IDENTIFYING AND MANAGING IMPACTS OF POINT AND NON-POINT SOURCE POLLUTION ON SURFACE WATER QUALITY

by

Patrick R. Malone

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Patrick R. Malone

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APPROVED:

Dr. Jeanine D. Plummer, Major Advisor

Dr. Paul P. Mathisen, Advisor

ABSTRACT

Surface waters can be impacted by point and non-point source (NPS) pollution including stormwater culverts, runoff, and septic systems. It is important to develop water quality monitoring plans that can be implemented within resource constraints while still providing useful data. The goal of this research was to develop a sampling strategy to identify the impacts of point and NPS pollution on surface waters. This research incorporates water quality monitoring, land use data, precipitation data, and statistical modeling to improve understanding of pollutant impacts on surface waters. Research was conducted at a 152-acre private lake in western Massachusetts. Lake water samples were collected approximately twice per month over 12 months at ten sample locations selected to isolate land uses, including (1) shoreline samples adjacent to homes with septic systems, (2) shoreline samples at stormwater discharge sites, and (3) control samples at the lake influent, lake effluent, and a private beach. Sampling events included dry and wet weather conditions. Water samples were analyzed for physical, chemical, and microbiological parameters including: pH, conductivity, dissolved oxygen, turbidity, alkalinity, nutrients, anions, organic carbon, and microbial indicators (total coliform, *E. coli*, enterococci, male-specific and somatic coliphages). The data were statistically analyzed to determine how land use, season, and precipitation affect the risk of contamination to surface waters. Results indicated significant water quality variations by land use, season, and precipitation and identified important correlations between water quality parameters.

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1.0 INTRODUCTION

Surface water bodies are susceptible to a variety of potential pollutants including natural and anthropogenic contaminants. Pollutants are discharged to surface waters through point and non-point sources. While point sources such as storm water culverts can typically be identified and directly monitored, non-point sources such as overland runoff or groundwater intrusion represent diffuse sources that are more difficult to quantify and analyze. Surface waters can serve as both recreational waters and drinking water sources, which represent exposure pathways through direct human contact with the water. Additionally, ecological system health and aesthetics are important. Therefore, it is essential that surface water quality be monitored and protected to prevent public health or ecological risks.

Surface water quality is regulated at both the federal and state levels. The United States Environmental Protection Agency (USEPA) promulgated the Clean Water Act (CWA) and amendments that set ambient or recreational water quality standards. In addition, the USEPA enacted the National Pollutant Discharge Elimination System (NPDES) that regulates discharges to surface waters. For drinking water sources, the USEPA also promulgated the Safe Drinking Water Act (SDWA) and the various Surface Water Treatment Rules (SWTR). At the state level, the Massachusetts Department of Environmental Protection (MADEP) enacted Surface Water Quality Standards.

In order to ensure that these water quality standards are met, water quality monitoring plans must be implemented. Water quality monitoring involves collecting surface water samples for analysis of physical, chemical, and microbiological parameters. Physical water quality parameters include turbidity and temperature. Chemical water quality parameters include pH, dissolved oxygen, conductivity, alkalinity, organic carbon, anions, and nutrients. Lastly, microbiological water quality parameters include bacterial indicators and microbial source tracking parameters such as coliphages.

In addition to considering which parameters to monitor for, land use and climatological factors must be considered as part of any water quality monitoring plan. Land use has significant impacts on water quality especially for non-point source pollutants where fertilizers, pet and livestock fecal matter, or roadway contaminants are discharged through overland runoff. Likewise, temperature, season, and rainfall can greatly affect water quality.

The objectives of this research were to: (1) identify point and non-point source pollution to a surface water body, (2) determine land use, season, and precipitation impacts to water quality, and (3) find relationships between water quality parameters and/or water quality variables that will be useful in developing water quality monitoring plans and will help distinguish pollution sources. The research was conducted at a 152-acre lake in western Massachusetts. Sampling sites were selected to isolate, as much as possible, potential pollutant sources including storm water discharges, septic systems, and background locations. Surface water samples were collected approximately twice per month for 12 months and analyzed for the physical, chemical, and microbial parameters listed previously.

The water quality data were statistically analyzed for correlations and analysis of variance. Based on the findings, water quality variations by sampling location, target influences, season, and precipitation were evaluated. Key correlations between the water quality parameters were also assessed. From the available analytical and statistical data, recommendations were made both for the study site as well as for general water quality monitoring plans.

2.0 LITERATURE REVIEW

This literature review provides information on water quality management including key regulations and potential contaminant types and sources. This chapter also provides background on applicable water quality monitoring parameters and the effects of land use and climatic conditions on water quality.

2.1 Water Quality Management

Surface water bodies are susceptible to a variety of potential pollutants including pollutants emanating from landfills, storage tanks, septic systems, and runoff (USEPA, 2002a). Pollutants can be natural or anthropogenic and commonly include fertilizers, herbicides, pesticides, petroleum products, sediments, toxic chemicals (organic or inorganic), microbial contaminants (bacteria, protozoa, and viruses), and nutrients (USEPA, 2002b). Pollutants may pose human health risks, ecological risks, or may affect general water quality and contribute to eutrophication. Pollutant sources can generally be characterized as point and non-point sources. The United States Environmental Protection Agency (USEPA, 2002b) defines point source discharges as "any discernible, confined, and discrete conveyance" with the potential to discharge pollutants. Non-point source pollution is defined as coming from diffuse sources typically resulting from precipitation, snowmelt, or irrigation water running over land or through the ground (USEPA, 2002b).

While it is not realistic to protect surface waters from all pollutant types and sources, it is imperative that certain standards be met that are protective of human and ecological health and preserve the aesthetics and general water quality of surface water bodies. Surface waters are protected by the Clean Water Act (CWA) and the National Pollutant Discharge Elimination System (NPDES). Recreational surface water bodies are also subject to the regulations and guidance set by the USEPA Recreational Water Quality Criteria and the Beaches Environmental Assessment and Coastal Health (BEACH) Act. Similarly, laws such as the Safe Drinking Water Act (SDWA) protect surface waters used as source waters for drinking water. Collectively, these regulations and criteria define how surface waters are protected from and monitored for point and non-point source pollutants.

2.1.1 Point Source Pollution

As stated above, point source pollution emanates from discrete discharge points. Point sources may include pipes, conduits, channels, or culverts that discharge into surface water bodies. Among the most high-risk sources of fecal contamination is untreated human sewage, because it is known to carry human specific pathogens including bacteria, protozoa, and viruses (Staley *et al.*, 2013). Combined and separated sewer overflows are a common source of wastewater to surface water bodies (Lee and Bang, 2000). Stormwater conveyances can carry metals, oils, and sediment from the runoff of roofs, roadways, driveways, and parking lots directly into surface water. In a large storm event, these loads can shock the receiving water (Lee and Bang, 2000). Additionally, the inner pipe walls of the stormwater conveyances often accumulate pollutants over years of use, and these pollutants are washed through the system and directly into surface water by rainwater during storm events (Hongbing *et al.*, 2009). Because point source discharges are isolated, identifiable locations, they can be regulated. These regulations are implemented under the NPDES Stormwater Program that is part of the CWA and described further in Sub-section 2.1.3.

2.1.2 Non-Point Source Pollution

As defined above, non-point source pollution generally occurs when surface runoff from precipitation, snowmelt, or irrigation flows over land and into surface water. As runoff flows over the ground, it can transport chemicals, pesticides, metals, oils, sediments, and fecal waste (Parker *et al*., 2010). Land development can increase both the mass of contaminants discharged to a watershed and the total volume of overland runoff carrying these contaminants. Land development such as farmland can increase the total mass of contaminants like manure and fertilizers without changing the overland runoff. However, increases in paved surfaces can increase contaminants such as petroleum constituents or road salts as well as significantly increasing overland runoff that carries these pollutants by decreasing subsurface infiltration. Watershed development or percent impervious surfaces have been associated with degradation in water quality and biotic conditions and positively correlated with fecal contamination (Mallin *et al*., 2009). Similarly, specific land uses have significant effects on non-point source pollution as described in Section 2.3.

Another contribution to non-point source pollution is on-site wastewater treatment systems or septic systems, which are used by approximately 25 percent of the United States population (Conn *et al*., 2006). Septic systems release nutrients, organic carbon, and biological contaminants into the environment. While functional systems allow for the microbial degradation of these contaminants in the unsaturated subsurface, failing or overloaded systems have the potential to discharge contaminants to groundwater and nearby surface waters. Failing septic systems have been associated with excessive phosphorus inputs to surface water (Kramer *et al*., 2006), increased nitrogen loadings to surface water (Meile *et al*., 2010), and increased organic contaminants and conductivity to downgradient groundwater plumes (Conn *et al*., 2006). While point source pollutants have generally declined under NPDES, non-point source pollution remains a significant problem given its variability and diffuse nature (Kramer *et al*., 2006).

2.1.3 Surface Water Regulations

The Federal Water Pollution Control Act was enacted in 1948 and was significantly expanded and reorganized in 1972, when it became known as the CWA. Part of the 1972 amendments required the USEPA to publish criteria for water quality reflecting the latest scientific knowledge. In 1976, the USEPA Quality Criteria for Water set surface water quality standards protective of human health and shellfish in recreational waters (USEPA, 1976). One of the standards set was for fecal coliforms, and it stated that for no less than five samples collected over a 30-day period, the log mean concentration of fecal coliform samples was not to exceed 200 colony forming units (cfu) per 100 milliliters (mL) of sample, and not more than 10 samples can exceed 400 cfu per 100 mL.

Surface water quality criteria were again updated to reflect the latest scientific knowledge when the USEPA Ambient Water Quality Criteria (1986) was published to set *Escherichia coli (E. coli)* and enterococci standards protective of human health in recreational fresh and marine waters. Based on no less than five samples collected over 30 days, the geometric mean for samples should not exceed the values shown in Table 2-1.

Table 2-1: Ambient Bacteria Indicator Limits (Source: USEPA, 1986)

Water	Indicator	Geometric Mean (cfu/100 mL)
Fresh	*E. coli*	126
	Enterococci	33
Marine	Enterococci	35

The CWA was amended in 2000 to include the BEACH Act. The BEACH Act transferred regulatory authority to the individual states. The BEACH Act authorized federal grants to assist states in developing and implementing monitoring and public notification programs for their coastal recreational waters and required states to adopt improved water quality standards for pathogen indicators, at least as stringent as the ambient standards established in 1986, for recreational waters (USEPA, 2000a). Coastal recreational waters are defined as the Great Lakes and coastal waters designated by the state for swimming, bathing, or surfing.

The recommendations for recreational waters established in 1986 were again updated in the USEPA Recreational Water Quality Criteria (2012). Table 2-2 presents the revised values. As shown in Table 2-2, the revised criteria give two recommendations for geometric means (GMs) and statistical threshold values (STVs) that are not to be exceeded by more than ten percent of the samples collected. Primary contact is considered to be protected if either set of recommendations is met.

Table 2-2: Revised Ambient Bacteria Indicator Limits (Source: USEPA, 2012)

Indicator	Recommendation 1 Estimated Illness Rate 36/1,000		Recommendation 2 Estimated Illness Rate 32/1,000	
	GM (cfu/100 mL)	STV (cfu/100 mL)	GM (cfu/100 mL)	STV (cfu/100 mL)
E. coli (freshwater)	126	410	100	320
Enterococci (marine & fresh)	35	130	30	110

In addition to regulating ambient water quality, the CWA also implemented the NPDES Program in 1972 to regulate the discharge of point source pollutants to navigable waters by setting discharge limits, monitoring and reporting requirements, and special conditions (USEPA, 2014). The NPDES Program was revised to include the Phase I and Phase II programs for stormwater discharges in 1990 and 2000, respectively. Phase I of the NPDES Program began in 1990 and regulated discharges from medium to large (>100,000 people) municipal separate storm sewer systems (MS4s), construction activities disturbing 5 acres or more, and industrial activities. Phase II of the NPDES Program was implemented in 2000 to include small MS4s and construction activities that disturb one acre or more (USEPA, 2000b).

