Comparing Water Quality at Three Creeks in the Greater Yamhill Watershed

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INTRODUCTION

The importance of water cannot be overstated. There is no known organism that does not depend on it for survival, and having water that is potable is a fundamental requirement of the existence of life on Earth. Considering how integral water is to life, advocacy for high water quality is vitally important. Despite this fact, water pollution has been a problem for thousands of years, dating back at least as far as our transition from societies of nomadic hunters and gatherers to that of sedentary horticulturalists (Diamond 1999). It is no less important in modern industrial society. Contaminated water can affect thousands of people living in close proximity.

There are two primary types of water pollution—point source and non-point source. Point source refers to the type of pollution that is easily linked to a direct contaminant. Non-point source is the main problem today because it encompasses pollution that is unidentifiable as to source. When a source cannot be identified, regulation of that pollution becomes practically impossible. Without regulation nothing will change because no one can be held accountable. Without the chance of enforcement the health of bodies of water affected by non-point source pollution will continue to be degraded on a daily basis without much hope of improvement (EPA 2012e).

It wasn't until the 1800s that people realized the importance of sanitation and potable water, leading to the widespread development of sewage and water treatment facilities (NOAA 2008). In the U.S., the first federal water pollution law dates back to the Rivers and Harbors Act of 1886 (recodified in 1899) that banned the intentional release of pollutant discharges (with the focus being on oil discharges) from ships into American rivers and harbors, but set no limitations on pollutant discharges into the open ocean. This act was amended in 1924 to add penalties for gross negligence (Christine 1994). In 1948, the Federal Water Pollution Control Act (FWPCA) was passed as a means to try and create a stronger and more unified policy to protect all of the nation's bodies of water, however the FWPCA delegated the task of water regulation to state and local agencies that led to inconsistencies in water quality standards. The FWPCA was amended in 1956, 1965, 1966 and 1970. By 1972 it had become apparent that the act was in need of an overhaul due to the somewhat ambiguous wording and the American public's rising concern over pollution levels in the nation's water (EPA 2014a). Later that year, the FWPCA was amended and the Clean Water Act (CWA) was passed. The CWA implemented a formal structure to regulate pollutant discharges, gave the EPA the authority to establish pollution control programs, made navigable water point-source pollution discharges illegal unless permits were granted through the National Pollutant Discharge Elimination System (NPDES), and used federal grants to construct sewage treatment plants (EPA 2014c, EPA 2014d). The CWA instigated proper economic valuation of good water quality including its use and nonuse values. As long as water sources are properly valued and the public understands that their actions must reflect that value, they will be more willing to support regulations that improve water quality (EPA 2012e).

According to the DEQ, watersheds are geographically related bodies of water that drain into a single waterway. The Watershed Approach is the current method that the EPA uses to consult with local, state, and federal agencies, allowing for direct, interactive feedback between the DEQ and its many stakeholders (DEQ 2006). The increase in nonpoint source pollution is what inspired the need for a broader environmental management strategy. The Watershed Approach provides the solution to help identify the nonpoint source pollution by analyzing how hydrological bodies flow by geographic area, thus allowing the EPA to better identify the sources of pollutants (EPA 2014d) Hydrologic watershed units (HUCs) were developed by the United States Geological Survey (USGS) in conjunction with the National Elevation Dataset (NED) project to provide geospatial information on stream flows and their hydrologic drainage basins. Twenty-one HUCs divided into smaller sub-classifications: regions, sub-regions, accounting units, and cataloging units, define the whole hydrologic system of the United States with some specificity (USGS 2014a).

Water quality is a defining ecological factor, and poor water quality can send a ripple effect across all trophic levels in an ecosystem. Quality is measured by determining the biological, physical, and chemical suitability of a water source (USGS 2012). Contaminants in water may be either naturally occurring, caused for example by groundwater passing through sediment high in a metallic compound like iron, or anthropogenic from industrial activities, urbanization, agricultural production, or other human activities (USGS 2014a). High levels of contaminants in water, particularly nutrients from agricultural runoff and point-source pollution may cause eutrophication of the water source. Eutrophication occurs when increased nutrient levels lead to algal blooms; consequently increasing the number of aerobic bacteria that consume dissolved oxygen. Eutrophication may coincide with alterations in the temperature and/or pH, making the waterway a dead-zone, unsuitable for habitation by many organisms dependent on dissolved oxygen (Mueller and Helsel 2009).

It is vital that local communities routinely test bodies of water to determine if they contain contaminants in concentrations above those defined as below harm by the CWA. The Environmental Science Research Methods class (ENVS 385) of fall 2014 collected water samples from Mill, Gooseneck and Cozine creeks, which are all water bodies located in the Greater Yamhill Watershed. Our goal was to determine water quality levels and compare the sites. Similar water quality studies were performed in 2011, 2012 and 2013 by earlier ENVS 385 classes. The repeated sampling allows a temporal comparison of variance in stream water quality (Bailey et al. 2012, Colahan et al. 2011, Hollenbeck et al. 2013, Weinbender and Crane 2011).

In addition to studies conducted by the students of Linfield College, the Oregon Department of Environmental Quality (ODEQ) has assessed the water quality of each creek, reported in the agency's Integrated Report Assessment Database in 2010 and updated in 2012. The ODEQ uses a five-category system to rank the quality of the water at a site. Category 1 waters are exemplary, meeting and exceeding all criteria for clean water. This category is not actually assigned to bodies of water being tested, but is instead used to establish the baseline for perfect water quality, that categories two through five are measured against. Category 2 waters are those that meet the required standards outlined by Category 1. Category 3 is assigned to bodies of water that have insufficient data and has two subcategories, 3B, and 3C. 3B indicates that the test results for a water body have failed to meet the minimal criteria to assign it to Category 2, but lacks enough information to assign it elsewhere. 3C indicates the presence of an unknown pollutant, and requires further testing. Category 4 indicates the presence of a known contaminant, but at a level low enough that a Total Maximum Daily Load (TMDL) calculation is not required (minimal risk of harm from exposure). A TMDL is the calculated maximum level of a pollutant allowable within a body of water such that the standard acceptable quality of water is still met. The use of TMDL calculations is vital to the monitoring of both point and nonpoint sources of pollutants in bodies of water (EPA 2012e, ODEQ 2012). Category 4 is broken down into three subcategories: 4A, 4B and 4C. Category 4A indicates that a TMDL has previously been ordered here and another is not required at this time. Category 4B indicates that other water pollution controls are underway that will in all likelihood restore water quality back to levels within tolerance of ODEQ standards. Category 4C indicates that the factor causing the impaired quality is not a contaminant, but related to another factor, such as the lack of flow. Lastly, Category 5 waters are those waters with compromised quality at levels significant enough to require a TMDL calculation as outlined in Section 303(d) of the CWA. A single body of water may have several tests performed on it with a categorical rankings applied to each water quality factor being examined. For example, a creek may be classified as Category 3 for coliform bacteria and Category 5 for temperature (ODEQ 2012).

General area history

Historically the Kalapuya Indians managed areas of the watershed with fire, and maintained the Greater Yamhill Watershed (Yamhill Watershed Council 2005b). For the last four thousand years and likely longer, the Native Americans burned large areas of the land. Native Americans historically managed oak trees through prescribed fires that helped the fire resistant oak become the dominant species in the ecosystems (Abrams 1992). The long term results of this practice created an ecosystem typified by large stretches of open grassland populated by clustered groupings of large oak trees, making it ideal for industrialized agriculture and cattle ranching. Systematic burning maintained oak savannas and prairies, but following settlement, the influence of forestry led to the propagation of Doug-fir forests currently dominating much of western Oregon (Yamhill Basin Council 2001).

History of Cozine Creek

Cozine Creek was historically dominated by wet oxbows and standing water, but they were eliminated during settlement of Yamhill County. Cozine quickly became surrounded by municipal development. The community of McMinnville grew until it became a recognized city, and the urbanization altered Cozine and other south Yamhill streams significantly. Research has shown that urban water systems have lower quality of water especially in regards to biochemical oxygen demand and fecal coliform bacteria (Ensign et al. 2009).

The Oregon DEQ investigated the water quality of Cozine Creek and although there were anecdotal reports from residents of sewage overflow, the reports were not sufficient to get the creek on the ODEQ 303(d) list; more data was deemed necessary (Yamhill Basin Council 2001). In 1989, 1998, and 2009 high levels of fecal contamination were found in Cozine Creek, but the points of highest contamination were where the creek entered the city from agricultural areas and the levels decreased as the creek ran through the city (ODEQ 2012 Yamhill Basin Council 2001).

The summary of the 2010 water quality testing by the Oregon DEQ for the Lower Yamhill Watershed, a sub-area of the Greater Yamhill Watershed, is shown in Table 1. This table indicates that Cozine Creek and its headwaters, the South Yamhill River, were both severely degraded. Cozine Creek and the South Yamhill River had heightened bacterial levels and temperatures; they were also labeled at risk due to increased nutrient levels, sedimentation, and heavy metals, and a decreased DO (Yamhill Basin Council 2001). Moreover, the research class from Spring 2011 found Gooseneck to have higher water quality than Cozine due to higher DO and flow levels that were found in Gooseneck versus Cozine in Spring 2011. Higher amounts of bacteria were also found in Cozine rather than Gooseneck. In addition, there was also a greater diversity of macroinvertebrates at Gooseneck rather than Cozine, which indicated lowest water quality at Cozine creek. Cozine Creek has continued to have the lowest water quality proven by the data from the past research classes. (Colahan et al 2011).

