	0.14 (0.090)	0.1271
Nitrate (ppm)	0.0 (0.85) A	0.0 (0.85) A	0.1 (0.8) A	2.0 (0.85) A	2.6 (0.66) A	0.036
Phosphate (ppm)	0.2 (0.04) AB	0.0 (0.041) C	0.0 (0.041) BC	0.1 (0.04) BC	0.3 (0.2) A	<.0001
E. coli* *(# per 100ml)	22.2 (27.3)	44.4 (27.3)	2.22 (4.41)	0.00 (0.00)	15.0 (40.4)	0.052
Aeromonas (# per 100 ml)	8.89 (14.5) B	1170 (466) A		156 (188) B	127 (258) B	< .0002
Salmonella (# per 100ml)	17.8 (25.4)	0.00 (0.00)		22.2 (44.1)	30.0 (136)	0.9019
Other Coliforms (# per 100ml)	0.00 (0.00) C	75.6 (44.5) A	55.6 (37.1) AB	0.00 (0.00) C	25.0 (43.7) BC	< .0001

When we compared this year's data from Gooseneck Creek to that collected between 2011 and 2015, we found significantly higher pH, temperature, and nitrate in 2015 than 2014 (Table 5).

Table 5: Mean (standard deviation) for water quality variables at Gooseneck Creek each year from 2011 to 2015. Means with different letters are significantly different from one another.

	2011	**2012**	**2013**	**2014**	**2015**	**P-VALUE**
pH	6.62 (0.371655) C	7.12 (0.242218) B	6.54 (0.581442) C	6.34 (0.187617) C	7.52 (0.104935) A	<.0001
Flow (cm/s)	5 (3) B	10 (0) A	11 (0) A	0 (0) C	0 (0) C	<.0001
Temperature (°C)	12.2 (0.180) C	12.3 (0.705) C	8.2 (0.99) D	13.6 (0.280) B	15.4 (0.679) A	<.0001
DO(%)	97.022222 (1.19768) A	89.422222 (4.72249) B	96.743333 (2.77573) A	75.611111 (5.05802) C	95.353333 A	<.0001
BOD(%)	32.9 (2.68) A	32.9 (2.68) A	11.3 (6.26) B	3.9 (6.4) B C	-0.66 (6.7) C	<.0001
Turbidity (FTUs)			2.42 (0.58)	2.16 (0.73)	3.10 (1.37)	0.0979
Ammonia (ppm)			0.09 (0.03)B	0.14 (0.040)A	0.15 (0.046) A	0.0027
Nitrate (ppm)	0.5 (0.49) B	0.0 (0.0) B	0.0 (0.0) B	0.0 (0.0) B	4.0 (0.42) A	<0.0001
Phosphate (ppm)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1328
***E.coli* (per 100ml)**	24.4 (21.9) AB	2.2 (22) B	26.7 (21.9) AB	100.0 (21.9) A	7.4 (9.8) B	0.0059
***Aeromonas* (per 100 ml)**	31.1 (230.0) B	8.9 (230) B		4011.1 (230.6) A	16.3 (103) B	<0.0001
***Salmonella* (per 100ml)**	6.7 (3.2)	0.0 (0.0)		0.0 (0.0)	2.2 (1.4)	0.4178
Other Coliforms (per 100ml)	13.3 (19.2) B	4.4 (19) B	8.9 (19) B	177.8 (19.23) A	5.3 (8.6) B	<0.0001

When we compared this year's data from Mil Creek to that collected between 2011 and 2015, we found significantly higher pH, DO, and nitrate in 2015 than 2014 and significantly lower BOD (Table 6).

Table 6: Mean (standard deviation) for water quality variables at Mill Creek each year from 2011 to 2015. Means with different letters are significantly different from one another.