In addition to federal regulations, many states also regulate surface water quality. The Massachusetts Surface Water Quality Standards (314 CMR 4.00) were enacted to protect inland and coastal surface waters in Massachusetts and were last amended in 2013. Massachusetts inland surface water bodies are divided into three classes: Class A surface water bodies are designated for drinking water supply; Class B surface water bodies are designated for primary contact recreation; and Class C surface water bodies are designated for secondary contact recreation. The Massachusetts standards set criteria for water quality parameters protective of human health, aquatic life, and aesthetics.

There are also regulations set to protect surface waters used as source waters for drinking water. One of these laws is the 1974 SDWA, which was significantly amended in 1986 and 1996 (USEPA, 2002a). While previous versions of the SDWA focused on treatment of source water, the 1996 amendments greatly enhanced the focus on source water protection and a multi-barrier approach. Under the SDWA, the USEPA sets National Primary Drinking Water Regulations which dictate maximum contaminant levels and require source water assessment for specific contaminants.

Under the SDWA, the USEPA promulgated the Surface Water Treatment Rule (SWTR) in 1989 and various amendments including the 1998 Interim Enhanced Surface Water Treatment Rule (IESWTR), and the 2002 Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) to improve public health protection through the control of microbial contaminants (USEPA, 2004). The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) was set by the USEPA in 2006 to further target additional *Cryptosporidium* treatment techniques (USEPA, 2006). Table 2-3 summarizes the key components of each rule.

These surface water regulations indicate a need to protect surface waters from influences that are detrimental to human or ecological health or that degrade general water quality. The NPDES Program protects surface waters from point source discharges, and the CWA and SDWA along with their various amendments require the assessment of surface water quality. These federal regulations have led to increased protection and preservation of surface waters in the United States. However, with continual development and growing water demands, pollutant impacts remain a significant threat to surface water quality especially from much harder to regulate non-point sources. Therefore, surface water quality monitoring plans are a key component in identifying and mitigating potential contaminant sources in surface waters.

Table 2-3: Overview of Surface Water Treatment Rules [Adapted from USEPA (2004) and USEPA (2006)]

Applicability		**Final Rule (Date)**			
		SWTR (1989)	**IESWTR (1998)**	**LT1ESWTR (2002)**	**LT2ESWTR (2006)**
Population Served	≥ 10,000	✓	✓	N/A	✓
	≤ 10,000	✓	N/A (except for sanitary survey provisions	✓	✓
Source Monitoring	Cryptosporidium and E. coli	N/A	N/A	N/A	✓
Regulated Pathogens	4 Log Removal - Viruses	✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR
	3 Log Removal - *Giardia lamblia*	✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR
	2 Log Removal - *Cryptosporidium*	N/A	✓	✓	Regulated under IESWTR
	Bin Classification and Treatment - *Cryptosporidium*	N/A	N/A	N/A	✓
Residual Disinfectant Requirements	Entrance to distribution system (> 2 mg/L)	✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR
	Detectable in distribution system	✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR
Turbidity Performance Standards	Combined Filter Effluent - Slow Sand and DE	✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR
	Combined Filter Effluent - Alternative	✓	✓	✓	Regulated under SWTR
Disinfection Profiling and Benchmarking	Systems must profile inactivation levels and generate benchmark if required	N/A	✓	✓	Regulated under IESWTR
Sanitary Sewers (state requirement)	CWS - Every 3 years NCWS - Every 5 years	N/A	✓	Regulated under IESWTR	Regulated under IESWTR
Covered Finished Reservoirs/Water Storage Facilities (new construction only)		N/A	✓	✓	Regulated under IESWTR
Operated by Qualified Personnel as Specified by State		✓	Regulated under SWTR	Regulated under SWTR	Regulated under SWTR

2.2 Water Quality Monitoring Parameters

Selecting which water quality parameters to analyze for is an essential part of every water quality monitoring plan. Physical, chemical, and microbiological parameters all contribute to overall water quality. Certain water quality parameters such as fecal coliform bacteria are directly linked to public health risk, while other parameters are indicative of ecosystem health or affect treatability. The following sub-sections describe the water quality parameters analyzed as part of this research and give typical values for surface waters in New England to provide context for the results from the study site.

2.2.1 Physical Parameters

The following sub-sections summarize key physical parameters measured as part of this research.

2.2.1.1 Temperature

Temperature readings are used in the calculation of alkalinity, saturation and stability with respect to calcium carbonate, and salinity, and elevated temperatures may have significant ecological impacts (APHA *et al*., 2012). Temperature is inversely related to dissolved oxygen concentration, partly because dissolved oxygen saturation levels decrease with increasing temperature. Temperature, therefore, directly impacts aquatic life by controlling the amount of available oxygen. Similarly, studies have shown that microorganism growth and survival rates are significantly affected by water temperature (Walters *et al*., 2011; Wilkes *et al*., 2011).

The MADEP states that water temperature should not exceed 20°C in cold water fisheries or 28.3°C in warm water fisheries, and thermal pollution should not contribute more than a 1.7°C rise in temperature (MADEP, 2013). Typical water temperatures in New England range from frozen ice at 0°C to approximately 25°C. For example, in a 15-month study of tributaries at the Wachusett Reservoir watershed, which includes drinking water sources and recreational waters in central Massachusetts, surface water sample temperatures ranged from 0.5°C in the winter to 22.4°C in the summer (Plummer and Long, 2009).

2.2.1.2 Turbidity

Turbidity is the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample. Turbidity is caused by suspended matter and is affected by the size, shape, and refractive index of the particulates in suspension (APHA *et al*., 2012). Turbidity is used as an aggregate measure of suspended solids and is measured in Nephelometric Turbidity Units (NTU). The MADEP states that waters should be free from turbidity that would be aesthetically objectionable or would impair water use (MADEP, 2013). Turbidities in surface waters range from less than 1 NTU in a clear mountain spring to around 10 NTU in a large river during dry-weather conditions, and turbidity values can reach hundreds of NTU during storm events (USEPA, 1997). For example, in the Wachusett Reservoir watershed study mentioned in Sub-section 2.2.1.1, turbidity values ranged from 0.21 to 17.2 NTU with higher turbidity observed after rainfall events (Plummer and Long, 2009).

2.2.2 Chemical Parameters

The following sub-sections summarize key chemical parameters measured as part of this research.

2.2.2.1 Conductivity

Conductivity is a measure of the ability of an aqueous solution to carry an electric current and is affected by the presence (concentration and type) of ions and temperature (APHA *et al*., 2012). Therefore, conductivity in natural waters is an aggregate measure of cations and anions in solution. No surface water guidance exists for conductivity from the MADEP. Typical surface waters in the United States have conductivities in the range of 50 to 1,500 microsiemen per centimeter (µS/cm) with conductivities in the range of 50 to 500 µS/cm being more suitable for mixed fisheries (USEPA, 1997).

In a 15-month study at the Wachusett Reservoir watershed, sample conductivities ranged from 95.3 to 855 µS/cm with increases in conductivity linked to anthropogenic inputs and higher temperature (Plummer and Long, 2009). Similarly, in a study on population density impacts to water quality, Tu *et al*. (2007) compared surface water data from 37 United States Geological Survey (USGS) sampling sites over a 34 year period from 1970 to 2004. The study area included watersheds ranging from 11.5 to 770 square kilometers located between Worcester (central) and Boston (eastern), Massachusetts. Results indicated specific conductance values ranging from approximately 75 µS/cm to 750 µS/cm, with higher specific conductance values related to higher population density and percentage land development. In a climate change study performed on two lakes in the European Alps, conductivity was shown to increase from approximately 24 to 451 µS/cm due to increased contributions of sulfate, magnesium, and calcium (Thies *et al*., 2007). The increased contributions of ions in this study were linked to melting glaciers; however, similar trends have been observed as a result of chloride contributions from road salt or nitrate from fertilizers.

2.2.2.2 Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen in the aqueous phase. DO levels in natural waters are affected by the physical, chemical, and biological activities occurring in the water body (APHA *et al*., 2012). The MADEP states that DO shall be greater than or equal to 6 milligrams per liter (mg/L) in cold water fisheries, and 5 mg/L in warm water fisheries. DO concentrations in natural waters can vary from very low concentrations (< 1 mg/L) to the saturation level (approximately 8 to 14 mg/L for temperatures observed in New England). In the Wachusett Reservoir watershed study, DO values ranged from 5.94 to 14 mg/L with higher DO concentrations observed in the winter when temperatures were lowest (Plummer and Long, 2009). Lattanzi *et al*. (2007) measured vertical DO concentration profiles in 2002 in 12 lakes located between western Massachusetts and Cape Cod. DO concentrations ranged from approximately 0 to 12 mg/L, and concentrations decreased significantly at depths greater than 5 to 10 meters below the water surface.

2.2.2.3 pH

At a specific temperature, pH is the intensity of the acidic or basic nature of a solution or the hydrogen ion activity. pH is one of the most frequently measured parameters in waters, and it affects alkalinity, acidity, and many water treatment processes (APHA *et al*., 2012). pH is often called the master variable in natural waters, because it determines suitability for biological growth and survival, and it influences the chemical speciation and solubility of many dissolved compounds (Hemond and Fechner-Levy, 2000). The MADEP requires Class B waters to be in a pH range of 6.5 to 8.3 standard units (2013). In the Wachusett Reservoir watershed study, pH values ranged from 6.44 to 7.88 (Plummer and Long, 2009). Mattson *et al.* (1997) compared pH values measured quarterly between 1983 and 1993 at 330 streams throughout Massachusetts. Results indicate that median pH values ranged between approximately 6.1 and 6.8. Plummer *et al*. (2014) measured pH, turbidity, organic carbon, and bacterial indicators from treated and untreated drinking waters and wastewaters from Massachusetts, North Carolina, Florida, Wisconsin, Colorado, Nevada, and Washington. pH values for drinking water sources ranged from approximately 6 to 8.

2.2.2.4 Alkalinity

Alkalinity is the acid-neutralizing capacity of a water, and in natural waters, it is often taken to represent the concentrations of carbonate, bicarbonate, and hydroxide present (APHA *et al*., 2012). Standard Methods (APHA *et al*., 2012) provides different titration end-points for alkalinities ranging from 20 to 500 mg/L as $CaCO_3$, corresponding to values that could be observed in natural waters. Low alkalinity is defined as less than or equal to 20 mg/L as $CaCO_3$. Typically, high alkalinities and high ionic strength waters are found in regions of sedimentary rock, while low alkalinities and dilute waters are found in regions that have a mixture metamorphic rock or in glacial outwash areas (Mattson *et al*., 1997).

In a study on a tributary of the Quabbin Reservoir, which serves as a drinking water source for Boston and is located in western Massachusetts, surface water samples were collected over an approximately four and a half year period, and alkalinity values were low, ranging from approximately 1 to 17.5 mg/L as $CaCO_3$ (Shanley *et al*., 1995). Mattson *et al.* (1997) compared alkalinity values in their study of 330 streams in Massachusetts. Results indicated that median alkalinity values ranged between 3 and 14 mg/L as $CaCO_3$.

2.2.2.5 Organic Carbon

Total organic carbon (TOC) is a convenient and direct expression of total organic content in water, which is composed of a variety of organic compounds in various oxidation states (APHA *et al*., 2012). TOC in untreated drinking water can range from less than 0.1 to 25 mg/L (APHA *et al*., 2012). In the Wachusett Reservoir watershed study, TOC values ranged from 1.04 to 7.92 mg/L, and most of the organic matter was in the dissolved phase with dissolved organic carbon (DOC) concentrations ranging from 0.97 to 7.53 mg/L (Plummer and Long, 2009). This same study found that the highest TOC/DOC concentrations were observed near a wooded wetland. Long *et al.* (2006) measured concentrations of TOC ranging from 1 to 51 mg/L in a similar study of two watersheds within the Wachusett Reservoir. Results indicated higher concentrations in the fall. Plummer *et al*. (2014) measured TOC concentrations in drinking water sources in their multi-state study ranging from less than 1 mg/L to approximately 18 mg/L, and DOC concentrations ranged from less than 1 mg/L to 12 mg/L.