Table 1: Watershed Conditions Summary (Yamhill Basin Council, 2001)

Sub-Basin	Riparian Conditions	Wetland Conditio	Water Quality	Sediment Sources	Hydrology and Water Use
Cozine/South Yamhill	Most degraded riparian areas in the watershed. Very narrow bands of vegetation with agricultural uses bordering closel Many areas with bare ground or short vegetation Some areas with no vegetation or streambed remaining.	Many wetlands along the South Yamhill and its tributaries. Only NWI mapped information available. No Loc Wetland Inventor Data available/ Large acreage of drained hydric so	South Yamhill 303(d) listed for bacteria and temperature. Also risk for pH, nutrients, sedimen toxins, dissolved oxygen (DO), and chlorophyll. Cozin Creek is at risk for bacteria.	Some debris flow hazard potential. Large areas of impervious surface urban runoff non-point sources of pollution, construction sites, annual grasses, row crops, clean cultivated orchard	Heavily irrigat along South Yamhill river, many domestic wells, and som in-stream reservoirs.

As an urban stream, Cozine was labeled at risk of bacterial contamination in 2009, a hazard that was discovered to be from a leaking sewage pipe. A restoration effort noticeably dropped the levels of these coliforms, but Cozine Creek water quality has failed to improve beyond that (Hollenbeck et al 2013).

History of Mill and Gooseneck Creeks

Mill and Gooseneck Creeks are geographically close to one another, with Gooseneck flowing into Mill. . The Mill Watershed was historically shaped by the burgeoning timber and agriculture industries. The land surrounding the creeks has changed to accommodate farming and livestock production. In the 1800s, fields and wetlands in the watershed were drained to make way for future agriculture. In the 1890s and the early 1900s, several projects were implemented by the logging industry to help stabilize stream banks to facilitate the movement of logs downstream. This included the construction of a dam that was attached to a sawmill and a 10-mile long flume. Splash dams were built in as many as 70 locations within the watershed, altering seasonal flows (Yamhill Basin Council 1999, Bower et al 1999).

One of the largest impacts on Gooseneck Creek was the diversion project that altered its original path (Yamhill Basin Council 1999). Landowners straightened the banks adjacent to their property, which had the effect of increasing stream flow rates and eroding the streambed down to the bedrock (Waterways Consulting 2009). Studies have shown that removal of riparian trees and alterations in stream morphology causes unpredictable changes in debris abundance and water flow patterns, and negatively impacts the ecological viability of aquatic organisms (Bisson et al. 1987). In September 2009, a restoration project was initiated to rectify previous damage. Log weirs were installed along a section of Gooseneck creek to slow water velocity and help restore the natural riffle and pool composition that had existed prior to aforementioned industrial altercations. The restoration also included the installation of wooden and rock structures to reduce the rate of sediment erosion from the streambed. A side channel that had been blocked was reopened to help reduce stream flow during high water events (Waterways Consulting 2009, National Fish and Wildlife Foundation 2011). Unfortunately, in 2013 it was discovered that one weirs had been washed out, but overall the project was successful in reducing stream flow during high flow events (Waterways Consulting 2009, Forsberg and Tennant 2013).

The ODEQ performed water quality tests on Gooseneck and Mill creeks in 2012 and gave them each multiple Category 5 ratings relating to salmonid (salmon and trout) proliferation and habitability. These ratings were for insufficient DO and excessive temperatures for salmonid spawning, as well as an unknown biological criterion. In all cases, TMDLs were ordered, and the sites were added to the EPA's 303(d) list. Mill creek is still awaiting a TMDL ordered in 2010 for excessive levels of phosphorus. Previous studies noted that DEQ testing between 1998 and 2004 revealed that Gooseneck creek was given a category 3 rating due to the presence of unknown pollutants. Similarly, testing done between 2003 and 2004 classified Mill creek with a category 3 due to the presence of unknown pollutants in certain areas; however, in other areas it was given a category 2 classification – not impaired (ODEQ,2012),

Water Quality Indicators

The factors measured and rated by the ODEQ include Dissolved Oxygen (DO), rate of flow, water depth, pH, temperature, turbidity, Biochemical Oxygen Demand (BOD), macroinvertebrates and bacterial coliforms. Each of these is important to determine the water quality of a particular body of water (USGS 2014a).

Dissolved oxygen (DO) is a measure of the oxygen available to organisms in a body of water. This measurement is directly related to flow and temperature. As water flows over rocky substratum in fast moving, shallow areas, riffles form to aerate the water, increasing levels of DO. Water temperature is important because cold water can hold more oxygen than warm water. Many species of fish, including salmonids, are sensitive to oxygen and require high DO levels to proliferate. DO can be measured in ppm (parts per million) or as a percentage. The state of Oregon has set the minimum acceptable DO concentration at 9.0 parts per million (ppm). Levels below this have been shown to reduce salmonid survivorship and reproduction (EPA 2012b, Wasowski et al. 2013).

Biochemical oxygen demand (BOD) is a measure of the oxygen used by organisms and chemical oxidants in the water. BOD is often negatively correlated to DO. If the DO level is low and the BOD is high, the water may be uninhabitable by aquatic organisms. Factors that increase BOD include anything that introduces eutrophic factors or organic material into a body of water, including leaf litter and woody debris from trees, as well as runoff from feedlots, wastewater treatment facilities and paper mills (EPA 2012b).

Temperature affects DO levels in water and as mentioned previously, cold water can hold more oxygen than warm water. Temperature can be affected by numerous factors. Seasonal changes in ambient air temperature will lead to changes in water temperature, shade from overarching vegetation may decrease water temperature depending on the width of the stream, and increased flow rate is correlated with lower temperature (WA. DOE 2012).

Flow is a measure of the rate at which a river or stream is moving. Flow affects DO and temperature and is itself affected by the hydromorphological architecture of the stream. Top quality streams have both fast moving and shallow riffle areas, as well as slower, deeper pools that serve as resting areas for fish and other aquatic organisms (EPA 2012f).

Turbidity is a measure of the amount of particulate matter suspended in the water column. In large enough quantities, particulate matter can raise the temperature of the water as it absorbs solar energy. Turbidity also affects fish survivorship and reproduction. Excessive levels of particulate matter can clog the gills of fish, reducing their growth rates and damaging their respiration system. In streams with low flow rates, particulate matter may form a layer of sediment over the stream bottom, suffocating eggs deposited there as well as benthic macroinvertebrates (EPA 2012e).

The measure of the acidity of a body of water is known as pH, which is the negative logarithm of hydrogen ion activity in solution and ranges from 0 to 14. The EPA recommends a range of 6.5 to 8.5 for freshwater streams (EPA 2014b). These numbers are logarithmic units, and a change of one pH equals a ten-fold change in either alkalinity (increase) or acidity (decrease). Changes in pH affect the solubility of nutrients and heavy metals, with many heavy metals becoming more toxic at lower (more acidic) pH levels (EPA,2012d) For example, the toxicity of ammonia is ten times more alkaline at a pH of 8 than a pH of 7. When the pH of most aquatic systems falls below 6, fish populations begin to disappear, the stream bottom becomes covered with undecayed material, and mosses may dominate shores and shallow areas (USGS 2014b).

Coliform bacteria such as *Escherichia coli* (*E. coli*) are indicators of fecal contamination in water and may correlate with increased levels of nutrients. Fecal bacteria tests typically examine total number and variety of coliforms, as well as specific counts for *E. coli*, enterococci, fecal coliforms, and fecal streptococci. The EPA has recently revised their testing recommendations to focus primarily on *E. coli* and enterococci, with *E. coli* being the primary indicator of health risk from fecal bacteria in freshwater streams (EPA 2012c). Coliform bacteria are present in large numbers in the feces of warm-blooded animals. Although coliform bacteria themselves do not normally causes serious illness, their presence is used to indicate organisms of fecal origin may be present. Such pathogens include disease-causing bacteria, viruses, protozoa and many multicellular parasites. In addition, coliform bacteria that can be harmful to the ecosystem and humans who come into contact with it in the water (Garrido 2014).

We also tested for the bacterium, *Aeromonas*. The genus *Aeromonas* includes a diverse collection of different bacteria. *Aeromonas* is of concern because the bacteria are regarded as pathogenic organisms that can cause gastroenteritis—an inflammation of the stomach and intestines. Other species, such as*Aeromonas hydrophila, Aeromonas sobria* and *Aeromonas caviae*, have been reported to cause wound infections and septicemia (Gavriel et al. 1998).

Macroinvertebrates are defined as benthic organisms lacking vertebrae that are visible to the naked eye. They spend a significant portion of their lifespans in localized stretches of water and do not migrate long distances, making them relatively easy to collect and identify. Because they spent most of their lives in the stream, they are useful indicators of both short and long term pollution events. Different species have significant variances in their ability to tolerate water pollution. A presence or absence of a macroinvertebrate species in an area typically correlates with water quality. Over 95% of organisms in water sources are benthic macroinvertebrates, ensuring that there will always be enough specimens available to analyze. Macroinvertebrates are significant to nekton (mobile) organisms such as fish by providing an essential food source (EPA 2012a, EPA 2012b, Krueger and Waters 1983).