	2012	**2013**	**2014**	**2015**	**P-VALUE**
pH	6.53 (0.20) B	6.95 (0.20) A B	6.41 (0.20) B	7.38 (0.15) A	0.0014
Flow(cm/s)	16 (3) A	17 (3) A	10 (3) A B	2 (3) B	0.0031
Temperature (°C)	8.2 (0.34) C	15.8 (.34) B	18.1 (.34) A	15.2 (0.26) B	0.0001
DO(%)	90.22 (1.0520) B C	91.8 (1.05) A B	86.77 (1.05) C	94.74 (0.81) A	0.0001
BOD(%)	10.6 (1.48) B	29.9 (1.48) A	7.6 (1.48) B	0.5 (1) C	0.0001
Turbidity (FTUs)		1.12 (0.227) B	2.84 (.983) A	2.07 (.804) A	<0.0002
Ammonia (ppm)		.04 (.03) B	.13 (0) A	.09 (.06) AB	<.0011
Nitrate (ppm)	0.0 (.32) B	0.0 (.32) B	0.0 (.32) B	5.1 (1.6) A	<.0001
Phosphate (ppm)	0.0 (0.0) A	0.0 (0.0) A	0.0 (0.0) A	0.0 (.049) A	<0.0133
***E. coli* (per 100ml)**	2.2 (6.5) A	4.4 (8.8) A	1.4 (9.8) A	0.0 (0.0) A	0.3092
***Aeromonas* (per 100 ml)**	8.9 (10.0) B		56.2 (69.3) A	2.2 (7.6) B	<0.0001
***Salmonella* (per 100ml)**					
Other Coliforms (per 100ml)	8.9 (14) A	0.0 (0.0) B	0.9 (4) B	0.0 (0.0) B	<0.0001

We found no significant differences in any macroinvertebrate variables (PTI, number of pollution intolerant organisms, number of intermediate organisms, number of pollution tolerant organisms, or number of species) among the creeks (Table 7). We also found no correlation between substrate at each pull site to the PTI found (results not reported).

Table 7: Mean macroinvertebrate variables (standard deviation) in terms of PTI, the number of pollution intolerant organisms, the number of intermediate organisms, the number of pollution tolerant organisms, and the number of macroinvertebrate species.

	Cozine	Gooseneck	Mill	P-value
PTI	9 (2)	14 (6.3)	13 (8.7)	0.2438
# Intolerant	2 (3)	3 (2)	3 (3)	0.4252
# Intermediate	18 (32)	1 (0)	0 (0)	0.0982
# Tolerant	85 (150)	3 (1)	2 (1)	0.0980
# Species	6 (0.8)	7 (0.8)	6 (0.8)	0.3253

When we compared the macroinvertebrate data collected between 2013 and 2015 at Cozine Creek, we found significantly higher PTI and species richness in 2015 than 2014 (Table 8). Data from 2011 and 2012 were not included because nonrandom methods for sampling macroinvertebrates were used prior to 2013.

Table 8: Mean macroinvertebrate variables (standard deviation) in terms of PTI the number of pollution intolerant organism, the number of intermediate organisms, the number of pollution tolerant organisms, and the number of macroinvertebrate species at Cozine Creek between 2013 and 2015. Means with different letters are significantly different from one another.

	2013	2014	2015	P-value
PTI	7 (2) AB	5 (0.8) B	9 (2) A	0.0114
# intolerant	1 (0.7)	1 (2)	2 (3)	0.5728
# intermediate	7 (6)	5 (8)	18 (33)	0.3249
# tolerant	8 (10)	12 (7.6)	85 (51)	0.1442
# species	5(2) A B	4(2) B	6(1) A	0.0118

When we compared the macroinvertebrate data collected at Gooseneck Creek between 2013 and 2015, we found significantly fewer pollution intolerant and pollution tolerant organisms in 2014 and 2015 than in 2013 (Table 9).

Table 9: Mean macroinvertebrate variables (standard deviation) in terms of PTI the number of pollution intolerant organisms, the number of intermediate organisms, the number of pollution tolerant organisms, and the number of macroinvertebrate species at Gooseneck Creek between 2013 and 2015. Means with different letters are significantly different from one another.