2.2.2.6 Nutrients and Anions

Phosphorus and nitrogen containing compounds are nutrients that in excess contribute to the eutrophication of surface waters. Eutrophication results in increased phytoplankton and algal growth, decreased dissolved oxygen, and aesthetical issues. Nutrients can enter surface waters through atmospheric deposition or the weathering of geologic materials (Thies *et al*., 2007), or these contaminants can come from anthropogenic sources such as urban landscapes or wastewater discharges (Surbeck *et al*., 2010).

Phosphorus is often the limiting nutrient that controls eutrophication, and inputs range from fertilizers and overland runoff to household detergents and failing septic systems (Kramer *et al*., 2006). Most studies traditionally focus on orthophosphate, the fully oxidized state, because it is typically the dominant form of phosphorus in the environment (Han *et al*., 2012). Typical total phosphorus concentrations range from approximately 3 to 208 micrograms per liter (μg/L) in surface water in eastern New England (USEPA, 2001b). In their review of 34 years of Massachusetts water quality data, Tu *et al.* (2007) found total phosphorus concentrations ranging from approximately 5 to 65 μg/L and orthophosphate concentrations between approximate 10 and 70 μg/L in their study on population density impacts to water quality.

Nitrogen, typically in the form of nitrate, nitrite, ammonia, or ammonium ion, also contributes to eutrophication. Typical total nitrogen concentrations in eastern New England range from approximately 0.18 to 1.66 mg/L (USEPA, 2001b). In the Quabbin Reservoir tributary study, nitrate concentrations were found to range from 0.06 to 0.6 mg/L (Shanley *et al*., 1995). Tu *et al.* (2007) found nitrate concentrations between 0 and 2.5 mg/L, nitrite concentrations between 0 and 0.1 mg/L, and ammonia concentrations between 0 and 3.2 mg/L, all as nitrogen.

Although no recreational water quality standards are set for nutrients, the Massachusetts Surface Water Quality Standards prohibit the discharge of nutrients at concentrations that would cause or contribute to eutrophication. The USEPA Ambient Water Quality Criteria regulate total phosphorus and total nitrogen in lakes and reservoirs by ecoregion to be protective of aquatic life. Additionally, the Ambient Water Quality Criteria regulate ammonia with standards being set based on temperature and pH. Also, NPDES permits typically regulate the discharge of nutrients such as phosphorus and nitrogen. For surface waters that serve as sources of drinking water, the United States Environmental Protection Agency (USEPA) has set a drinking water Maximum Contaminant Level (MCL) of 10 mg/L for nitrate and 1 mg/L for nitrite (both as nitrogen) to be protective of blue-baby syndrome in infants under the age of six months who could consume the water (USEPA, 2009).

In addition to orthophosphate, nitrate, nitrite, and ammonia, other anions have been shown to affect surface water quality. For example, increased chloride concentrations have been shown to change the timing and patterns of natural lake mixing and influence aquatic life and biodiversity (Novotny and Setefan, 2010). Chloride is most commonly associated with road salt for deicing; however, it is also found in fertilizers and animal feeds (McGinley, 2008). The Ambient Water Quality Criteria for chloride is set at 860 mg/L for acute exposures and 230 mg/L for chronic exposures. Also, the USEPA has set a Maximum Contaminant Level Goal (MCLG) for chloride of 250 mg/L (2009). Tu *et al.* (2007) observed chloride concentrations ranging from 25 to 240 mg/L in their Massachusetts based study. In a study of 138 lakes in the Adirondack Park area of New York, average chloride concentrations ranged from 0.24 to 0.55 mg/L in lakes with no paved roadways (no roadway deicing), and chloride concentrations ranged from 3.6 to 7.2 mg/L in lake with paved roads (Kelting *et al*., 2012).

The USEPA has also set MCLGs for fluoride (protective of tooth discoloration) and sulfate (protective of taste) of 2 and 250 mg/L, respectively (2009).

2.2.3 Microbiological Parameters

The following sub-sections summarize key microbiological parameters measured as part of this research.

2.2.3.1 Indicator Organisms

Because it would be too time consuming and expensive to monitor waters for every pathogen, indicator organisms are measured to determine whether pathogens are likely to be present. Indicator organisms provide evidence of the presence or absence of pathogenic organisms under existing physical, chemical, and nutrient conditions. Indicator organisms should (1) be easily detected using simple laboratory tests, (2) be generally not present in unpolluted waters, (3) be observed at concentrations that can be correlated with the extent of contamination, and (4) have a die-off rate that is not faster than the die-off rate of the pathogens of concern (USEPA, 2002c). The most commonly measured fecal indicator bacteria are total coliforms, fecal coliforms, *E. coli*, fecal streptococci, and enterococci (USEPA, 1997).

Total coliforms are a group of bacteria that are generally not harmful to humans. Due to their presence in fecal matter and the environment and their ability to be injured by environmental stresses and water treatment consistent with many pathogens, total coliforms are considered a useful indicator of pathogens (USEPA, 2001a). Although there is no standard for total coliforms in recreational waters, the Total Coliform Rule requires testing for total coliforms in drinking water systems and stipulates further testing of fecal coliforms in the event of total coliform detections. In the multi-state study on treated and untreated drinking and wastewaters, Plummer *et al*. (2014) found total coliform concentrations in raw surface waters serving as drinking water sources (prior to treatment) ranging from 5.4 and 1,600 MPN/100 mL.

E. coli and enterococci are types of fecal coliforms that are present in the intestinal track of warm-blooded mammals; therefore, the presence of these bacteria in surface waters indicates that fecal contamination is likely. Direct relationships have been observed between the concentrations of fecal coliforms in recreational waters and gastrointestinal illness (Dufour, 1983; Cabelli, 1981). Current regulations use enterococci as a fecal indicator bacteria in fresh and marine recreational waters and *E. coli* as a fecal indicator in fresh recreational waters. The USEPA *E. coli* standards were discussed in Sub-section 2.1.3. In Massachusetts, the criteria are similar for Class B waters at 126 *E. coli*/100 mL and 33 enterococci/100 mL for geometric means, and one sample maximum values of 235 *E. coli*/100 mL and 61 enterococci/100 mL (MADEP, 2013).

The Wachusett Reservoir watershed study found *E. coli* concentrations ranging from 2 colony forming units (cfu) per 100 mL to 4,800 cfu/100 mL (Plummer and Long, 2009). Plummer *et al*. (2014) observed *E. coli* concentrations in raw surface source waters ranging from below the method detection limit to 35 MPN/100 mL. Likewise, in another Wachusett Reservoir watershed study focusing on two subbasins, Plummer and Long (2007) found enterococci concentrations ranging from 1 to 3,200 cfu/100 mL.

2.2.3.2 Coliphages

Coliphages are bacterial viruses found in human and animal feces that infect and replicate in *E. coli*. Coliphages are useful fecal indicators because traditional bacterial indicators do not accurately indicate the presence of nonbacterial organisms such as human pathogenic viruses (USEPA, 2001a). The two most common types of coliphages used for microbial water quality monitoring are male-specific coliphages and somatic coliphages. The major differences between the two coliphage types are that male-specific coliphages infect male bacteria cells through the F-pilus, whereas the somatic phages infect bacteria cells through the cell surface. Also, male-specific coliphages cannot replicate in the environment, while somatic coliphages can. Therefore, while male-specific coliphages should be a more suitable indicator of fecal contamination, somatic coliphages should be more prevalent in the environment making somatic coliphages easier to detect when fecal contamination is relatively low.

Male-specific coliphages have been successfully used in microbial source tracking applications, and the Wachusett Reservoir watershed study found male-specific coliphage concentrations ranging between non-detect and 14.5 plaque forming units (pfu) per 100 mL (Plummer and Long, 2009). In some cases, however, coliphage concentrations are so low that due to a lack of detections coliphages cannot be used for routine monitoring (Plummer and Long, 2007). In the multi-state treated/untreated drinking and wastewater study, Plummer *et al*. (2014) found that concentrations of male-specific coliphages ranged from below the method detection limit to 1.83 pfu/100 mL in raw surface source waters. Similarly, somatic coliphage concentrations ranged from below the method detection limit to 5.8 pfu/100 mL in raw surface source waters.

2.3 Water Quality Impacts

Understanding the fate and transport of physical, chemical, and microbial contaminants in a watershed can be challenging because of the variety of inputs emanating from agricultural, industrial, and domestic uses combined with spatial and temporal variability (Barber *et al*., 2006). Studies have shown that water quality parameters such as fecal indicator bacteria can be highly variable across different sample locations associated with varying land uses (St. Laurent and Mazumder, 2013), and different water quality parameters may be better indicators of overall water quality during different climactic conditions (Ouyang *et al*., 2006). The use of statistical analysis to examine spatial and temporal patterns of water quality and identify parameters related to hydrological conditions is, therefore, an important aspect of any water quality monitoring plan (Ouyang *et al*., 2006). The following sub-sections outline some of the key influences on surface water quality.

2.3.1 Land Use

Land use is a factor that can have significant impacts on surface water quality. Developed (residential/urban), undeveloped, agricultural, or industrial land uses can contribute different pollutants in different proportions to nearby surface waters. Numerous studies have focused on differentiating water quality impacts based on land use (Staley *et al*., 2013; Wittmer *et al*., 2010; St. Laurent and Mazumder, 2013). Agricultural land can be a significant source of microbial contaminants from livestock as well as a source of pesticides and herbicides, and industrial land can introduce toxic chemicals from industrial processes; however, these land uses are not discussed in further detail as they do not apply to the study site for this research as described in Chapter 3.

Developed land can be categorized as rural, suburban, or urban and can be defined by percent development or percent imperviousness. Percentage of land development refers to the percentage of land area within a watershed with any type of development, while the percentage of impervious land refers to the land within a watershed where infiltration cannot occur (i.e. paved surfaces and buildings). Percent development and percent imperviousness are often related; however, not all developed land changes the percent of impervious surfaces (e.g. an agricultural development). The percent of impervious surfaces has a significant impact on the ability of overland runoff to transport contaminants to a water body. Lee and Bang (2000) measured biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids versus runoff in nine different watersheds. Results indicate that for small watersheds (< 100 hectares) with high percentages of impervious area (>80%) contaminant peaks were observed prior to runoff peaks in watershed runoff, while in larger watersheds with lower percentages of impervious area, the runoff flow peaks were observed prior to contaminant peaks in watershed runoff. This effect has also been documented in other studies and is commonly referred to as the first flush effect. St. Lauren and Mazumder (2013) collected fecal coliform samples from 43 sites in British Columbia monthly between 2000 and 2006 in a study on the effects of hydro-meteorological regimes and land use on surface water quality. Results demonstrated the first flush effect at the onset of snowmelt characterized by a sharp peak and then sharp decline in fecal bacteria concentrations, where fecal coliforms that accumulated in a catchment were flushed into surface water by initial overland runoff. Subsequent runoff then had little affect because the bulk of accumulated bacteria had already been flushed from the catchment.

Mallin *et al*. (2009) monitored water quality at 12 sample sites in streams located in undeveloped, suburban, and urban watersheds in North Carolina between July 2001 and April 2002. The percentage of residential land ranged from 0 to 99 percent, percentage of business-use land ranged from 0 to 87 percent, percentage of agricultural land ranged from 0 to 14 percent, and the percentage of impervious surfaces ranged from 5 to 26 percent. Results indicated that percent watershed development and percent imperviousness were positively correlated with BOD, suspended solids, orthophosphate, and surfactants and negatively correlated with organic carbon. This same study found that fecal coliform concentrations were generally highest in the most urbanized areas with an average concentration of 955 cfu/100 mL in the most urban stream and 536 cfu/100 mL in the most rural stream. However, correlations for fecal bacterial to percent development/imperviousness were found to be statistically insignificant (Mallin *et al*., 2009).

Along with developed land use, septic systems potentially impact groundwater quality and surface water quality where impacted groundwater discharges to the surface water body. Septic systems are a significant input of phosphorus to surface waters and have been found to be the most significant phosphorus source in urban watersheds with limited agricultural use (Kramer *et al*., 2006). Phosphorus in surface water is a primary cause of eutrophication, which causes increased phytoplankton and algal growth, decreased dissolved oxygen, and aesthetical issues. Groundwater containing even low concentrations of phosphorus (<0.02 mg/L) can lead to the eutrophication of surface waters (Ptacek, 1998). Kramer *et al*. (2006) assessed water quality in 25 lakes in Minnesota that have watershed areas ranging from 2 to 61 square kilometers, lake areas ranging from 0.5 to 15 square kilometers, and development of 1 to 46 residences per kilometer of shoreline. Septic systems were found to contribute between 1 and 64 percent of the total phosphorus inputs to these lakes with input values of 42 to 282 μg/L of phosphorus.