Goals of Study and Hypotheses

Our study continued the research of previous ENVS 385 classes to evaluate the water quality of three local streams and to compare our findings to those of previous years. We hypothesize that due to its urban setting, water quality would be lower in Cozine Creek than in

Gooseneck or Mill Creek, similar to the findings of past classes (Bailey et al 2012, Colahan et al 2011, Hollenbeck et al 2013, Weinbender and Crane 2011). Due to the efforts of the restoration project, we hypothesized that water quality at Gooseneck creek would be increasing over time.

SITE DESCRIPTIONS

GPS/GIS

The previously established study sites were navigated to, and new GPS coordinates for each sample location along each creek were collected with a Garmin Etrex Vista H handheld GPS. Coordinates were uploaded into ArcMap via the ArcGIS suite 10.2.2 (ESRI 2014). Spatial layers were downloaded from public access resources into ArcMap. Gathered layers include HUC-8 watershed boundaries and hydrography, orthographic imagery, statewide precipitation and temperature, and land cover (USGS 2014, NRCS 2014). Maps were developed to examine specific geographic information relevant to the area within the HUC-8 boundary for the Greater Yamhill Watershed, and then locally by creek.

General site locations

Cozine, Mill, and Gooseneck Creeks are all located within the Greater Yamhill Watershed with the unique HUC8- ID 17080009. The Greater Yamhill Watershed covers 529,510 acres due east of the Coastal mountain range in Oregon and west of the Willamette river. Cozine Creek and the South Yamhill River make up a sub-watershed called Lower Yamhill Watershed that is approximately 63,748 acres in size (Yamhill Basin Council 2001). Mill and Gooseneck Creeks are located in Polk County, which is sparsely populated and mostly rural in comparison to the urban surroundings of Cozine Creek. Both Mill and Gooseneck Creeks are located in the Mill watershed, and Gooseneck flows into Mill directly below our Mill sampling sites. Precipitation, soil, and land cover descriptions are included, but are general area descriptions not necessarily intended to capture local discrepancies. Field observations are therefore included for each of the creeks following general area descriptions.

Precipitation

Geographically, the Greater Yamhill Watershed is located in the eastern rain shadow of the Coastal Mountain Range, reducing precipitation levels and increasing temperature relative to the western or coastal side. A rain shadow is an ecological phenomenon where warm, moist, high-pressure air rises over elevated terrain due to a prevailing wind current, releasing pressure and precipitation until it reaches the peak elevation. Arriving on the opposing face, air is warmer and moisture is reduced, resulting in a lower precipitation distribution (Pendelton 1949). The prevailing wind movement eastward reduces precipitation drastically, from 155 to 37 inches per year, with a calculated average of approximately 62 inches per year (Figure 1). Geographically, Gooseneck and Mill Creeks are southeast of Cozine Creek, with increased precipitation in downstream areas, although the study sites (indicated by red points) are similar in their local precipitation levels between Gooseneck, Mill, and Cozine Creeks. Their relatively homogeneous precipitation levels are due in part to the flattening of elevation characteristic of the shift from the Coastal Mountain Range to the Willamette valley.

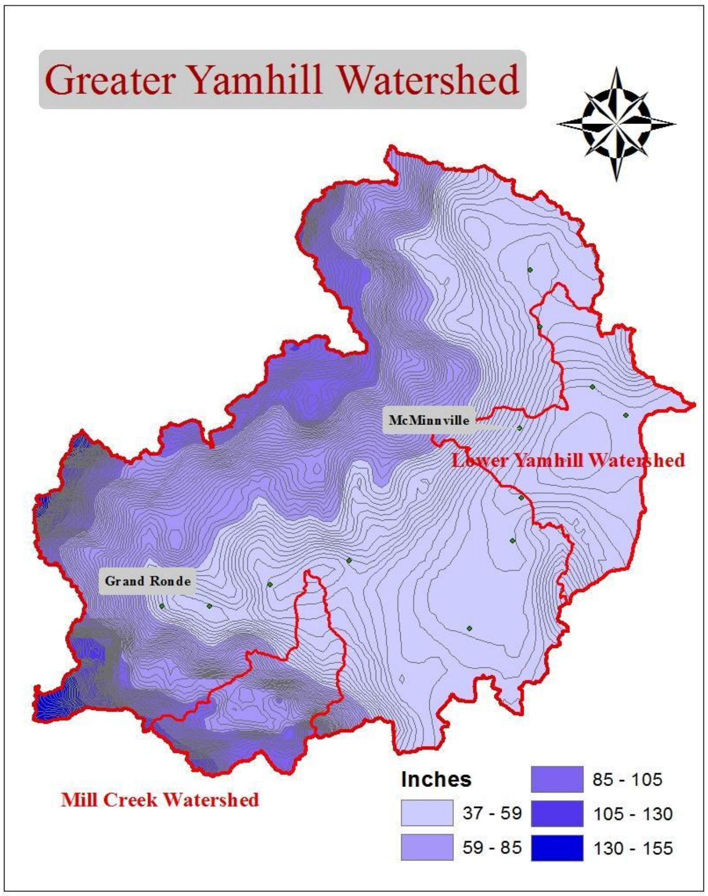

Figure 1: Greater Yamhill Watershed average precipitation between the years 1981 and 2002 (source: USGS, 2014; created by Robin Fahy 2014).

Soils

The Yamhill Basin Council identified most of the soil types and their respective regions in the Lower Yamhill watershed. At the headwaters of Cozine Creek, basalt and gabbro sills and dikes are intermingled with Nestucca formation deposits that are mixed with volcanic flows, tuffs, marine siltstone and sandstone (Yamhill Basin Council 2001). The soil type affects sediments found in the water as it slowly erodes the bedrock, taking minerals with it. The type of bedrock under the body of water also impacts how quickly and under what conditions erosion occurs (Miller 1991). The geology of the Mill Creek Watershed is similar to the Lower Yamhill, and the volcanic minerals in soil are predominantly basalt based (Yamhill Basin Council 1999).

Land cover

The 2010 land cover for the Greater Yamhill Watershed is shown in Figure 2. Evergreen, deciduous and mixed evergreen/deciduous forests dominate the western half of the watershed. Common Pacific Northwest evergreen tree species include Western red cedar (*Thuja plicata*), Western hemlock (*Tsuga heterophylla*), and Douglas-fir (*Pseudotsuga menziesii)*. Common deciduous species include big-leaf maple (*Acer macrophyllum*), vine maple (*Acer circinatum*), red alder (*Alnus rubra*), Oregon ash (*Fraxinus latifolia*), and Oregon white oak (*Quercus garryana)*. Land cover in the eastern half of the watershed is predominantly agricultural, with even distributions of cultivated crops and hay/pastureland. Most of the developed land is found in this section in high-density populated cities such as McMinnville and Sheridan. Each rise in the scale of intensity on the map is indicative of an increase in area covered by impermeable surfaces (USGS 2014, NRCS 2014).

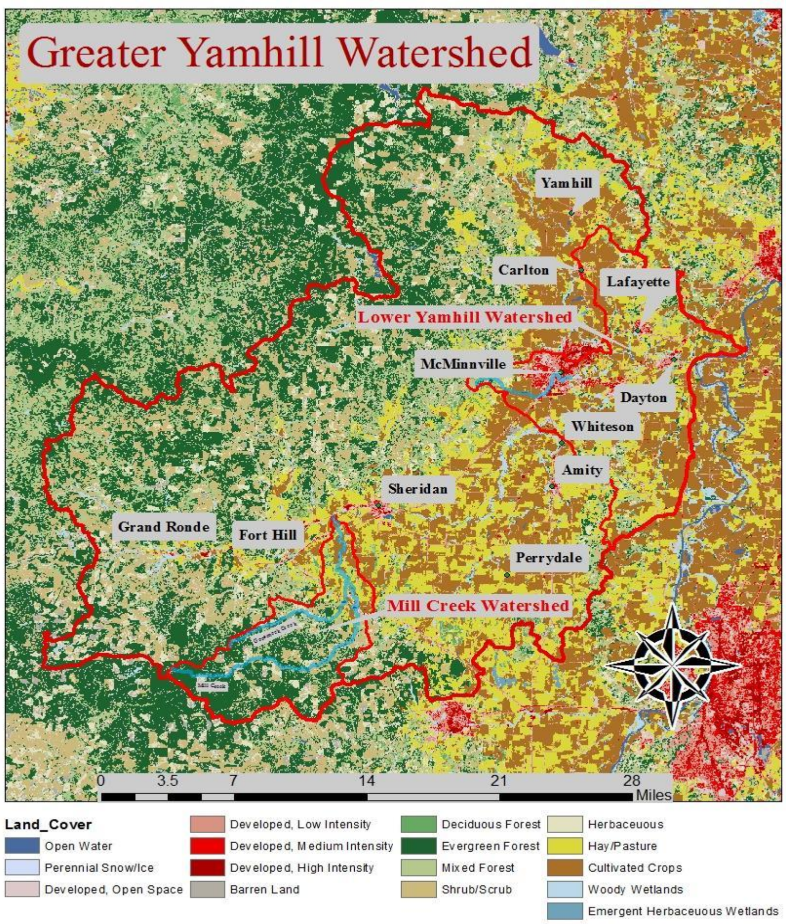

Figure 2: Greater Yamhill Watershed: Land Cover (source: NRCS 2014; created by Robin Fahy 2014).

A more specific designation of land cover surrounding Cozine Creek is shown in Figure 3. The majority of the immediately surrounding area is established human developed (low to medium intensity) and cultivated cropland.