	2013	**2014**	**2015**	**P-value**
PTI	10 (6)	9 (5)	14 (6.3)	0.1782
# intolerant	13 (11) A	4 (6) B	3 (2) B	0.012
# intermediate	0 (0)	1 (3)	1 (1)	0.5331
# tolerant	13 (11) A	4 (6) B	3 (2) B	0.0152
# species	4 (2)	5 (3)	7 (3)	0.055

When we compared the macroinvertebrate data collected at Mill between 2013 and 2015, we found significantly fewer pollution intolerant organisms in 2014 and 2015 than in 2013 and significantly more pollution tolerant organisms in 2014 than in either 2013 or 2015 (Table 9).

Table 9: Mean macroinvertebrate variables (standard deviation) in terms of PTI the number of pollution intolerant organisms, the number of intermediate organisms, the number of pollution tolerant organisms, and the number of macroinvertebrate species at Mill Creek between 2013 and 2015. Means with different letters are significantly different from one another.

	2013	**2014**	**2015**	**P-value**
PTI	10 (5)	10 (5)	13 (9)	0.4726
# intolerant	17 (16) A	5 (5) B	3 (3) B	0.0135
# intermediate	1 (1)	0 (1)	1 (1)	0.196
# tolerant	1 (0.8) B	9 (6) A	2 (1) B	0.0003
# species	4 (2)	5 (2)	6 (3)	0.4157

DISCUSSION

Our data suggests that Cozine Creek has the poorest water quality compared to Mill or Gooseneck Creek. We are basing this conclusion on the fact that in 2015, Cozine Creek had the lowest pH and DO, and the highest temperature, BOD, turbidity, phosphate, *Aeromonas*, and other coliform bacteria.

Cozine Creek's poor water quality is most likely related to its urban location and close proximity to impervious surfaces like U.S. 99 located just upstream from Site 3.

Impervious surfaces in the city of McMinnville may lead to increased surface runoff (USGS 2015e). Runoff can contain animal waste, sediment from erosion, nutrients from garden fertilizers, and chemical contaminants including pesticides (USGS 2015f). The increased amount of nutrients from these non-point pollution sources can result in increased algal growth and lead to eutrophication (St. Johns River Water Management District, 2014). Eutrophication results in higher BOD and lower DO levels, which is what we found at Cozine (St. Johns River Water Management District, 2014). In addition, the warmer water found at Cozine Creek can not hold as much oxygen as the cooler waters found at Gooseneck and Mill Creeks (Penn et. al. 2009). These combined variables may be responsible for Cozine Creek having the lowest DO and highest BOD in 2015 as shown in Figure 1 (Penn et al. 2009). BOD appears to have fallen in the last few years at Mill and Gooseneck Creeks, while it has risen at Cozine.

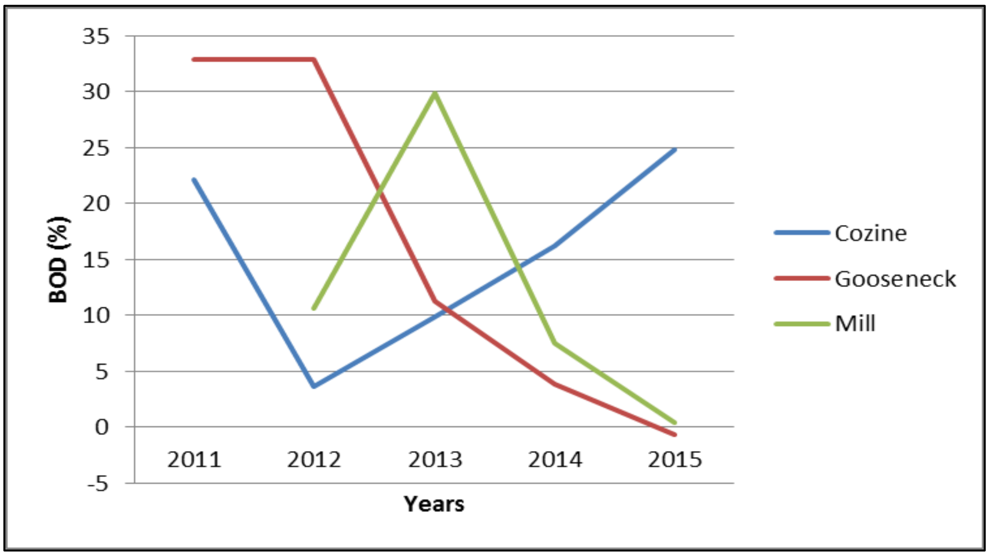

Figure 1: Comparison of BOD Levels at Cozine, Gooseneck, and Mill Creeks from 2011 to 2015