Other studies have shown that shallow groundwater near septic systems contains elevated nitrate, orthophosphate, ions, organic carbon, and microbial concentrations, and has decreased dissolved oxygen and pH (Katz *et al*., 2011). Katz *et al*. (2011) collected water samples from 1,848 public wells and 123 monitoring wells throughout the United States, and samples were analyzed for ions, organic carbon, and nutrients among other parameters. Results showed that chloride to bromide concentration ratios may be useful indicators of septic influence, with ratios between 400 and 1100 linked to septic impacts. The chloride to bromide ratio was a useful indicator because both anions are generally conservative in the environment. According to Katz *et al*. (2011), elevated chloride concentrations have been linked to human influence; therefore, ratios of chloride to bromide above natural levels signified human inputs. The study also points out that comparing these ratios with sulfate or organic carbon concentrations may increase the certainty of the results. Ptacek (1998) studied a septic system at Camp Henry in Ontario, Canada, and found that increased concentrations of nutrients, organic carbon, ions, and metals were observed in the effluent of the system holding tank. In the groundwater plume downgradient of the tank, concentrations of organic carbon ranged from 6 to 13 mg/L, nitrate and nitrite concentrations ranged from 1 to greater than 80 mg/L as nitrogen, phosphorus ranged from 0.3 to 1.5 mg/L, and the plume traveled greater than 60 meters in under 16 years. Also, Staley *et al*. (2013), described in more detail below, found human-related viruses in surface water surrounded by undeveloped land that were linked to an upgradient septic systems at a housing development.

In contrast to developed land, runoff from undeveloped areas can carry organic debris and microbial contaminants, but is not typically a source of anthropogenic pollutants. In the study performed by Mallin *et al*. (2009), described above, results indicated that organic carbon concentrations were the highest in the most rural areas with an average concentration in the most rural stream of 14.5 mg/L compared to an average concentration in the most urban stream of 7.1 mg/L. Staley *et al*. (2013) performed a study of water quality at eight man-made lakes in central Florida that were between 8 and 55 hectares, eutrophic or hypertrophic, and representative of either undeveloped land use, cattle grazing, or urban land use. Monthly samples were collected from September 2009 to February 2010 and again in July 2010, and results indicated that fecal indicator bacteria concentrations at the undeveloped lakes were comparable to concentrations at the cattle grazing and urban lakes with average values at the three lakes ranging from 56 to 69 cfu/100 mL for enterococci and 76 to 182 cfu/100 mL for fecal coliforms.

It is clear that the land uses surrounding surface waters can significantly impact the water quality. Similarly, the source and type of contaminant from each land use can play a role in determining water quality. A comparison by Wittmer *et al*. (2010) of biocides and pesticides in surface waters from urban and agricultural land uses identified five concentration patterns from different compounds and sources as outlined in Table 2-4. Although biocides and pesticides are not parameters of concern for this research, their fate and transport may be indicative of other chemical parameters.

Table 2-4: Summary of Concentration Patterns by Contaminant Source Type (Adapted from: Wittmer *et al.*, 2010)

#	Concentration Pattern	Indication
1	Elevated background concentrations throughout the year	A constant source
2	Elevated concentrations driven by rain events throughout the year	A constant urban outdoor source (eg. Facades)
3	Seasonal peak concentrations driven by rain events	Urban and agricultural sources that vary with seasonal use
4	Unpredictable sharp peaks	Improper handling or disposal of chemicals
5	Compounds used in large quantities but not detected	Compounds with very high decay rates in the environment

These results highlight the importance of understanding land use and pollutant characteristics along with seasonal impacts and fate and transport effects.

2.3.2 Climate

Climatic factors such as temperature and precipitation can have significant impacts on surface water quality. In climates like New England, seasonal variations in surface water quality have also been observed. Seasonal and climatic variations make it essential for monitoring plans to consider sampling frequencies that capture these changes (Rowny and Stewart, 2012; Ouyang *et al*., 2006).

2.3.2.1 Temperature

Temperature has been shown to correlate with many water quality parameters. Ouyang *et al*. (2006) monitored 16 physical and chemical parameters at 22 monitoring stations in the lower St. Johns River in northeast Florida from 1998 to 2001. The results indicated that temperature had weak to fair correlations ($R < 0.7$) throughout the year with parameters such as conductivity, DO, BOD, nitrogen and phosphorus compounds, and organic carbon; however, the strength of the correlations and positive/negative relationships vary seasonally (Ouyang *et al*., 2006).

Lower temperatures are known to increase the DO saturation level resulting in greater DO concentrations, and dissolved oxygen concentrations significantly impact aquatic life. Temperature also directly affects the growth and survival rate of bacteria. Fecal indicator bacteria and pathogens were documented to have greater persistence and survival in colder temperatures due to reduced metabolic activity and predation. Walters *et al*. (2011) collected samples from 14 water bodies in California over 2 years, and results indicated a negative correlation between temperature and the fecal indicators bacteria *E. coli* and enterococci. Similarly, Wilkes *et al*. (2011) stated that cooler temperatures in the spring and fall can promote bacteria survival and coincide with times when the application of manure is likely to occur. In their study at a river basin in

Ontario, Canada between 2004 and 2008, Wilkes *et al.* (2011) found that bacterial pathogens were detected more frequently at lower water temperatures (<14°C).

However, other studies have shown positive correlations between temperature and bacterial concentrations. In a water quality study at 27 surface water sample locations in Pennsylvania between July 2007 and August 2009, Duris *et al.* (2013) found that both *E. coli* and enterococci were positively correlated with temperature. In addition, they found significantly higher concentrations of *E. coli* and enterococci (1186 and 1330 cfu/100 mL respectively) in the summer than in the winter (295 and 322 cfu/100 mL respectively). Similarly, Long *et al.* (2006) found in their Wachusett reservoir tributary study that fecal coliform concentrations typically ranged from 100 to 2,500 cfu/100 mL in the summer compared to winter months when fecal coliform concentrations were typically less than 100 cfu/100 mL. These results indicate that temperature likely has variable effects on bacteria concentrations depending on the source of contamination and factors like predation, persistence, and growth in the environment.

2.3.2.2 Rainfall

Rainfall has been shown to increase the concentration of contaminants such as bacteria, suspended solids, turbidity, orthophosphate, total phosphorus, and BOD in surface waters. Mallin *et al.* (2009) studied undeveloped, suburban, and urban rivers in North Carolina, and results showed that mean concentrations for fecal indicator bacteria for all three river types increased with antecedent rainfall. The mean dry and wet fecal coliform concentrations were approximately 500 and 3,500 cfu/100 mL for the urban stream, and 300 and 1500 cfu/100 mL for the rural stream. Similarly, this study found that for all stream types, turbidity, total phosphorus and orthophosphate concentrations were significantly higher after rain events, while total nitrogen concentrations were higher in all streams during dry periods. Other studies report significant positive correlations between antecedent rainfall and indicator bacteria concentrations such as fecal coliforms, *E. coli*, and enterococci (Staley *et al.*, 2013; Wilkes *et al.*, 2009). Staley *et al.* (2013), in the central Florida lake study, found antecedent rainfall for 1, 3, and 7 days prior to sampling was significantly correlated with fecal coliforms, and antecedent rainfall for 2 and 7 days prior to sampling was significantly correlated with enterococci. This study also found that concentrations of fecal coliforms and enterococci generally exceeded regulatory standards after recent rainfall events.

The hydrology and geology of a watershed has a major impact on source water contamination due to the effects of overland transport, especially from increased precipitation and snowmelt in the late winter and early spring (Duris *et al.*, 2013; St. Laurent and Mazumder, 2013). In addition to rainfall and snowmelt serving to transport pollutants, increased runoff can change surface water flow and turnover or hydraulic residence time, which may also result in different contaminant distributions. Duris *et al.* (2013), in the Pennsylvania water quality study, found that both *E. coli* and enterococci increased with increased stream flow, which was a result of precipitation or snowmelt. Mean concentrations of *E. coli* and enterococci during low stream flow (<25th percentile of daily mean stream flow) were 49 and 32 cfu/100 mL respectively, while mean concentrations during high stream flow (>75th percentile of daily mean stream flow) were 1,242 and 1,441 cfu/100 mL respectively. In this same study, *Giardia* concentrations were found to increase with increased stream flow similar to the fecal indicator bacteria; however, *Cryptosporidium* were unaffected by stream flow indicating a different source or different transport characteristics.

St. Lauren and Mazumder (2013) also reported that non-point source pollution typically varies more with precipitation than point source pollution due to the diffuse nature and impacts of land-use and overland runoff on non-point sources. In a hydro-meteorological study in British Columbia, St. Lauren and Mazumder (2013) found that the impact of rainfall on fecal coliform concentrations was highly variable between different sites likely due to stronger correlations between rainfall and fecal coliform concentrations observed at sites with clear non-point sources (i.e. manure spreading at agricultural sites). Other studies have found that rainfall induced turbulence can re-suspend contaminants that have settled in bottom sediments significantly increasing water concentrations (Goyal *et al*., 1977).

2.3.2.3 Season

The season of surface water sample collection has been shown to have variable effects on water quality parameters. In the Pennsylvania water quality study referenced above, Duris *et al*. (2013) found that while season had no significant impact on parameters such as *Cryptosporidium,* season affected both the concentration and frequency of detection for parameters such as fecal indicator bacteria and *Giardia*. The authors suggest that the difference was related to different sources of the contaminants. *Giardia* were likely related to non-point sources that were seasonally variable due to the nature of overland flow and transport.

Barber *et al*. (2006) collected samples from 29 locations in June and October 2000 while studying the spatial chemical loading of contaminants in the Boulder Creek Watershed in Colorado. Results showed increased organic carbon concentrations in an upper basin during spring runoff due to flushing from soil and shallow groundwater. In contrast, organic carbon concentrations at two sample locations near the effluents of wastewater treatment plants in the same watershed remained relatively constant despite flushing or precipitation effects. Similarly, this study found that during spring runoff, chloride concentrations in the effluent from a wastewater treatment plant accounted for approximately 38 percent of the downstream flow versus approximately 75 percent during baseline flow.

Correlations between different water quality parameters also vary seasonally; therefore, a parameter that is a good indicator of water quality in one season may have a weak or no correlation with water quality parameters of interest in another season (Ouyang *et al*., 2006). In the lower St. Johns River study in Florida, Ouyang *et al*. (2006) found that dissolved oxygen had strong correlations with total nitrogen and organic carbon in the spring (>0.90), but the correlations were weaker in the summer ($R<0.79$) and fall ($R<0.44$). This same study determined that dissolved organic carbon and conductivity were the most important parameters contributing to water quality for all four seasons.

Similarly, the relationships between water quality indicators and different hydrological indices such as rainfall and stream discharge vary seasonally (Wilkes *et al*., 2009). In a river water quality study in Ontario, Canada, Wilkes *et al*. (2009) collected bi-weekly samples from 24 sampling sites between 2004 and 2006. This study found that although rainfall and stream discharge were generally positively correlated with indicator bacteria density and pathogen detection, stream discharge was found to be negatively correlated with indicator bacteria densities at times during the spring and summer possibly due to dilution effects.

2.3.3 Impact Interactions

Water quality is not defined by any one impact, but instead is a result of a variety of different land-uses and climatic conditions. As stated above, point and non-point source contaminants can respond differently to rainfall events. Similarly, the impact of stormwater runoff on surface water quality can be significantly influenced by land-use and watershed characteristics such as soil permeability or the presence of natural or man-made buffers (Tate *et al*., 2004). In a laboratory based study on *Cryptosporidium* transport to surface water from cattle feces in California grasslands, Tate *et al*. (2004) found that *Cryptosporidium* concentrations entering the surface water could be reduced by up to a 1.44 log reduction with the implementation of grass vegetated buffer strips.