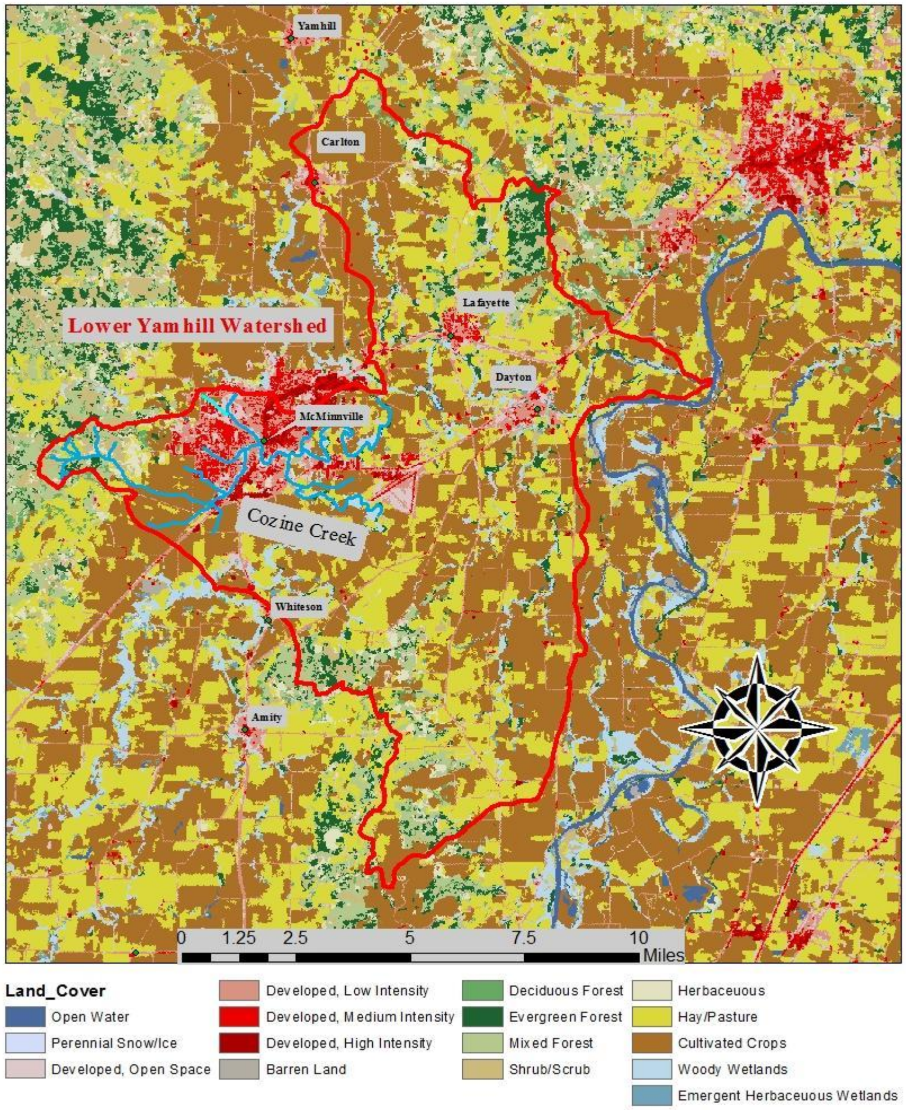

Figure 3: Land Cover - McMinnville and Cozine Creek (source: NRCS, 2014, created by Robin Fahy).

A more specific designation of land cover around Gooseneck and Mill Creeks is shown in Figure 4. The majority of the surrounding area is cultivated cropland and hay/pastureland, with evergreen and mixed forests on the southern end and localized areas of medium-low intensity development in the north.

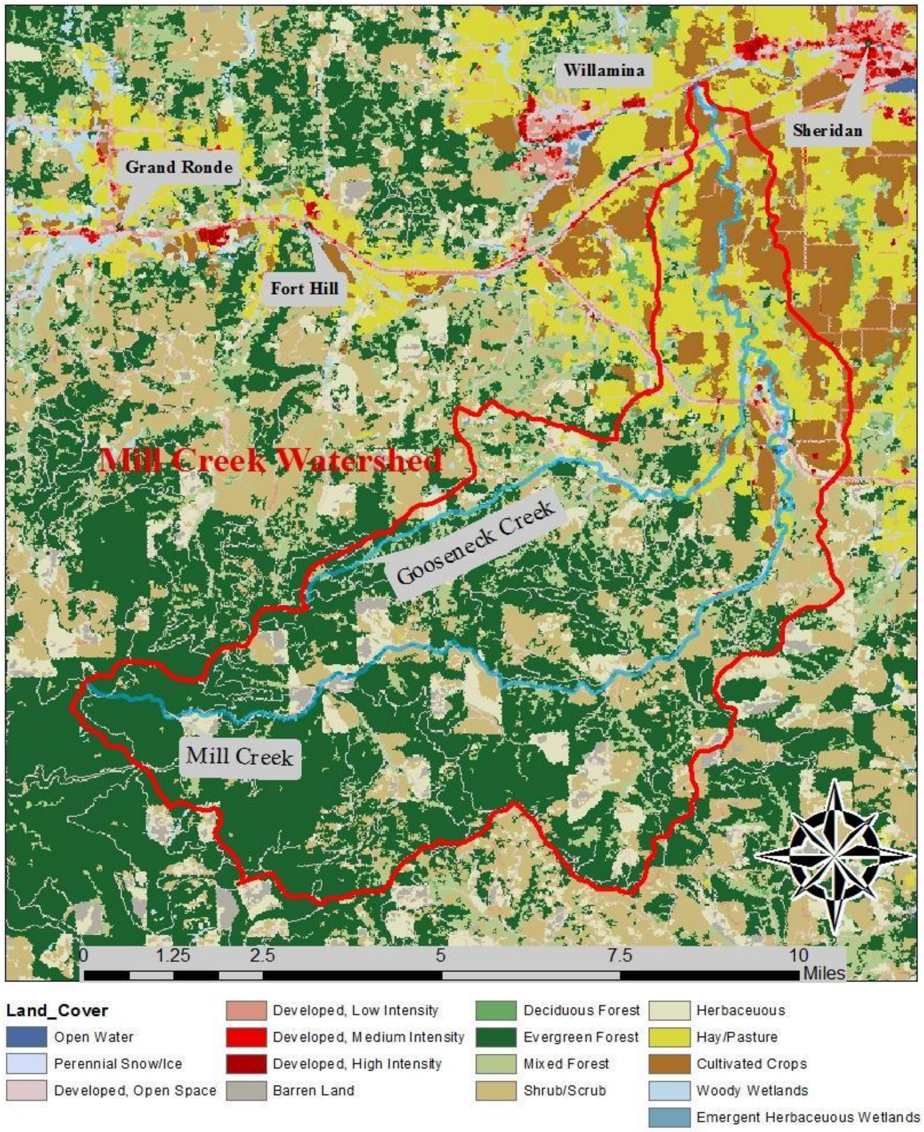

Figure 4: Gooseneck and Mill Creek: Land Cover (source: NRCS 2014; created by Robin Fahy 2014).

Cozine Creek Site Description

Our brief outlook of the land cover around Cozine Creek showed that agriculture and development were the dominant land uses (Figure 3). The permanent study sites selected in 2011at Cozine creek are encompassed by urban development. The positions of the three study points and their relative location to Linfield campus, downtown McMinnville, and Highway 99 are shown in Figure 5.

Figure 5: Cozine creek site-positions (source: USGS, 2014; created by Robin Fahy 2014)

Field observations were taken at each of the permanent site positions at Cozine Creek. The banks at site one (the most downstream site) were covered in dense thickets of Himalayan blackberry (*Rubus armeniacus)* and Oregon ash. Woody debris was visible within the stream, and some fallen logs spanned the creek. Creek width was about five meters, and depth was no more than 1½ meters. Sediment in the water column obstructed visibility to the stream bottom, indicating high turbidity.

The banks at site two were covered with shrubs and herbaceous species, including deadly nightshade (*Atropa belladonna*), Oregon grape (*Mahonia aquifolium*), and Himalayan blackberry. Surface substratum was composed of angular rocks, and a culvert opened into the creek on the north bank. The stream at site two was only two to three meters wide and approximately one meter deep.

Site three was located upstream from the other two sites and was the closest of the three positions to Highway 99. The banks of the creek were covered in Himalayan blackberry, red alder, and willow (*Salix spp.*). The creek at this location is approximately six meters wide and one-half meter deep. A tree had fallen across the creek, just in front of the culvert underneath Highway 99, and a nearby cement pipe opened out of the north bank into the creek.

Mill Creek Site Descriptions

The location of the Mill Creek site is shown in Figure 6, which also shows the proximity of Mill Creek to Gooseneck Creek. Field observations were taken at each of the permanent sampling locations at Mill Creek. The banks at site one and site two were covered by red alder, big-leaf maple, and Himalayan blackberry. Several logs had fallen in the creek, but none spanned the entire creek. The creek was approximately 15 meters wide and 30 centimeters deep.

Site three was located at a riffle upstream from the other sites. The banks were covered with black cottonwood (*Populus trichocarpa*), red alder, and big-leaf maple. Stream width was approximately ten meters and the creek was approximately 50 cm deep.