It is difficult to ascertain the exact cause of Cozine's poor water quality because water quality can be influenced by so many interconnected variables. Temperature stands out as a significant source of water quality degradation this year because 2015 was the hottest summer on record in the Northwest (Dolce 2015). Temperature affects multiple water quality variables. Higher water temperatures can result in lower DO levels because warmer water holds less oxygen than cooler water. Low DO levels makes it difficult for some species of fish to survive (EPA 2012b). Higher temperatures can increase the abundance of bacteria and algal growth. This can increase BOD as organic matter decays and consumes oxygen (USGS 2015c). pH decreases as water temperature increases, which makes the water more acidic when temperatures rise (EPA 2012d). Turbidity can increase water temperature because suspended particles near the water's surface absorb extra heat from sunlight, which raises the overall water temperature (USGS 2015a).

Water testing and samples were taken at Mill and Gooseneck Creeks prior to rainfall. Water quality sampling for Cozine occurred approximately one week after a period of rainfall. This rain could account for the higher flow and turbidity found at Cozine Creek compared to the other two creeks. The rainfall may have also resulted in increased urban runoff containing nitrate and phosphate, which were both found in higher quantities at Cozine than at Mill and Gooseneck Creeks (USGS 2015b).

Although we found no significant differences in the macroinvertebrate variables among the three creeks, the average PTI at Cozine indicated poor water quality, whereas the average PTIs of Gooseneck and Mill Creeks indicated fair water quality (EPA 1997).

We found that Cozine had significantly higher turbidity than either Gooseneck or Mill Creek from 2013 to 2015 (Figure 2). Turbidity affects the kinds of organisms that live in freshwater streams. Coho salmon (*Oncorhynchus kisutch)*, a keystone species found Yamhill and Polk Counties, require turbidity measurements 10 FTUs and below in order to survive (Osmond et al. 1995). Cozine Creek is approaching the upper limit of turbidity where the fish could thrive (Figure 2). Both Gooseneck and Mill Creeks have turbidity levels well below the maximum level of turbidity suitable for salmon. If Cozine Creek turbidity levels continue to increase, fish health will suffer as high levels can clog gills, lower growth rates, reduce disease resistance, and slow egg development in fish (USGS 2015a).

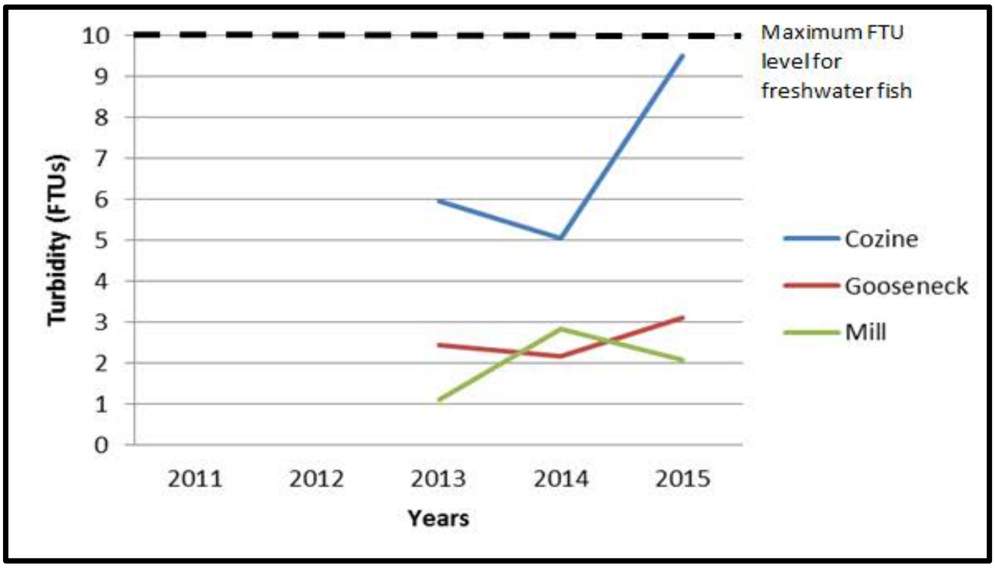

Figure 2: Comparison of Turbidity Levels at Cozine, Gooseneck, and Mill Creeks from 2013 to 2015. The hatched line represents the maximum FTU level for freshwater fish.