The way that contaminants are distributed in the environment can also play a role in how surface waters are influenced by different factors. A number of studies have shown that anthropogenic sources showed greater spatial variability due to differences in land use, while natural or distributed contaminants were more significantly affected by climatic conditions such as season or rainfall. For example, Duris *et al*. (2013) found that *Giardia* was likely related to non-point sources due to its seasonal variability and correlation with agricultural land, while fecal indicator bacteria were linked to urban land use and point source discharges. Similarly, in a study where river samples were collected quarterly over 2.5 years from 3 stations along a river in Spain, Vega *et al*. (1998) showed through statistical analysis that natural pollutants typically varied temporally as a result of season and climate changes, while anthropogenic pollutants varied spatially from different land use inputs.

In a study on storm events in nine watersheds over two years, Lee and Bang (2000) found that the relative magnitude of pollutant loading rates was a function of land use, where the highest loading rates were observed in high density residential areas followed by low density residential, industrial, and undeveloped land. However, other studies have shown that rainfall has a more significant impact on water quality than land use (Staley *et al*., 2013; Mallin *et al*., 2009). Hongbing *et al*. (2009) found that total pollution loads were primarily based on three parameters (rainfall intensity, total land area, and percent imperviousness), which shows that both land use and rainfall account for variations in water quality. Therefore identifying the processes that control surface water quality is critical to protecting surface waters and public health (St. Laurent and Mazumder, 2013).

2.4 Conclusions

Surface water bodies are vulnerable to a variety of point and non-point source pollutants, and water quality can be significantly impacted by land use and climatic conditions; therefore, it is important to understand and protect water quality. Regulations are currently in place to control discharges to surface waters, and standards exist that require monitoring for specific contaminants or indicators. Research demonstrates that certain water quality parameters can be used to indicate water quality as it relates to human or ecological health and that factors such as land use and climate contribute to water quality. However, the current literature also shows discrepancies in correlations between water quality parameters and that climatic factors or land use may change the relationship between water quality parameters. Further research is needed to identify the most significant water quality parameters and to better understand the impacts of land use and climatic conditions on water quality monitoring.

3.0 METHODS

The objective of this research was to identify water quality impacts of point and non-point source pollution on a surface water body. This research incorporated water quality monitoring; data on land use, precipitation, and seasonal trends; and statistical modeling to provide an improved framework for understanding pollutant impacts on surface waters. Grab surface water samples were collected approximately twice per month over a 12-month period from 10 sampling locations at Beaver Lake in Ware, Massachusetts. This chapter summarizes the sampling plan, sampling procedures, analytical methods, and statistical analyses employed in this research.

3.1 Experimental Design

Physical, chemical, and microbial water quality is affected by point and non-point source pollution as well as climatic conditions and watershed characteristics. The sampling locations were selected to target different potential pollution sources and the sampling dates to capture varying environmental conditions.

3.1.1 Sampling Locations

Beaver Lake is a private, man-made lake in Ware, Massachusetts located south of the Quabbin Reservoir, which is one of the primary source waters for Boston. Beaver Lake is a recreational surface water body with primary and secondary contact recreation. This lake has no public access and thus provided controlled conditions for this study. In addition, private control of the lake allows for the practical implementation of potential mitigation approaches.

Ten shoreline sample locations were selected around Beaver Lake. The sampling locations were selected to isolate, as much as possible, the impact of specific land uses. Data on potential sample sites were gathered in fall 2013 through site visits to determine physical access; board of health records for septic system plans; and public works department records on stormwater conveyances. Final site selection was performed in January 2014 and included (1) three shoreline samples adjacent to year-round homes with septic systems in close proximity to the lake, (2) four shoreline samples at the effluent of stormwater discharge pipes or culverts, and (3) three background samples including the lake influent at a beaver dam, the lake effluent over a controlled weir, and a private beach. The background locations were intended to represent water quality at locations without septic or direct stormwater discharge influences. Sampling sites are shown on Figure 4-1 in Chapter 4.

3.1.2 Sampling Dates

Samples were collected over a 12-month period from late January 2014 to early February 2015 on a monthly basis during the winter, early spring, and late fall, and twice-monthly during the warmer spring, summer, and fall time periods when water quality conditions were anticipated to be more variable. Collecting samples regularly over a full year was intended to capture seasonal variations in water quality. Sample dates were also intended to capture both dry weather and storm events in order to assess the effects of stormwater runoff on water quality. In total, 21 sampling events were performed in 2014/2015, including 13 dry weather and 8 wet weather sampling events. Wet weather was defined by the inches of rainfall in the 24 hours preceding sampling. Data on rainfall amounts were obtained from the hourly precipitation data available at the National Oceanic and

Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) online Quality Controlled Local Climatological Database for Springfield/Chicopee: Westover Airforce Base.

3.1.3 Sampling Protocols

Shoreline surface water samples were collected in accordance with the USEPA National Beach Guidance as derived from Bordner *et al*. (1978) and IITF (1999). Sampling locations were chosen where the water depth was approximately three feet, and samples were collected from depths of approximately 6 to 12 inches below the surface of the water. One exception was a culvert sampling location (Location 6), where water was collected directly from a culvert discharge only when water was flowing through the culvert. Also, during winter sampling events when the lake was frozen, a hand-auger was used to core through the ice prior to sample collection. Surface water samples were collected by grasping sample bottles from the bottom, submerging the bottles to the target depth, and tipping the bottles upwards facing the flow of water in the lake to collect each sample. Samples were collected at each location into two, one-liter, wide-mouth, screw-cap, high density polypropylene (HDPP), Nalgene bottles (Nalge Nunc International, Rochester, NY). One bottle was pre-autoclaved and the water used for microbial analyses, and the other bottle was cleaned and the water used for physical and chemical analyses. A temperature blank sample was also collected at the first sampling location during each round. Samples were placed in a cooler on ice and transported to the laboratory for analyses.

A YSI 85 field meter (YSI Inc., Yellow Springs, OH) was used at each sample location to measure conductivity, dissolved oxygen and temperature, as described in Sub-section 3.2.1. Results were logged in a field book.

3.2 Analytical Procedures

The analyses performed on each sample are summarized in Table 3-1. Physical and chemical water quality analyses were performed in the field and in the environmental engineering laboratory at Worcester Polytechnic Institute (WPI) in Worcester, MA. Microbial indicator organisms were also measured in the environmental laboratory at WPI.

3.2.1 Field Physical and Chemical Analyses

Temperature, dissolved oxygen (DO), and conductivity were measured in the field using a YSI 85 field meter. The YSI 85 was calibrated for DO prior to each sampling event in accordance with the instruction manual. After samples were collected at each sample location, the YSI 85 probe (YSI Inc., Yellow Springs, OH) was submerged at the same location and depth as sample collection. The probe was continuously passed through the water at a velocity of approximately one foot per second in accordance with the manufacturer's recommendation until parameters stabilized. Temperature (^{o}C), conductivity (μS/cm), and DO (mg/L) were recorded upon stabilization.

3.2.2 Laboratory Physical and Chemical Analyses

Physical and chemical parameters measured in the laboratory included pH, turbidity, organic carbon, anions, ammonia, and alkalinity. These analyses were performed in accordance with accepted methods as summarized in Table 3-1.

Table 3-1: Sample Analyses

Category	Parameter	Method	Instrumentation/Comments
Field	Temperature	SM 2550	YSI 85 Field Meter
	Conductivity	SM 2510 A	YSI 85 Field Meter
	Dissolved Oxygen	SM 4500 - O G	YSI 85 Field Meter
Physical and Chemical	pH	SM 4500 - H^+ B	Orion 720 pH Meter
	Turbidity	SM 2130 B	Hach 2100N Turbidimeter
	Organic Carbon	SM 5310 B	Shimadzu TOC-5000A Analyzer
	Anions (F^-, Cl^-, NO_2^-, SO_4^-, Br^-, NO_3^-, PO_4^{-3})	SM 4110 ASTM D4327	Thermo Scientific Dionex ICS-2100
	Ammonia	SM 4500-NH_3 USEPA 350.1	Hach DR6000 Spectrophotometer
	Alkalinity	SM 2320	Volumetric Titration
Microbial	Total Coliforms	SM 9223	Colilert® Enzyme Substrate Test
	E. coli	SM 9223	Colilert® Enzyme Substrate Test
	Enterococci	SM 9230	Enterolert® Enzyme Substrate Test
	Male-Specific/Somatic Coliphages	USEPA 1602	Single Agar Layer Method

Notes:
SM = Standard Method; ASTM = American Society for Testing and Materials

3.2.2.1 pH

An Orion 720 pH probe (Thermo Electron Corporation, Waltham, MA) with an Accumet AB15 Benchtop pH Meter (Fisher Scientific, Pittsburg, PA) was used to measure pH in the laboratory in accordance with <u>Standard Method</u> 4500-H^+ B (APHA *et al*., 2012). Samples were refrigerated or kept on ice prior to analysis. The pH meter was calibrated the day of use with Fisher Scientific pH 4, 7, and 10 buffers (Fisher Scientific, Pittsburg, PA). One pH measurement was taken for each sample by inserting the pH probe into a small volume (~50 mL) of sample and recording the resulting measurement.

3.2.2.2 Turbidity

Turbidity was measured using a HACH 2100N turbidimeter (Hach Company, Loveland, CO) with a range of 0 to 4,000 NTU in accordance with <u>Standard Method</u> 2130 B (APHA *et al*., 2012). The turbidimeter was calibrated every three months using Stabl Cal Formazin calibration standards (<0.1, 20, 200, 1,000, and 4,000 NTU) (Hach Company, Loveland, CO) to ensure accurate readings. Samples were allowed to equilibrate to room temperature (to avoid vial fogging), inverted several times, and transferred to clean, oiled, 25 mL turbidity cells. The cell was placed and aligned in the turbidimeter, and an average value was recorded in NTU after approximately 30 seconds of readings.

3.2.2.3 Total and Dissolved Organic Carbon

TOC and DOC were measured using a Shimadzu TOC-5000A analyzer (Shimadzu Corporation, Kyoto, Japan). Samples were prepared, stored, and analyzed in accordance with <u>Standard Method</u>

5310 B (APHA *et al*., 2012). All glassware used for TOC analysis was acid washed in a 20 percent sulfuric acid bath for a minimum of one hour and rinsed at least three times with reagent grade water prior to use. All samples were analyzed in duplicate and results were averaged. Approximately 30 mL of each sample were transferred into two acid-washed vials and acidified to a pH of 2 with 6 N HCl at a ratio of 1 µL acid per 1 mL sample for the measurement of TOC. DOC samples were filtered through 2.5 cm diameter Whatman glass fiber filters (GF/F) with a pore size of 0.7 µm (Whatman Inc., Clifton, NJ). The filters were prewashed with approximately 30 mL of reagent grade water prior to use and the first 5 to 10 mL of sample through each filter were discarded. Then, approximately 30 mL of sample were filtered into two acid-washed vials and then acidified and processed as TOC samples. Acidified samples were capped with Parafilm (Bemis Company Inc., Oshkosh, WI) and plastic Shimadzu caps (Shimadzu Corporation, Kyoto, Japan) and stored at 4°C prior to analysis.

The TOC analyzer was calibrated with two separate three-point potassium hydrogen phthalate calibration curves (0, 2, 5 mg/L TOC and 0, 5, 10 mg/L TOC) prior to analysis. Calibration standards were prepared by first creating a potassium hydrogen phthalate stock primary standard of 1000 mg/L. The stock standard was prepared by weighing 0.75 grams of potassium hydrogen phthalate, drying it at 103-110°C in an oven for 30 minutes, and cooling it in a desiccator for an additional 30 minutes. After cooling, 0.5314 grams of the dried potassium hydrogen phthalate were weighed and added to an acid-washed 250 mL volumetric flask. The 250 mL flask was then filled to 250 mL with reagent grade water. The stock primary solution of 1,000 mg/L was stored in an acid-washed, opaque glass bottle at 4°C for up to one month.