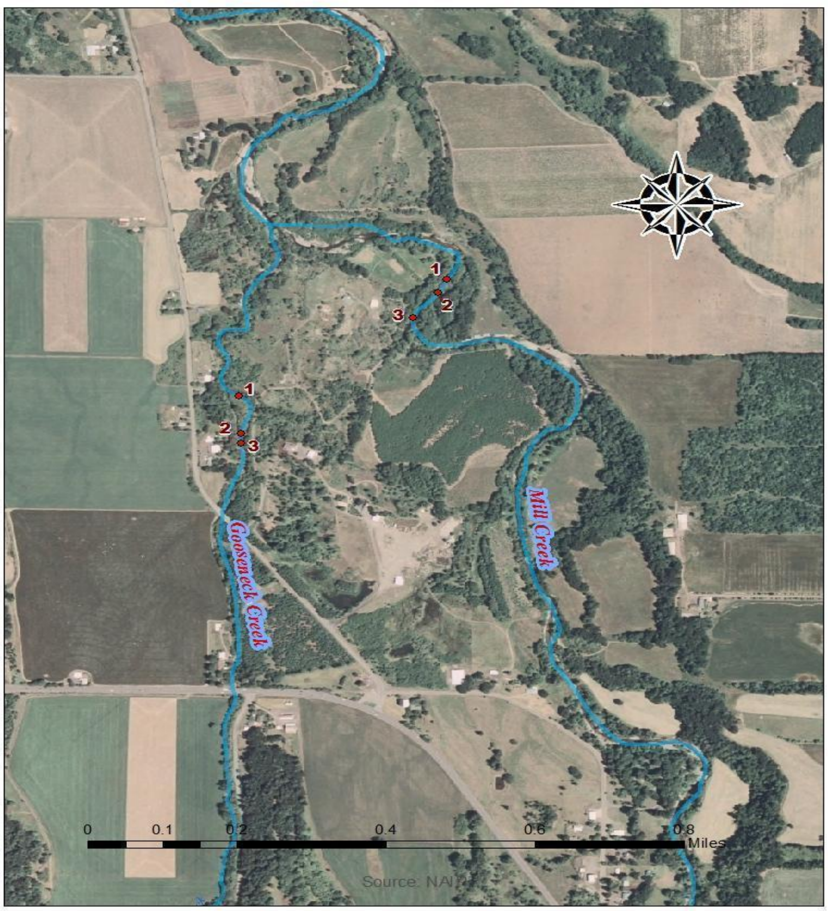

Figure 6: Mill and Gooseneck creek site-positions (source: USGS, 2014; created by Robin Fahy 2014).

Gooseneck Creek Site Descriptions

Gooseneck Creek flows into Mill Creek just downstream from our sample sites on Mill (Figure 6). Field observations were taken at each of the permanent sample sites at Gooseneck Creek. Site one on Gooseneck Creek is upstream from a series of log weirs installed during the restoration project. Red alder, Himalayan blackberry, willow and big-leaf maple were found on the banks.

Site two began at the base of another log weir. A plunge pool one meter deep had developed below the weir and the creek got shallower as it flowed downstream. The width of the creek here ranged from three to five meters, and the far bank was steep. Red alder, big-leaf maple and Himalayan blackberry were present on the banks.

Site three was a below another weir. The creek here was four to five meters wide and was about one-half meter deep.

METHODS

In Field Procedures

Three sample sites at each of the three creeks (Gooseneck, Mill, and Cozine) were previously established by previous environmental research methods classes. Sites at Gooseneck were chosen to evaluate the success of the GYWC restoration project. The sites at Cozine were selected due to their location adjacent to Linfield College. The original intent was to compare urban to rural streams (Colahan et al. 2011). Mill creek was added in 2012 to examine what appeared to be a higher quality rural stream (Bailey et al. 2012). The sampling sites on each creek were randomly located (Colahan et al 2011; Bailey et al. 2012).

Water Sample Collection

Two water samples were collected at each location at each creek to be used for further analysis. Water samples were collected prior to other stream measurements to ensure minimal disturbance in the stream. A 300ml sample was collected in a sterile Nalgene bottle, and the other sample was collected in a glass BOD bottle. The BOD bottle was submerged completely until air bubbles ceased appearing and then carefully recapped with the stopper to ensure no air bubbles were in the sample. The BOD bottle was covered in aluminum foil. Both bottles were placed in a cooler with ice and transported back to the ENVS laboratory at Linfield College. The Nalgene bottle was placed in the freezer until needed for water quality analysis. The BOD bottle was placed in a dark area at room temperature for five days (Lindbo and Renfro 2003).

Dissolved Oxygen and Temperature

Dissolved oxygen (DO) and temperature were measured in the field at each sample location using a Hanna Instruments DO meter (model HI9146). Prior to recording, the DO meter was calibrated to both 0% and 100% oxygen in the laboratory to ensure accuracy. It was calibrated to 100% before each reading in the field. To measure oxygen, the DO probe was submerged in the stream until the reading stabilized. To minimize in stream disturbance, DO was measured immediately after water samples were collected. DO was recorded as a percentage and parts per million (ppm) of dissolved oxygen. The DO meter also measured water temperature, which was recorded as degrees Celsius (Hanna Instruments 2010). DO and temperature were measured in triplicate at each location.

pH

The pH of the water at each site was measured using a Hanna Instruments pH meter that was calibrated that day (model H198128). The probe tip was submerged in the stream without touching the creek bed until the reading stabilized (Hanna Instruments 2005b).pH was measured in triplicate at each location.

Flow Rate

The rate of water flow at each site was measured using a Geopack Flow Meter (model MFP51). The propeller fixture was submerged perpendicular to the stream current and averaged for six seconds each measurement (JD Instruments 2013). This year, flow rate was only measured at Mill and Gooseneck Creeks. We lost the propeller at the first Cozine Creek site and could not get those measurements. Flow, when it was measured, was done so in triplicate.

Air Temperature

To help us better understand variation in water temperature, air temperature was measured at each sample site using a mercury thermometer.

Stream Depth

Stream depth was measured with a meter stick at the same location where each DO reading was taken, to see if there were any correlations between depth and water quality variables.

Macroinvertebrates

We collected three samples of macroinvertebrates at each sample site at each creek. Three collection areas were randomly located at each site using a grid system set up with measuring tapes. We used two D-nets to collect macroinvertebrates at each site. One net was placed at the downstream end of the site in such a manner that all dislodged organisms would wash into it. The other was placed approximately one foot upstream and parallel to the first net. All rocks within the square foot between the nets were vigorously rubbed to remove all attached macroinvertebrates. The stream bed in the area also was scraped with the upstream D-net. Material collected in both nets was transferred to basins. All visible macroinvertebrates in each basin were collected and placed into marked jars containing a 95% isopropyl alcohol solution. The jars were returned to the ENVS laboratory to be analyzed later (Lindbo and Renfro 2003).

In Lab Procedures

We used the water samples that had been collected and returned to the ENVS laboratory to measure BOD, turbidity, nitrates, ammonia, phosphate, and coliform bacteria. In addition, the macroinvertebrates that had been collected and preserved were identified and counted. BOD was measured using the sample of water collected in the field five days earlier. Turbidity, nitrate, ammonia, phosphate and coliform bacterial counts were determined using the water samples previously collected and frozen in sterile Nalgene bottles. Bottles were removed from the freezer and thawed at room temperature for approximately five hours before testing.

Biochemical Oxygen Demand

After storage for five days at room temperature in the lab, BOD was determined from three samples from each BOD bottle. Water from each bottle was carefully poured into three beakers. The dissolved oxygen content (DO) in each beaker was measured using the same Hanna Instruments DO meter. BOD was calculated as the difference between the average of the three in stream DO readings and the DO measured in each BOD sample (Lindbo and Renfro 2003).

Turbidity

Turbidity was measured using a Hanna Instruments Turbidity Meter that was calibrated before use (model H193703). Each water sample was mixed well and a small portion poured into the glass reading cuvette for the meter. The cuvette was wiped well, placed into the turbidity meter reading chamber, and covered. Measurements recorded as FTUs (Formazin Turbidity Units). Triplicate readings were made of each sample. (Hanna Instruments 2005a).

Ammonium Nitrogen

Each thawed water sample was tested for ammonia-nitrogen using a LaMotte test-kit (3121-02) according to the instructions provided (LaMotte 2012a). Each sample had three aliquots removed and tested.

Nitrate Nitrogen

Each thawed water sample was tested for nitrate nitrogen using a LaMotte Nitrate Nitrogen water test kit (No. 3345-01) using the instructions provided (LaMotte 2012c). Each sample had three aliquots removed and tested.

Phosphorus

Each thawed water sample was tested for phosphate using a LaMotte Low Range Phosphorus water test kit (No. 5864-01) using the instructions provided (LaMotte 2012b). Each sample had three aliquots removed and tested.

Coliform Bacteria

The abundances of *E. coli, Aeromonas, Salmonella* and other coliforms were determined using Coliform Easygel Media (No. 26001). Water from each thawed bottle was pipetted using aseptic technique into an Easygel liquid agar bottle, which was mixed and then poured into an Easygel petri dish. The amount of water used for each plate varied from one to 5 ml, depending on the perceived cleanliness. After the agar set, plates were placed in an incubator at 35° C for 24 hours. Colonies were counted by color: *E.coli* were dark blue , *Aeromonas* were light pink or red, *Salmonella* were green, and other coliforms were light blue (Micrology Laboratories 2008). Multiple plates were made from each sample.