We found that nitrate levels at Gooseneck and Mill Creeks have increased significantly since 2014, whereas nitrate levels at Cozine have been increasing since 2013 (Figure 3). When levels of nitrate reach two ppm sensitive aquatic species like coho salmon, begin to die (Camargo et al. 2005). All three creeks had nitrate levels above the recommended level for coho salmon in 2015. Mill Creek had the highest level of nitrate, followed by Mill and then Cozine. Excess nitrate can cause reproductive problems, as well as reduced development and spawning rates in salmon. The high levels of nitrate could decrease the coho salmon populations in the creeks, especially Mill (EPA 2015d).

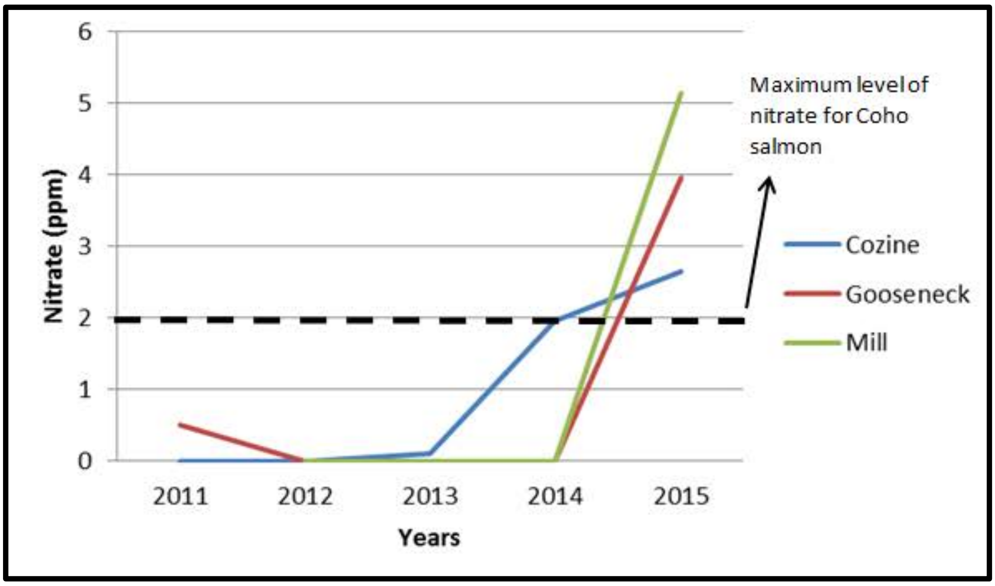

Figure 3: Comparison of Nitrate Levels at Cozine, Gooseneck, and Mill Creeks from 2011 to 2015. The hatched line represents the maximum nitrate level for coho salmon.

We found that phosphate levels in Gooseneck and Mill Creeks were significantly lower than Cozine for all years since 2011, but all creeks had an increase in phosphate, especially Cozine (Figure 4). The recommended maximum levels of phosphate in freshwater streams and rivers is 0.1 ppm. If streams and rivers go above that amount, freshwater organisms, like Coho salmon, begin to suffer (EPA 2015d). Both Mill and Gooseneck Creeks have phosphate levels below the maximum amount recommended for coho salmon and thus are safe environments for fish. Cozine Creek, on the other hand, has had phosphate levels above the recommended amount for three out of the five years tests, potentially contributing to a reduction in salmon in the creek. Excess phosphate in the water can lead to higher BOD, leaving less oxygen in the water for fish. Excess phosphate also can lead to declines in reproduction, growth rate, spawning rate, and egg development (EPA 2015d).