An intermediate standard of 100 mg/L was prepared by transferring 10 mL of the primary stock standard into an acid-washed 100 mL volumetric flask and filling to 100 mL with reagent grade water. As mentioned above, the working standards used in the calibration curves were 10, 5, 2, and 0 mg/L. For each working standard, an acid-washed 100 mL flask was filled approximately halfway with reagent grade water, and 100 µL of 6 N HCl were added. The applicable volume of intermediate standard was then added to each volumetric flask to create the necessary calibration standards (e.g. 10 mL of intermediate standard for the 10 mg/L calibration standard). Finally, each volumetric flask was filled to 100 mL with reagent grade water, and the standards were transferred to TOC vials and capped. For quality control purposes, two calibration standards with known concentrations were analyzed as samples with each set of samples analyzed.

All standards and samples were sparged for three minutes with ultra-zero air before analysis to remove any carbon dioxide. The standards and samples were then analyzed a minimum of three times, after which the standard deviation and coefficient of variation were calculated. If the standard deviation was not less than 200, or the coefficient of variation was not less than 2.0 percent after the third reading, then additional measurements were taken until the standard deviation or coefficient of variation values were in the desired range or until 5 measurements were taken. Area counts from the standards were used to create a linear calibration curve, and sample organic carbon concentrations in mg/L were measured based on the calibration curve.

3.2.2.4 Anions

Anions including fluoride, chloride, nitrite, sulfate, bromide, nitrate, and phosphate were analyzed using ion chromatography in accordance with Standard Method 4110 (APHA *et al.*, 2012). A Thermo Scientific Dionex ICS-2100 ion chromatography system (Thermo Scientific Inc., Waltham, MA) was used with a Dionex AS-15 4X150 mm analytical column, a Dionex AG-15 4X50 mm guard column, a Dionex ASRS 300 4 mm suppressor, and a DS6 conductivity cell. A calibration curve of anion standards was developed for concentrations ranging from 100 to 5,000 µg/L as provided in Table 3-2 from a stock calibration solution purchased from Dionex. The seven calibration standards were run prior to sample analysis. The detection limits for the analyses were assumed to be equal to the lowest calibration standard (i.e. 10 µg/L for fluoride, 50 µg/L for chloride, nitrite, sulfate, bromide, and nitrate, and 100 µg/L for phosphate) due to the accurate linear calibration curve for each anion. Standard Methods provide an approximate detection limit of 100 µg/L.

Table 3-2: Anion Calibration Solutions

Standard (µg/L)	Fluoride Conc. (µg/L)	Chloride Conc. (µg/L)	Nitrite Conc. (µg/L)	Sulfate Conc. (µg/L)	Bromide Conc. (µg/L)	Nitrate Conc. (µg/L)	Phosphate Conc. (µg/L)
100	10	50	50	50	50	50	100
200	20	100	100	100	100	100	200
400	40	200	200	200	200	200	400
800	80	400	400	400	400	400	800
1,200	120	600	600	600	600	600	1,200
3,000	300	1,500	1,500	1,500	1,500	1,500	3,000
5,000	500	2,500	2,500	2,500	2,500	2,500	5,000

The samples were refrigerated at 4°C prior to analysis. Samples were transferred to 5 mL polypropylene Dionex sample cells with filter caps (Thermo Scientific Inc., Waltham, MA), which were loaded into the automatic sampler for analysis. The results of each sample analysis were integrated based on the calibration curve.

3.2.2.5 Ammonia

Samples were analyzed for ammonia as nitrogen using a Hach DR6000 spectrophotometer (Hach Company, Loveland, CO) and the USEPA Nessler Method (pre-programmed as 380 N, Nitrogen-Ammonia, Nessler Method) using a wavelength of 425 nanometers (nm).

This method is adapted from Standard Method 4500-NH_3 (APHA *et al.*, 2012), and the detection range is listed as 20 to 2,500 µg/L. Reagent grade chemicals were purchased ready to use from Hach. A blank was prepared by transferring 25 mL of reagent grade water into a sample cell;

adding 3 drops of Hach Mineral Stabilizer and inverting several times; adding 3 drops of Hach Polyvinyl Alcohol Dispersing Agent and inverting several times; adding 1 mL of Nessler Reagent and inverting several times; and allowing the sample to sit for one minute prior to analysis. The blank was used to zero the instrument. Samples were prepared similar to the blank but using 25 mL of sample water. The samples were analyzed and the results reported in mg/L as NH_3-N.

3.2.2.6 Alkalinity

The alkalinity of each sample was measured using potentiometric titration of low-alkalinity in accordance with Standard Method 2320 (APHA *et al.*, 2012). Sample volumes of 200 mL were titrated using approximately 0.02 N HCl (standardized as 0.018 N) in 10 mL burets to an intermediate endpoint pH between 4.3 and 4.7. The volume of acid used for the titration was recorded. Subsequently, the sample was titrated to a final endpoint pH exactly 0.3 pH units less than the intermediate endpoint. This volume of acid was also recorded. The pH values were measured as described in Sub-section 3.2.2.1. Alkalinity was then calculated using the method for *potentiometric titration of low alkalinity* shown in Equation 1.

$$Total\ Alkalinity\ \left(\frac{mg\ CaCO_3}{L}\right) = \frac{(2B-C)\times N\times 50{,}000}{mL\ sample} \qquad \text{(Equation 1)}$$

In Equation 1, B is the mL of titrant to the intermediate endpoint; C is the total mL of titrant to the final endpoint0; and, N is the normality of the acid.

3.2.3 Microbial Analyses

Microbial analyses were performed in accordance with accepted methods as summarized in Table 3-1. Microbial parameters included total coliforms, *E. coli*, enterococci, and coliphages. All microbial analyses were performed using aseptic techniques with autoclaved or pre-sterilized materials and supplies.

3.2.3.1 Total Coliforms and E. coli

Total coliforms and *E. coli* were enumerated for each sample in accordance with Standard Method 9223, the enzyme substrate test (APHA *et al.*, 2012). This method was performed using Colilert®, a commercially available enzyme-substrate liquid-broth medium that allows the simultaneous detection of total coliforms and *E. coli*, and the 97-well Quanti-Tray® method (IDEXX Laboratories Inc., Westbrook, ME). Each sample processed was 100 mL. Undiluted samples were composed of 100 mL of sample water, and diluted samples included sample water and buffered water as summarized in Table 3-3. Diluted samples were analyzed when the most probable numbers (MPN) for the undiluted samples were greater than the method upper limit of 2,419 MPN/100 mL. The appropriate volumes of sample water and buffered water were transferred to 250 mL, autoclaved dilution bottles.

Buffered water was used for sample dilutions and for positive and negative controls described below. Buffered water was made according to Standard Method 9050c.1a (APHA *et al.,* 2012), by diluting 5 mL of stock magnesium chloride and 1.25 mL of stock phosphate buffer up to 1 L with reagent grade water. The stock magnesium chloride was made by dissolving 20.275 g of $MgCl_2 \cdot 6H_2O$ to a total volume of 250 mL with reagent grade water, and the stock phosphate buffer was made by dissolving 8.5 g of KH_2PO_4 to a total volume of 125 mL with reagent grade water. If necessary, pH was adjusted to 7.2 ± 0.5 with sodium hydroxide.

Table 3-3: Microbiological Dilutions

Dilution	Volume Sample Water (mL)	Volume Buffered Water (mL)
4X	25	75
10X	10	90
100X	1	99

Once the samples and dilutions were prepared, one Colilert® packet was added to each 100 mL sample, which was then shaken to dissolve the media. The mixture was then poured into a 97 well Quanti-Tray® consisting of 49 large wells and 48 small wells and sealed in an IDEXX Quanti-Tray Sealer (IDEXX Laboratories Inc., Westbrook, ME). The Quanti-Tray was then incubated for 24 hours at 36°C ± 0.5°C. A yellow color indicates positive for total coliforms and fluorescence under UV light (Entela, UVL-23RW, Upland, CA) in a dark room indicates positive *E. coli* presence. Positive cells were counted and then compared to an MPN table to determine the MPN/100 mL of total coliforms and *E. coli* in each sample. The lower limit MPN/100 mL of the test is less than 1 (for 0 positive wells), and the upper limit is greater than 2,419 (for 97 positive wells). Duplicate samples were analyzed for each test including each dilution. The results from the duplicate samples were averaged, and the values were adjusted to account for the dilution of the sample to determine the MPN/100 mL in the original sample as collected.

One positive and one negative control were prepared for total coliforms and *E. coli* for each sampling event. For the positive control, *E. coli* (ATCC 11775, American Type Culture Collection, Manassas, VA) was cultured in the laboratory the day before sampling. Tryptic soy broth (TSB; Bacto 211825, Sparks, MD) was prepared by weighing 3 grams of tryptic soy broth powder and dissolving it into 100 mL of reagent grade water. Two 250-mL labeled shaker flasks were filled with 50 mL of TSB and autoclaved. The shaker flasks were allowed to cool and were each inoculated with one loop of frozen (-80°C) ATCC 11775 *E. coli* stock. The flasks were then incubated at 36°C on a shaker table set at 100 revolutions per minute for 18-20 hours. After incubation, 1 mL from one of the two flasks was added to 99 mL of autoclaved buffered water in a dilution bottle. This positive control was enumerated using the 97-well procedure described above. For the negative control, a dilution bottle with 100 mL of buffered water was processed using the 97 well procedure.

3.2.3.2 Enterococci

Enterococci were enumerated for each sample in accordance with Standard Method 9223, the enzyme substrate test (APHA *et al.*, 2012). This method was performed using Enterolert®, a commercially available enzyme-substrate liquid-broth medium that allows the detection of enterococci, and the 97 well Quanti-Tray® method (IDEXX Laboratories Inc., Westbrook, ME). Samples were processed and analyzed as described in Sub-section 3.2.3.1, except using Enterolert® instead of Colilert®. No positive control was prepared for enterococci; however, a negative control was prepared as described above. For enterococci, fluorescence under UV light (Entela, UVL-23RW, Upland, CA) in a dark room indicates positive enterococci presence. MPN values were calculated as discussed in Sub-section 3.2.3.1.

3.2.3.3 Coliphages

The single agar layer (SAL) method (EPA Method 1602) was used to enumerate F+, or male-specific, coliphages. Ampicillin and streptomycin resistant *E. coli* F_{amp} (ATCC 700891, American Type Culture Collection, Manassas, VA) was cultured as the host for the F-specific phages to infect. The host broth used for growing *E. coli* F_{amp} consisted of 3 g of tryptic soy broth (TSB, Difco Laboratories, Detroit, MI) per 100 mL of reagent grade water, which was autoclaved in 50 or 100 mL volumes. In order to select for the male-specific host bacteria, 150 mg ampicillin sodium salt and 150 mg of streptomycin sulfate (Sigma Chemical Company, St. Louis, MO) were dissolved in 100 mL of reagent grade water. The solution was filter sterilized using a sterile 0.22 µm pore size membrane filter assembly. The filter sterilized antibiotics were added to the TSB at 0.5 mL antibiotics per 50 mL of TSB. Next, one loop of frozen *E. coli* F_{amp}, stored at -80°C was transferred to 50 mL of TSB containing the antibiotics. The inoculated broth was then incubated at 36°C for 16-18 hours. One mL of this culture was then transferred to a flask containing 100 mL of TSB and 1 mL of antibiotic (streptomycin/ampicillin solution). This flask was then incubated at 36°C for 4-5 hours to create a log-phase host bacterial culture. After incubation, the log-phase host was placed on ice and used within two hours. Typically, this transfer procedure was used to create up to five log-phase host cultures so that an adequate volume of host was prepared and that the window of time available for phage enumeration was adequate to process all samples.

Agar was prepared prior to sample processing. The agar was a 2X tryptic soy broth (TSB, Difco Laboratories, Detroit, MI) with 1.5 percent agar (Bacto™ agar, Difco Laboratories, Detroit, MI). The 2X tryptic soy agar (2X TSA) contained 6 g TSB and 1.5 g agar for every 100 mL of reagent grade water. The TSB and agar were added to the reagent grade water, and the solution was heated and stirred until the TSB and agar were dissolved. The agar was then autoclaved at 121°C for 30 minutes. Next the agar was either transferred to a 48°C water bath for use or cooled and refrigerated at 4°C for later use. Refrigerated agar was re-autoclaved prior to use.