Macroinvertebrate Identification

The preserved macroinvertebrate samples were identified to the most specific taxa possible using dissecting microscopes. Organisms were removed from each jar and placed in shallow dishes. All organisms contained in each jar were identified as specifically as possible and the abundance in each jar counted under an Olympus SD 30 dissecting microscope using several available guides (Anonymous 2014, Edward 2008, Stroud Water Research Center 2013). Each jar was counted by at least two students to verify contents in each jar. Results were not recorded until the observers agreed to the identities and counts of all organisms in each jar.

We calculated the Pollution Tolerance Index (PTI) for each collected sample. PTI is an ordinal value calculated based on the presence or absence of various organisms in each sample, weighed based on each organism's pollution tolerance. Macroinvertebrates can be categorized by their specific tolerance to pollution, which gives a good indication of long term stream water quality. Each species has a designated PTI value from 1 to 3, with 1 being the most pollution tolerant, and 3 being the most pollution intolerant. For each jar, all the organism's PTI values were summed to provide the PTI value for that sample (Lindbo and Renfro 2003).

Statistic Analysis of Data

We statistically analyzed our data using JMP 11.0 (2014). We examined differences in water quality variables among the creeks, as well as among years, using ANOVA (analysis of variance) and Tukey-Kramer HSD Post Hoc Tests. Required assumptions of the parametric tests we used include random sampling, normal distribution, independent observations, no significant outliers, the dependent variable is normally distributed, and nearly equal variances among groups (Thomas and Zumbo 2012).

Prior to analyzing the data, we tested to discern whether the data was normally distributed (Villasenor and Gonzalez 2009). The majority of our data is not normally distributed meaning that we should transform our data or use a nonparametric test such as a Wilcoxon Kruskal-Wallis (Brown 2005). However, ANOVA is a relatively robust test (Thomas and Zumbo 2012) and after running both parametric and nonparametric tests on the same data sets, we found that the significances were not different and thus only report results from parametric tests.

Results:

Our class found flow, water temperature, and DO were significantly higher at Mill Creek; whereas turbidity was significantly greater at Cozine Creek (Table 4). Cozine Creek had the highest levels of ammonia and nitrate, but the results were not significant. Gooseneck Creek had significantly higher levels of *E. coli* and other coliforms.

Table 4: Mean (standard deviation) and probability from ANOVA analysis of water quality variables measured at Cozine, Mill, and Gooseneck Creeks in Fall 2014. Different letters denote significant differences as per Tukey-Kramer Post Hoc Tests.

	Gooseneck	Cozine	Mill	P-value
pH	6.34(0.19)	6.30(0.31)	6.41(0.21)	0.649
Flow (cm/s)	0.0(0.0)	n/a	9.78(13.48)	0.0449
Temperature (C)	13.6 (0.3) B	13.5 (1.2) B	18.1 (0.2) A	0.0001
DO (%)	75.61(5.06) B	52.43(10.07) C	86.77(3.42) A	0.0001
BOD (%)	3.88(6.36) A	16.23(16.77) A	7.57(3.53) A	0.0575
Turbidity (FTUs)	2.16(.73) B	5.04 (.65) A	2.84(0.98) B	0.0001
Ammonia(ppm)	0.13(0.12)	0.15(0.01)	0.13(0.12)	0.3827
Nitrate (ppm)	0 (0) A	2(3) A	0 (0) A	0.0514
Phosphate (ppm)	0(0) A	0 (0) A	0(0) A	0.0439
E. coli (per 100 mL)	96 (132) A	1 (6) B	1 (10) B	<.0001
Aeromonas (per 100 mL)	5100 (3351) A	174 (25) B	56 (69) B	<.0001
Salmonella (per 100 mL)	5 (30) A	4 (18) A	0 (0) A	0.5041
Other Coliforms (per 100 mL	223 (263) A	1(6) B	1(4) B	<.0001

When we compared out data from Cozine Creek in 2014 to the results of previous classes, we found pH, DO, ammonia, *E. coli, Aeromonas*, and other coliforms to have declined from 2011 to 2014 (Table 5). slightly below the EPA recommended pH range of 6.5 to 8.5 (EPA 2014b). Water temperature and concentration of nitrate had increased .Allow us to look more closely at the enteric bacteria present in all three creeks in 2014, figure 6, and then at the changing levels of *E. coli* and other coliforms from 2011 to 2014 in figures 7 and 8, respectively.

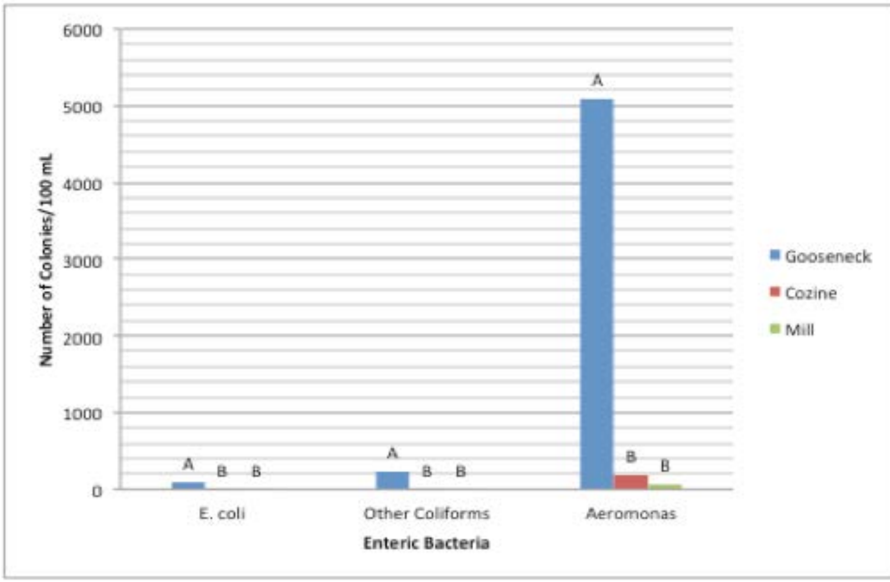

Figure 6: Mean enteric bacteria at Cozine, Mill and Gooseneck Creeks in 2014. Different letters denote significant differences according to the Tukey-Kramer Post Hoc test.

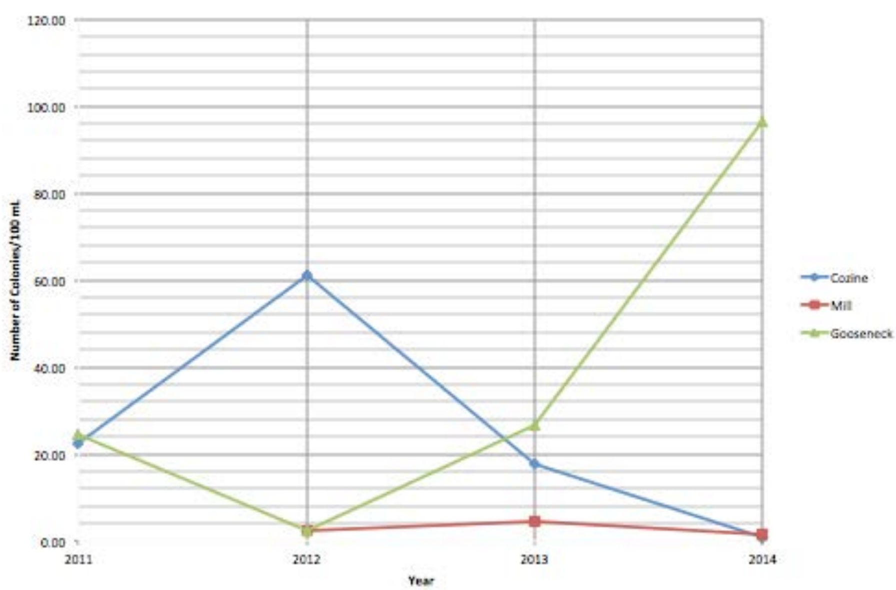

Figure 7: Mean E. coli colonies present in 100mL at Cozine, Mill and Gooseneck Creeks from 2011 to 2014.

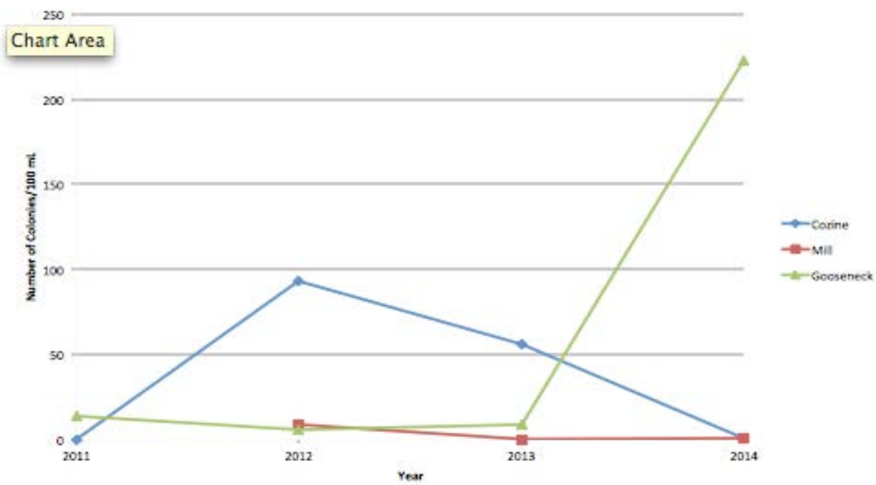

Figure 8: Mean other coliforms president in 100mL at Cozine, Mill and Gooseneck Creeks from 2011 to 2014.