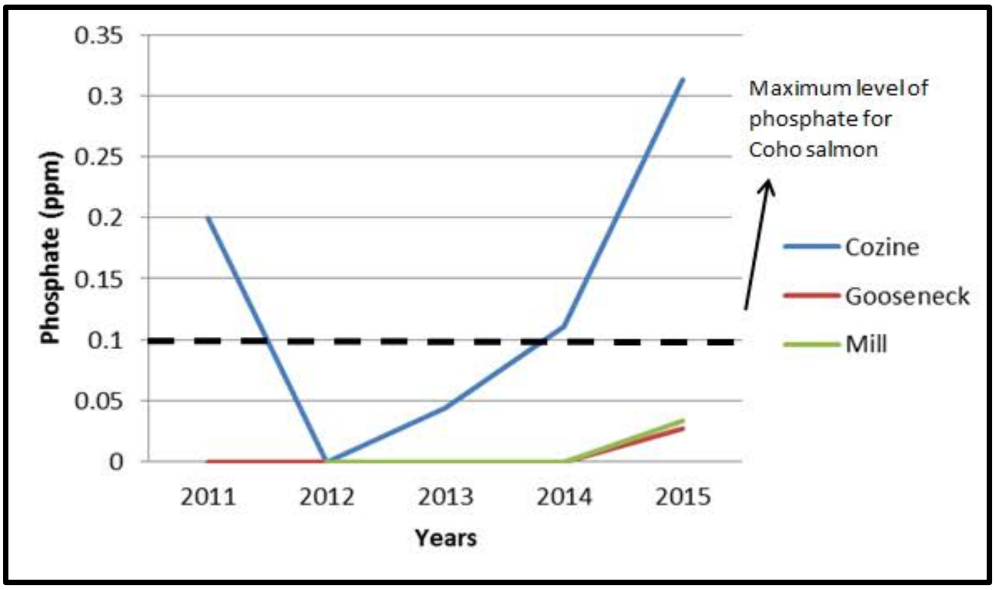

Figure 4: Comparison of Phosphate Levels at Cozine, Gooseneck, and Mill Creeks from 2011 to 2015. The hatched line represents the maximum level of phosphate for coho salmon.

We found that Cozine had significantly lower levels of DO than either Gooseneck or Mill Creeks in all three years from 2012 to 2015 (Figure 5). Aquatic life found in the three creeks including coho salmon have optimal DO ranges in which they can survive. Coho salmon require six ppm. The DO levels in Cozine Creek have been below the optimal DO level for salmon in two of the three years tested (Figure 5). DO levels at less than optimal levels can cause reduced swimming speed, slower growth rates, reduced reproduction, and death (USGS 2015b). Coho salmon will most likely be negatively affected by the low DO (ppm) levels in Cozine Creek. Dissolve oxygen levels in Gooseneck and Mill Creeks have been above coho salmon's optimal 6 ppm (EPA 2012b).