Duplicate 100 mL volumes of each sample were aseptically transferred into separate sterile 250 mL screw-cap polypropylene bottles (Nalge Nunc International, Rochester, NY). At least one temperature blank was also made by pouring 100 mL of sample water into another 250 mL screw-cap bottle. Then, 0.5 mL of 4 M $MgCl_2$ (81.4 g of $MgCl_2$ $6H_2O$ per 100 mL reagent grade water, autoclaved prior to use) were added aseptically to each bottle. The bottles were then placed in a 48°C water bath and heated until the temperature blank reached 36°C. Then, 10 mL of log-phase *E. coli* F_{amp} were added to each 250 mL sample bottle and the temperature blank bottle. The bottles were returned to the 48°C water bath and heated until the temperature blank reached 43°C. The samples were then removed from the 48°C water bath and placed in a 43°C water bath.

Ampicillin/streptomycin was then added to the 2X TSA. Two mL of antibiotics were added for each 100 mL of agar. Typically, 550 mL bottles of agar were used, thus 11 mL of ampicillin/streptomycin solution were added. The antibiotics were added along the inside of the bottle to avoid forming bubbles in the agar. The bottle of agar and antibiotics was then rocked gently to mix. Approximately 110 mL of 2X TSA was then added to each sample bottle. The sample bottle was then rocked gently to mix the sample with the agar and poured approximately equally into each of five 150 mm sterile plastic petri dishes (Fisher Scientific, Fair Lawn, NJ). The tops of the petri dishes were left askew for approximately five minutes, allowing the plates to cool and solidify. The plates were then covered, stacked upside down, and moved aside to proceed with the remaining samples. The plating method described above was repeated for each sample.

An MS2 positive control and a matrix spike were also plated. The MS2 positive control was created by spiking 100 mL of phage phosphate buffered saline (PBS) solution with a known concentration of MS2 stock coliphage (ATCC 15597-B1, American Type Culture Collection, Manassas, VA). The phage PBS solution was created by dissolving 80 g of NaCl, 2.0 g KH_2PO_4, 29 g $Na_2HPO_4 \cdot 12H_20$, and 1.0 g KCl to a total volume of 1 L with reagent grade water. The matrix spike control was created by spiking a 100 mL surface water sample with the same volume of MS2. The positive control and matrix spike were mixed with agar and poured into five plates consistent with the surface water samples.

Also plated were an agar-only (negative) control and a host and agar only (host positive) control. These controls were prepared in sterile plastic 50 mL centrifuge tubes (Fisher Scientific, Fair Lawn, NJ). The negative control contained 15 mL phage PBS, and the host positive control contained 15 mL phage PBS and 1.5 mL of log-phase *E. coli* F_{amp}. Both of the control tubes were filled to the 30 mL line with agar, rocked gently, and then poured into individual 150 mm petri dishes.

All plates were inverted and incubated for 16-24 hours at 36°C. The agar only plate appeared as clear agar with no *E. coli* or coliphages present. The host positive plate appeared as a clean lawn with visible *E. coli* present uninterrupted covering the agar in the plate. For samples and positive controls, plaque forming units were counted, and bacterial colony contamination was noted. Plaque forming units appeared as relatively small, circular clearings in the *E. coli* lawn.

Due to low detection rates observed for the male specific coliphages, somatic coliphages were measured starting on July 30, 2014 and analysis of male specific coliphages was terminated. Somatic coliphages were enumerated using the SAL method (EPA Method 1602) consistent with male-specific coliphages. The primary differences to the method were that *E. coli* CN-13 (ATCC 700609, American Type Culture Collection, Manassas, VA), resistant to nalidixic acid, was cultured as the host, and nalidixic acid sodium salt (1 g/100 mL) was used in the host broth and agar. Also, positive control and matrix spike samples were inoculated with ϕ-X 174 stock coliphage (ATCC 13706-B1, American Type Culture Collection, Manassas, VA).

3.3 Statistical Analyses

Two statistical methods were used to analyze water quality, climatological, and land use data. Correlation analyses were performed on water quality parameters and rainfall to identify statistical relationships between parameters. Analysis of variance (ANOVA) was performed to determine if water quality parameters varied by sampling site location, sampling site type, season, or precipitation conditions.

3.3.1 Correlation Analysis

Correlation analyses were performed using the International Business Machines (IBM) Statistical Product and Service Solutions (SPSS) Version 19 software. Using IBM SPSS, the Shapiro-Wilk test for normality was performed on the data, and all water quality data sets with the exception of fluoride and DO were determined to be non-normal. Based on the non-normal data sets, Spearman non-parametric correlation analyses were run on the water quality and rainfall data. The confidence interval used was a 95% ($p \leq 0.05$), which is commonly used for research. The sign of the correlation coefficient (R) indicates if correlation is direct or inverse. R values can also be used to assess the strength of a correlation as described in Chapter 4.

3.3.2 ANOVA Analysis

ANOVA is a method to determine the variation of the means of groups of data to evaluate statistical significance. One way ANOVA analyses were performed on the data to see if water quality parameters varied based on sampling site location, sampling site type, season, or precipitation. One way ANOVA analyses were performed using IBM SPSS software. The ANOVA test assumes a null hypothesis, which states that there is no difference between groups of data. If the analysis is found to be statistically significant, then the null hypothesis is rejected for the alternative hypothesis. The alternative hypothesis states that the means of the groups of data are different based on the variable being analyzed. Similar to the correlation analysis, a 95% confidence interval was considered to be statistically significant ($p \leq 0.05$).

4.0 RESULTS AND DISCUSSION

This chapter summarizes the results of the sampling program including the analytical and statistical data and discusses the significance of the findings.

4.1 Sampling Site Descriptions

All samples were collected from Beaver Lake in Ware, Massachusetts. Beaver Lake is located in western Massachusetts just south of the Quabbin Reservoir, which is one of the sources of drinking water for the City of Boston. Beaver Lake is an approximately 152-acre man-made lake that runs approximately 1.5 miles long flowing north to south. The lake is fed by Beaver Brook at the northern end and is designated for primary recreation. Beaver Lake is privately owned and managed by the Beaver Lake Trust. Land uses immediately surrounding the lake include undeveloped land, beaches, and residential properties. Residential properties are serviced by private drinking water wells and on-site wastewater disposal systems. Additionally, approximately eight stormwater conveyances drain runoff directly into Beaver Lake.

Ten sampling locations designated as Sites 1 through 16 (not continuous) were selected in an attempt to isolate different types of potential contaminant inputs. In particular, sampling locations were selected to target potential background locations, culvert discharges, and on-site wastewater disposal systems. Table 4-1 summarizes the sampling locations.

Sampling location designations start at Location 1 at the northern tip of Beaver Lake and progress clockwise around the lake to Location 16. Sampling locations 2, 3, 12, 13, 14, and 15 were originally considered, but were excluded from the sampling plan and never sampled due to access issues or redundancies. Figure 4-1 shows the sampling locations, and a brief description of each sampling site is included below. All site photographs were taken by Patrick Malone.

Table 4-1: Summary of Sampling Locations

Sampling Location	**Location Type/ Target**	**Key Features**
1	Background	Beaver dam at lake influent
4	Septic	Residence with leaching fields
5	Culvert	Culvert immediately adjacent to Location 4
6	Culvert	Sample directly from culvert discharge pipe
7	Culvert	Culvert immediately downstream of Location 6
8	Septic	Residence with leaching pits and steep slope
9	Culvert	Culvert discharge to a lake cove
10	Septic	Residence with leaching fields and steep slope
11	Background	Man-made dam at lake effluent
16	Background	Private beach

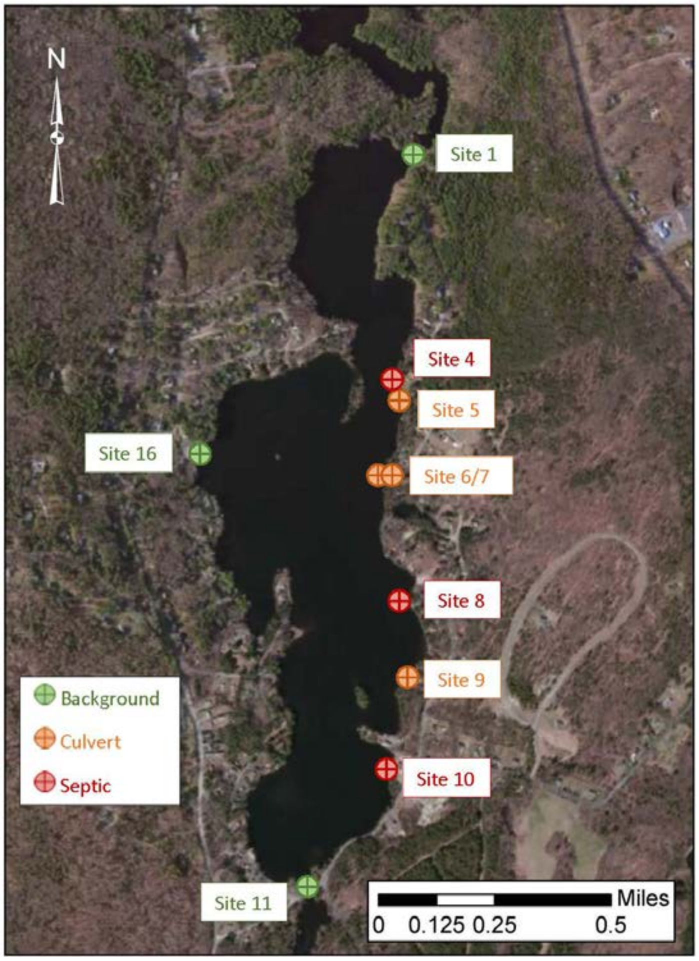

Figure 4-1: Sampling Location Plan (createded using ESRI's ArcMap GIS by J. Tupper and adapted by P. Malone)

Site 1

Site 1 is located where Beaver Brook enters Beaver Lake at the northernmost point in the lake. Beaver Brook runs through a beaver dam prior to entering the lake. Site 1 is located just south and downstream of the beaver dam within Beaver Lake. Land abutting Site 1 is primarily undeveloped.

Site 4

Site 4 is located approximately 0.4 miles south of Site 1 on the eastern shore of Beaver Lake adjacent to the residence at 98 Shoreline Drive. The sampling location targets potential septic system influences. The residence has a 1,000 gallon septic tank with a 500 gallon leaching pit replaced in approximately 1992.

Site 5

Site 5 is a culvert sampling location immediately south of Site 4. Although the culvert pipe is not visible due to thick vegetation, water was observed discharging to Beaver Lake at this location during rain events. In addition, storm drains were identified on Shoreline Drive in the vicinity of Site 5.

Site 6

Site 6 is a culvert sampling location where the sample was collected directly from the discharge pipe only when water was flowing through it. During dry sampling events, this location was not sampled. Site 6 is located approximately 0.1 miles south of Site 5 on the eastern shore of the lake. Land uses abutting Site 6 include residential, a large paved drive, and undeveloped land associated with the stormwater drainage area.

Site 7

Site 7 is the lake water sample adjacent to Site 6. This sampling location is immediately downstream of the culvert at Site 6. While Site 6 was only sampled when water is flowing through the culvert, Site 7 was sampled during both wet and dry sampling events.

Site 8

Site 8 is located approximately 0.25 miles south of Sites 6 and 7 on the eastern shore of Beaver Lake adjacent to the residence at 42 Shoreline Drive. The sampling location targets potential septic system influences, and there is a steep slope in the ground surface from the septic system to the lake. The residence has a 1,500-gallon septic tank with two 750-gallon leaching pits that were replaced/repaired in approximately 1996. Land surrounding Site 8 is generally residential.

Site 9

Site 9 is a culvert sampling location located approximately 0.1 miles south of Site 8 on the eastern shore of Beaver Lake. The culvert discharge pipe was not identified; however, a stormwater drainage swale was observed between the suspected discharge area and the lake. The sample site was located in a fairly stagnant cove of Beaver Lake, and lake has a thick layer of leaf litter and organic matter at the sample location. Site 9 is abutted by residential land, a large paved drive, and undeveloped land associated with the stormwater drainage area.

Site 10

Site 10 is located approximately 0.15 miles south of Site 9 on the eastern shore of Beaver Lake adjacent to 4 Shoreline Drive. The sampling location targets potential septic system influences, and a steep slope in the ground surface leads from the septic system to the lake. The residence has a 1,500-gallon septic tank with three 33 feet by 3 feet infiltration trenches installed in approximately 2010. Land surrounding Site 10 is generally residential.