Table 5: Mean (standard deviation) and probability from ANOVA analysis for differences among years 2011-2014 at Cozine Creek. Different letters denote significant differences as per Tukey Kramer Post Hoc Tests.

	2011	2012	2013	2014	P-valu
pH	6.84(0.23) A	6.49(0.26) AE	6.28(0.47) B	6.30(0.31) B	0.0035
Flow (cm/s)	8.84(6.29) A	10.5(8.56) A	2.58(0.92) B	n/a	0.0053
Temperature (C)	12.3(0.109) AE	9.56(0.347) C	11.48(1.40) B	13.46(1.22) A	0.0001
DO (%)	69.29(2.95) A	58.18(1.0) B	58.54(6.45) B	52.43(10.07) B	0.0001
BOD (%)	22.12(7.62)A	3.68(3.76) B	9.84(6.05)AB	16.23(16.77)AE	0.0026
Turbidity (FTUs)	n/a	n/a	5.95 (2.37)	5.04 (0.65)	0.2852
Ammonia (ppm)	n/a	n/a	0.23(0.08)	0.15(0.07)	0.0303
Nitrate (ppm)	0.0	0.0	0.11(0.22)A	1.96(1.07)A	0.035
Phosphate (ppm)	0.20(0.00)A	0.0(0.0)	0.04 (0.02)B	0.11(0.18)AB	0.0004
E. coli (per 100 mL)	22 (27) B	61 (34) A	18 (27) BC	1 (6) C	<.0001
Other Coliforms (per 100 n	0 (8) C	93(6) A	56 (8) B	1 (3) C	<.0001
Aeromonas (per 100 mL)	9 (15) B	1129 (388) A	n/a	174 (251) B	<.0001
Salmonella (per 100 mL)	18 (25) A	0.0 (0.0) B	n/a	4 (18) AB	0.0388

When we compared our data from Gooseneck Creek in 2014 to the results of previous classes, we found flow rate and DO had declined since 2011; whereas water temperature, *E. coli, Aeromonas*, and other coliform bacteria had increased (Table 6).

Table 6: Mean (standard deviation) and probability from ANOVA analysis for differences among years 2011-2014 at Gooseneck Creek. Different letters denote significant differences as per Tukey Kramer Post Hoc Tests.

	2011	2012	2013	2014	P-value
pH	6.61(0.37) B	7.12(0.24) A	6.54(0.68) B	6.34(0.19) B	0.001
Flow (cm/s)	5.47(0.23) C	10(0.0) B	11(0.0) A	0(0.0) D	0.0001
Temperature (C)	12.2(0.2) B	12.3(0.7) B	8.8(1.0) C	13.6(0.3) A	0.0001
DO (%)	97.0(1.20) A	89.42(4.72) B	96.7(2.78) A	75.61(5.06) C	0.0001
BOD (%)	32.89(2.68)A	4.09 (7.83)B	11.31 (6.26) B	3.88(6.36)B	0.0001
Turbidity (FTUs)	n/a	n/a	2.43(0.58)	2.16(0.73)	0.4078
Ammonia (ppm)	n/a	n/a	0.13(0.0)	0.10(0.06)	-
Nitrate (ppm)	0.5	0	0	0	-
Phosphate (ppm)	0	0	0	0	-
***E. coli* (ppm)**	24 (30) AB	2 (6) B	27 (28) AB	97 (131) A	0.0049
Other Coliforms (pp	13 (26) B	6 (11) B	9(15) B	222(263) A	0.0001
Aeromonas (ppm)	31 (28) B	7 (15) B	n/a	5100 (3351) A	<.0001
Salmonella (ppm)	7 (20) A	0(0) A	n/a	5 (30) A	0.75

When we compared our data from Mill Creek in 2014 to the results of previous classes, we found turbidity, concentration of ammonia, and level of *Aeromonas* had increased compared to 2011, whereas DO had decreased from the level in 2013 (Table 7).

Table 7. Mean (standard deviation) and probability from ANOVA analysis for differences among years 2012-2014 at Mill Creek. Different letters denote significant differences as per Tukey-Kramer Post Hoc Tests.

	2012	2013	2014	P-value
pH	6.53(0.090) A	6.67(0.102) A	6.40(0.090) A	0.1665
Flow (cm/s)	16.11(10.09) B	53.89(34.97) A	9.78(13.48) B	0.0006
Temperature (C)	8.2(0.3) B	7.2(1.3) C	18.1(0.2) B	0.0001
DO (%)	90.22(3.76) AB	91.08(3.29) A	86.07(3.42) B	0.0357
BOD (%)	10.58 (6.42) A	2.13(4.93)B	7.57(3.89)AB	0.007
Turbidity (FTUs)	n/a	1.12(0.08)	2.84(0.33)	0.0001
Ammonia (ppm)	n/a	0.04 (0.01)	0.13 (0.0)	0.0001
Nitrate (ppm)	0.0	0.0	0.0	-
Phosphate (ppm)	0.0	0.0	0.0	-
E. coli (per 100 mL)	2 (6) A	4(9) A	1 (10) A	0.6569
Other Coliforms (per 100 mL)	9 (14) A	0.0 (0.0) B	1 (4) B	0.001
Aeromonas (per 100 mL)	9 (10)	n/a	56 (69)	0.0056
Salmonella (per 100 mL)	0	n/a	0	-

The macroinvertebrate data showed that Cozine Creek had lower PTI values than Mill or Gooseneck creek. All but one of our water quality ratings was poor or fair. The lone good rating occurred at site three of Mill Creek.

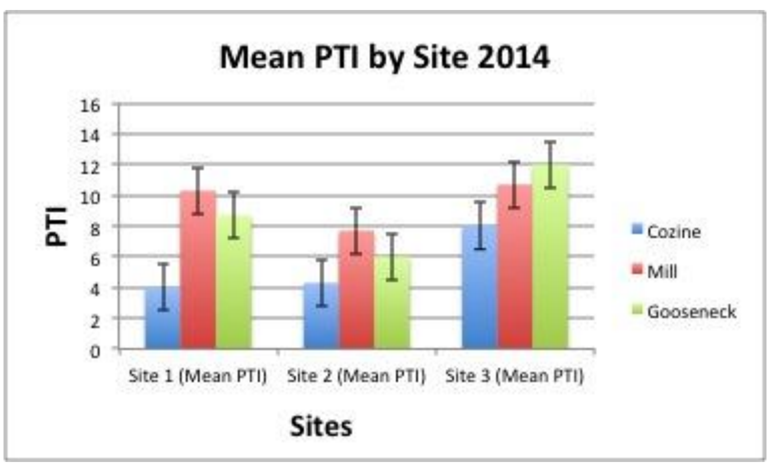

Figure 7: Mean PTI by site for 2014 data.

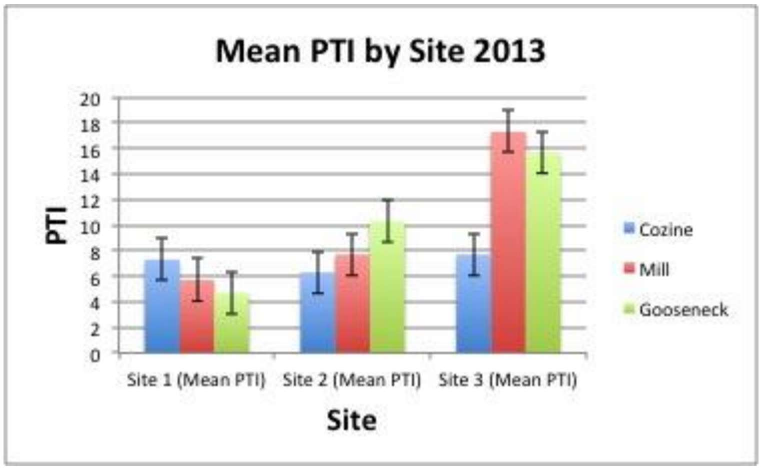

Figure 9: Mean PTI by site for 2013 data.

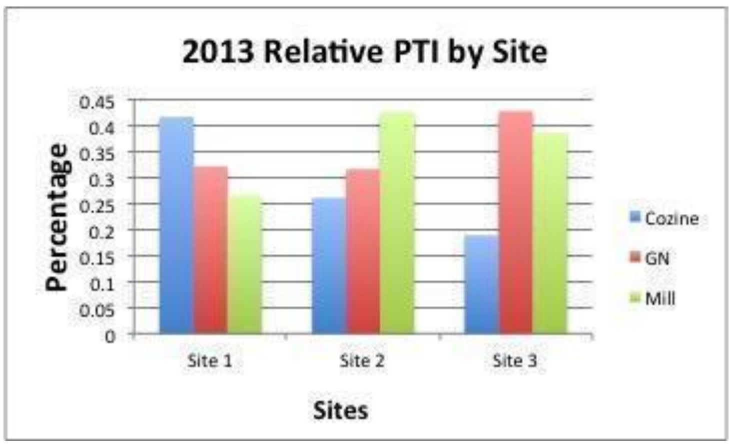

Figure 10: Relative PTI by site for 2013 data

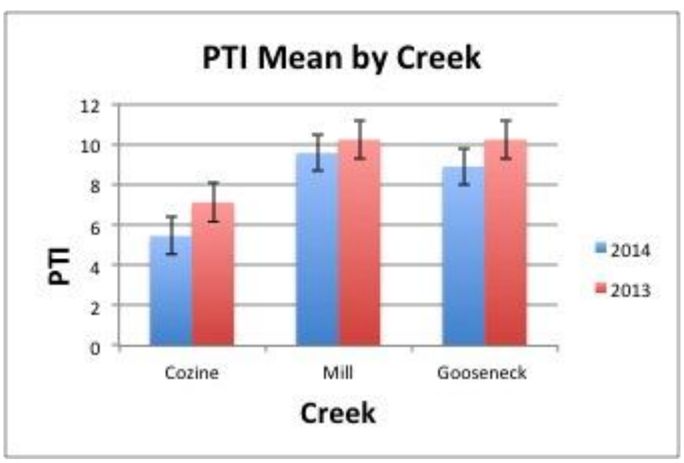

Figure 11: Mean PTI for each creek for 2014 and 2013 data.