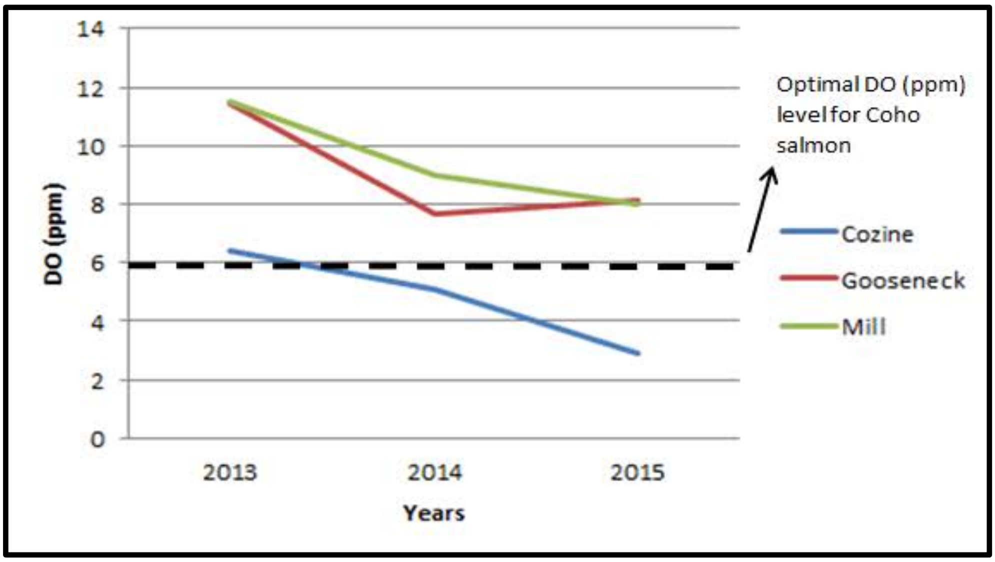

Figure 5: Comparison of DO Levels at Cozine, Gooseneck, and Mill Creeks from 2013 to 2015. The hatched line represents the optimal DO level for coho salmon.

Salmon are important indicators of the health of a watershed. Their presence or absence can reveal issues with turbidity, DO, nitrate, phosphate, and BOD. Furthermore, salmon play a significant role in transferring nutrients from marine to terrestrial ecosystems and provide a food source for native animals (Hilderbrand et al. 2004) as well as humans. Coho salmon are found in the Yamhill County Watershed from October to January to spawn. Recent drought has resulted in a reduction in Coho salmon populations; in 2015, approximately 5% of a typical Coho salmon population run has been found in Yamhill County creeks. This dramatic reduction in the population size of Coho salmon could reduce the health of entire creek ecosystems. In addition, local human economies, such as the Confederated Tribes of the Grand Ronde Community, depend on the salmon industry as a source of profit and food (Confederated Tribes of Grand Ronde 2014). Without healthy populations of salmon, creek ecosystems will deteriorate and possibly disrupt traditional practices. This could be a concern for Cozine Creek as DO has been below optimal levels for several years.

Over the years of our study, levels of BOD, nitrate, phosphate, turbidity and DO at Gooseneck have remained similar to that of Mill, an unrestored rural creek located in the same county (Figures 1 to 5). While the goal of the restoration at Gooseneck Creek was to improve the water quality over time, its similarity to Mill Creek shows that the restoration has not had the intended impact.

LIMITATIONS

One of the limitations of our study this year was the unreliability of the Hanna Instruments DO meters. While testing BOD in our water samples from the creeks, we observed that the DO readers seemed to give higher readings in the lab than at the creeks.. The DO of the five-day incubated water samples should either stay the same or decrease because of organisms and chemical reactions using dissolved oxygen. The inaccuracy in the readings not only limited our data’s reliability, but also caused concern for the accuracy of the DO and BOD calculations in past years’ data. The same meters, however, were used for all ENVS Research Method classes, which decreased the variability of the readings between years.

Another limitation was in our accuracy of counting the macroinvertebrates. Some pulls, in particular at Cozine site three, had very turbid waters and a lot of sediment in the samples, resulting in much more time spent going through each of the pulls. In addition, the turbidity hindered the quality of our counts because organisms were harder to find. For this reason, some of the Cozine jar's counts were not duplicated.

RECOMMENDATIONS:

There are several recommendations we would make to future Environmental Research Methods classes. First, the addition of a an upstream site in Cozine Creek would be beneficial to study possible changes in water quality as the stream moves from its rural headwaters into an urbanized area. Just focusing on sites along Cozine Creek and getting rid of the sites in Mill and Gooseneck would be an interesting project to conduct in the future.

When taking macroinvertebrate samples, it is recommended to not take samples on substrates that are rated a 5 (bedrock). This will prevent potential biases in the macroinvertebrate data because bedrock samples only contained snails.

Digital dissecting microscopes that took quality photographs of macroinvertebrates in the field would be helpful when trying to identify species, especially if the samples later become altered due to the alcohol preservation process. We experienced decomposition and disintegration of some macroinvertebrate samples that made identification difficult.

We recommend using an updated PTI system that has four categories of macroinvertebrates instead of the three categories that we used.

We also strongly recommend purchasing new DO equipment due to the fact that our current DO meters appeared unreliable.

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