Discussion:

We concluded that Cozine Creek has the worst water quality of the three streams. This decision was based on results from DO, turbidity, nitrogen levels and macroinvertebrates. This conclusion was expected and supported one of our hypotheses

Turbidity at Cozine Creek in 2014 was significantly greater than at the other two creeks and was above the 4.25 FTUs recommend by the EPA for freshwater streams in our ecoregion (EPA 2014d). This was also true in 2013. High levels of turbidity indicate high concentrations of particulate matter suspended in the water column. Particulate matter can harm aquatic life as it settles on plants, organisms, and the streambed, suffocating organisms. Particulate matter could be the result of sediment runoff from the surrounding urban area. Urban runoff could be high in nutrients that lead to algal blooms that remove oxygen from the water. Leading to lowered DO levels (MDNR 2013).

Cozine Creek had significantly lower dissolved oxygen compared to Gooseneck and Mill Creeks. Dissolved oxygen is a key factor in determining water quality and plays an important role the organisms that can inhabit the stream. The EPA recommends a 7 day average DO of at least 6.5ppm, which Cozine Creek did not meet on the day it was tested (EPA 1986). Cold water can have higher levels of dissolved oxygen and DO is also positively correlated with flow .In 2014 we were unable to measure flow rate at Cozine due to equipment malfunction. Trying to draw conclusions about DO related to our temperature data is difficult because temperature is a highly variable measurement. We did find that Cozine had significantly lower stream temperature compared to Mill, but in all cases, our stream temperatures were below the short term EPA recommended summer threshold for salmonoid species of 22ºC (EPA 1986).

Hypoxia, or depleted oxygen in waterways, is often the result of hypertrophic contaminants. Phosphates, nitrates, and ammonia (nutrients) boost primary productivity in aquatic ecosystems. Phosphorus and nitrogen contamination can have different sources in rural and urban settings,.. In rural settings, fertilizers and manure typically add nutrients. Fertilizers used in industrial agriculture and manure from animal feedlots gets funneled into water bodies during precipitation events. In urban areas, anthropogenic nutrient inputs include detergents and sewage. Runoff collects to form streams and rivers. Impermeable surfaces increase the velocity of surface runoff in urban settings, which can negatively affect water quality by transporting a myriad of post-consumer waste products (Cole et. al. 1993). Atmospheric exhaust from fossil fuel combustion includes contaminants that include nitrogen oxides. These frequently are pronounced in urban settings that have high traffic density. The concentration of the chemicals in waterways may be below detectability, but that does not discount the negative feedback associated with small changes (Bernhardt et al 2011). We found small to zero amounts of phosphate and ammonia, indicating that levels were not saturated enough to cause the observed low oxygen at Cozine. However, we collected our data in late summer, prior to the major fall/winter precipitation events. We did find levels of nitrate nearly seven times higher than the EPA recommended limit of 0.31mg/L, which may partially explain the low level of oxygen in the creek (EPA 2014d). Although not statistically significant , we found a 1,682% increase in nitrogen level in 2014 compared to 2013. We suspect low flow at Cozine may be partly responsible for the low DO level as well, but due to the aforementioned equipment malfunction, we were unable to verify that assumption.

Macroinvertebrate data also served as a red flag for Cozine Creek's water quality. Macroinvertebrates are used in water quality studies because the pollution tolerance is known for many different species of macroinvertebrates. A large, diverse population of macroinvertebrates is a good indication of long-term stream health and good water quality. Total PTI values rate ≤10 as poor, 11-16 as fair, 17-22 as good, and ≥ 23 as excellent water quality. Cozine Creek had the lowest mean PTI. PTI is a good indicator of long-term creek health because the organisms hatched from eggs and went through several development stages within the water. If no organisms are found in a stream we can assume some quality of the water prevents successful egg laying, hatching or development (Lindbo and Renfro 2003). The trends we see in water quality as indicated by macroinvertebrates also was consistent with what we saw in 2013 and show that water quality was low. The lack of macroinvertebrates could be the result of low pH at each stream, as all three had pH readings below the EPA's recommended limit of 6.5. Levels of pH below 6.5 have been shown to reduce biological diversity of vertebrate and invertebrate organisms in freshwater streams (EPA 2012e).

Our second hypothesis was that Gooseneck Creek would be improving because of the restoration efforts. Our results do not support this hypothesis. The hypothesis was rejected bases on DO, *E. coli*, *Aeromonas*, *Salmonella,* other coliforms. DO was highest in 2011 and has been decreasing to the lowest value we recorded in 2014 .This slow reduction of DO is part of the reason we believe water quality in Gooseneck is not improving, and that the restoration project may not have been effective. This conclusion is supported by our enteric bacteria data.

In 2014, the levels of *E. coli*, *Aeromonas, and* other coliforms in Gooseneck Creek were very high. *E. coli* is an indicator of fecal contamination. Elevated *E. coli* levels can pose a health risk to humans and organisms that live in or around the body of water (EPA 2012c). It is worth noting however, that all sites were below the EPA recommended threshold for bacterial density of 126 per 100 ml (EPA, 1986). Other coliform bacteria are present in high concentrations in the fecal matter from warm-blooded animals but they do not necessarily pose a threat to organisms (Garrido 2014). Although levels of *E. coli* and other coliform bacteria were high, levels of *Aeromonas* levels were even higher. *Aeromonas* bacteria can be pathogenic or fish parasites. They could be a threat to salmon populations the DEQ has been trying to encourage in Mill and Gooseneck Creeks (Gavriel et al. 1998). Our findings were unexpected because since 2011 nothing had suggested the spike we saw this year. One possible explanation could be flow. Gooseneck creek had a flow of zero in 2014 that may be due in part to the lack of rainfall prior to our sampling date. Low rainfall combined with low flow can allow any bacteria present to grow in excess (Gavriel et al. 1998).

Our conclusions are that Cozine had the lowest water quality among the three creeks and Gooseneck Creek's water quality is worsening. Cozine Creek had the lowest DO and highest turbidity and nitrogen levels, all of which were outside of EPA recommended levels. Cozine also had the lowest PTI score of all creeks. It would be nice to have information about water quality in Gooseneck Creek prior to the restoration project. Such data might allow us to examine whether the project has been effective.

Limitations

There were several limitations we believe could have altered our results or skewed some of our data. The first limitation was we gathered the water from the each sample site on the same day for each creek. It is likely that if we went on a different day (during spring, for example) the water quality results would have been different. The water at Cozine Creek and Gooseneck Creek seemed lower than usual whereas the water at Mill Creek was higher than usual when we went to collect water samples.

A second limitation was we are not completely sure if the nutrient data from previous classes was converted correctly when doing the tests. Some of their results for nutrients seem suspect, and it is possible that they did not follow the directions carefully and made mistakes.

Third, we lost a component of the flow meter that resulted in our inability to measure flow at Cozine Creek. This impacted our analysis because flow is an integral factor in water quality, especially in relation to dissolved oxygen. This did not allow us to compare flow data for Cozine Creek.

Lastly, equipment and human error could have occurred. We had several people taking notes that could have been misinterpreted or transcribed incorrectly. There is also the possibility of our equipment malfunctioning without our knowledge. However, we did everything in triplicate to try to reduce such errors, but making mistakes is always possible.

Recommendations for Future Classes

Recommendations for the future classes include making sure equipment is assembled correctly. Another recommendation would be to ensure the entire contents of each macroinvertebrate jar is emptied so they can be counted more precisely. We struggled with classification because the contents of the jar were sometimes not emptied completely or people counted incomplete remains of a macroinvertebrate.

An additional avenue of study would be to focus more on Cozine in particular because it was the only creek that consistently failed to meet EPA water quality standards. It also was the only creek hat has headwaters in a relatively rural area and then enters a relatively urbanized area (McMinnville). It would be interesting to examine Cozine's water quality before entering the city, inside the city at our existing site, and finally just before it empties into the Yamhill River. Due to the relatively small size of ENVS 385 classes however, it would likely mean scuttling research at Mill and Gooseneck Creek, which may not be reasonable due to the time already invested in studying these creeks.

Acknowledgements

We would like to thank Tom Rupers for allowing us to use the sections of Gooseneck and Mill Creek that we used for sampling and testing. A great deal of thanks is owed to Barbara Van Ness for lab and field assistance. Last but not least, we would like to thank the Greater Yamhill Watershed Council for encouraging the spring 2011 class to begin this research.

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