Site 11

Site 11 is located at the effluent of Beaver Lake at southernmost point in the lake. The sampling site is located within Beaver Lake just north and upstream of a man-made dam. Land abutting Site 11 includes a roadway, undeveloped land, and residences.

Site 16

Site 16 is located at a private beach on the western shore of Beaver Lake across the lake from Sites 6 and 7. Land abutting Site 16 is beach or undeveloped land.

4.2 Sampling Dates

Samples were collected from January 2014 to February 2015 at a frequency of once every two to three weeks. The sampling schedule was designed to capture a full year of seasonal water quality data and to target dry and wet weather conditions. Table 4-2 summarizes the sampling schedule. Seasons were defined using astronomical timing with spring starting on March 20, summer on June 21, fall on September 23, and winter on December 21 based on the equinoxes. As shown in Table 4-2, 21 sampling events were performed including 5 winter events, 4 spring events, 7 summer events, and 5 fall events. Additionally, measurable rainfall was recorded at the NOAA NCDC weather station at Westover Air Force Base in the 24 hours preceding sampling for eight of the sampling events with total antecedent rainfall measured between 0.04 and 1.55 inches.

Table 4-2: Summary of Sampling Dates

Sampling Date	Season	Rainfall 24 hours preceding (in)
01/29/14	Winter	0
02/19/14	Winter	0
03/17/14	Winter	0
04/25/14	Spring	0
05/14/14	Spring	0
05/28/14	Spring	0.23
06/18/14	Spring	0.18
07/01/14	Summer	0
07/16/14	Summer	0.70
07/30/14	Summer	0
08/13/14	Summer	1.17
08/19/14	Summer	0
09/03/14	Summer	0
09/17/14	Summer	0.04
10/02/14	Fall	0.32
10/23/14	Fall	1.55
11/05/14	Fall	0
11/25/14	Fall	0.21
12/09/14	Fall	0
01/06/15	Winter	0
02/04/15	Winter	0

4.3 Analytical Data Summary

This section presents the results of the physical, chemical, and microbial water quality analyses performed on samples collected from Beaver Lake. Table 4-3 provides a summary of analytical results for each water quality parameter. The full data set is included as Appendix A.

Table 4-3: Summary of Water Quality Analytical Results

Parameter	Units	No. of Samples	No. of Detects	% Detect	Avg. Value	Med. Value	Minimum Value		Maximum Value		Regulatory Standard
							Value	Site	Value	Site	
Temperature	°C	199	199	100	14	17	0.0	4,5,7	27	16	28.3(1)
DO	mg/L	199	199	100	8.9	8.2	2.1	1	16	6	>5(1)
Conductivity	µS/cm	199	199	100	89	93	1.1	7	205	6	NA
pH		199	199	100	6.8	6.9	6.0	10	7.6	11	6.5-8.3(1)
Turbidity	NTU	199	199	100	4.0	1.1	0.3	6	183	7	Visual(1)
Alkalinity	mg/L $CaCO_3$	96	96	100	11	12	1.1	16	30	7	>20(2)
TOC	mg/L	199	199	100	4.2	3.9	1.1	6	43	7	NA
DOC	mg/L	199	199	100	3.7	3.5	1.3	7	22	6	NA
Ammonia	µg/L	199	199	100	118	80.0	10.0	6	1820	6	1,900(3)
Fluoride	µg/L	199	198	99	23.0	22.709	0.0000	6	40.948	7.	2000(4)
Chloride	µg/L	199	199	100	23786	23312	314.64	6	82032	6	230000 (2)
Nitrite	µg/L	199	14	7	28.8	0.000	0.000	1-16	3624	16	320(5)
Sulfate	µg/L	199	199	100	4253	4004.7	228.92	6	11921	6	250000(4)
Bromide	µg/L	199	6	3	1.1	0.0000	0.0000	1-16	59.801	4	NA
Nitrate	µg/L	199	110	55	203	37.499	0.0000	1-16	5159.5	6	320(5)
Phosphate	µg/L	199	10	5	7.7	0.0000	0.0000	1-16	351.22	6	8(6)
Total coliforms	MPN/100 mL	199	199	100	2383	659	2.6	4	73975	6	NA
E. coli	MPN/100 mL	199	164	82	194	3	0.5	4,5,8-16	10349	9	126(1)
Enterococci	MPN/100 mL	199	165	83	370	3	0.5	1,5,7-16	19357	6	33(1)
Coliphages	cfu/100 mL	132	17	13	0.6	1	0.5	1-16	8.0	4	NA

Notes:
1. Massachusetts Department of Environmental Protection (MADEP)
2. United States Environmental Protection Agency (USEPA) Ambient Water Quality Criteria
3. USEPA Ambient Water Quality Criteria for pH=7, Temperature=20°C, and a 30-day rolling average
4. USEPA Maximum Contaminant Level Goal (MCLG)
5. USEPA Ambient Water Quality Criteria based on Ecoregion 14 for Total Nitrogen (N)
6. USEPA Ambient Water Quality Criteria based on Ecoregion 14 for Total Phosphorus (P)

As shown in Table 4-3, between January 2014 and February 2015, 199 samples were analyzed for each water quality parameter with the exception of alkalinity and coliphages. Alkalinity was only measured during select sampling events because alkalinity values were generally consistent and low. Coliphage analysis was terminated in October 2014 due to lack of detections. For nine of the sampling sites, samples were collected and analyzed for all 21 sampling dates. The culvert samples collected from Site 6 were only collected when water was observed flowing through the culvert. As such, samples were collected from Site 6 on ten of the sampling dates.

Most analyses indicated detectable concentrations for each parameter; however, certain anions were below the method detection limit for many samples. For example, detection rates were very low for nitrite (7%), bromide (3%), and phosphate (5%). For these analyses when results indicate concentrations below the detection limits, a value of zero µg/L was used for statistical purposes.

For the bacterial indicators (total coliforms, *E. coli* and enterococci), when no bacteria were detected the corresponding MPN/100 mL value is < 1. In these cases, a value of 0.5 MPN/100 mL, or half of the detection limit, was used for statistical purposes. This value was selected to be consistent with published literature and accepted methods (Shergill and Pitt, 2004). Also, as mentioned above, the detection rate for coliphages was very low (13%), and when coliphages were not detected a value of 0.5 pfu/100 mL was used, as the detection limit is 1 pfu per 100 mL of sample. Similarly, in cases where bacteria concentrations for total coliforms, *E. coli*, and enterococci were above the method range, the corresponding MPN/100 mL is >2419.6. In these cases, a value of twice the upper limit (4839.2 MPN/100 mL) was used for statistical purposes. Again, this value was selected as a representative value based on published literature (Haas and Heller, 1998).

Table 4-3 shows median concentrations, average concentrations, minimum, and maximum concentrations for each water quality parameter. In addition, for each minimum and maximum value, the sampling site where that value was recorded is provided. It is interesting to note that sampling Site 6, collected directly from the flowing culvert, accounted for the greatest percentage of minimum and maximum parameter values. Site 6 was the location of the minimum water quality parameter concentration for 11 of the 20 parameters, and the location of the maximum concentration for 10 of the 20 water quality parameters. Lastly, regulatory standards for each parameter are provided, where applicable, for comparison to the measured values. Regulatory standards were taken from the source shown and include federal (USEPA) and state (MADEP) standards.

As shown in Table 4-3, average and median water quality parameter concentrations meet the regulatory standards shown for all parameters except *E. coli*, enterococci, and alkalinity. The average *E. coli* concentration (194 MPN/100 mL) was slightly greater than the regulatory standard (126 MPN/100 mL), and the average enterococci concentration (370 MPN/100 mL) was an order of magnitude greater than the regulatory standard (33 MPN/100 mL). For alkalinity, the average and median concentrations were lower than the allowed regulatory criteria; however, the regulations state that the criteria cannot be set less than the "natural" conditions. Therefore, the naturally low alkalinity did not violate applicable regulations.

In addition, DO, pH, nitrite, nitrate, and phosphate minimum or maximum values did not meet the regulatory standards. For DO, the lowest detected concentration was 2.1 mg/L, which was well below the standard of 5 mg/L. Also, pH was detected as low as 6, which was slightly below the accepted range of pH 6.5 to 8.3. Maximum nitrate and nitrite concentrations were detected at 5,160 and 3,624 µg/L, respectively. The total nitrogen standard is 320 µg/L; therefore, the maximum nitrate/nitrate concentrations were an order of magnitude greater than the water quality standard. Lastly, the maximum detected phosphate concentration was 351 µg/L, which was well above the 8 µg/L water quality criteria. These values represent specific exceedances; however, the applicable average and mean values for these parameters meet the water quality criteria.

Figure 4-2 shows average values for selected physical and chemical water quality parameters over time. Parameter concentrations are plotted on a logarithmic scale on the primary y-axis to show concentration variability for a wide range of parameters. Temperature is plotted on a linear scale on the secondary y-axis. As shown on Figure 4-2, there was significant variability in many parameter concentrations over time. For example, average turbidity values ranged from 0.8 to 24 NTU and dissolved oxygen ranged from 5.5 to 14.6 mg/L. Other parameters remained more constant such as pH with a range of 6.4 to 7.4.

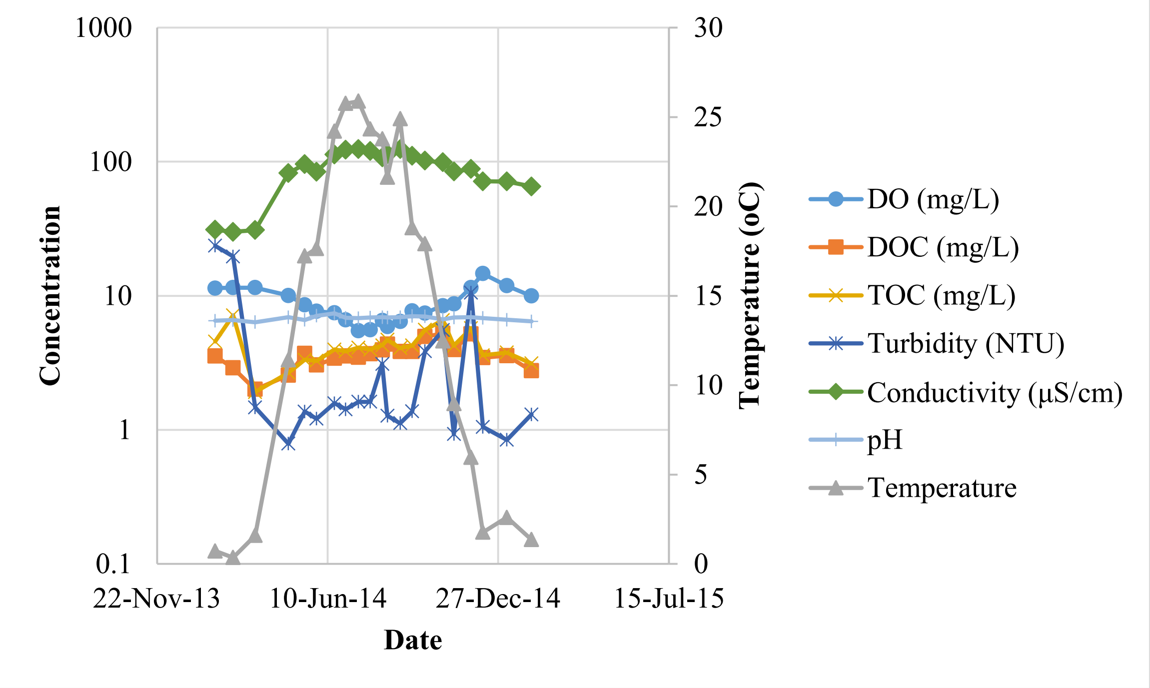

Figure 4-2: General Water Quality Parameters over Time

Figures 4-3A and 4-3B show box and whisker plots for the seven anions tested and ammonia. Figure 4-3A shows the full extent of the data with maximum anion concentrations ranging from 41 µg/L fluoride to 82,000 µg/L chloride. Figure 4-3B focuses on the first to third quartile ranges for chloride and more readily depicts the lower anion concentrations.

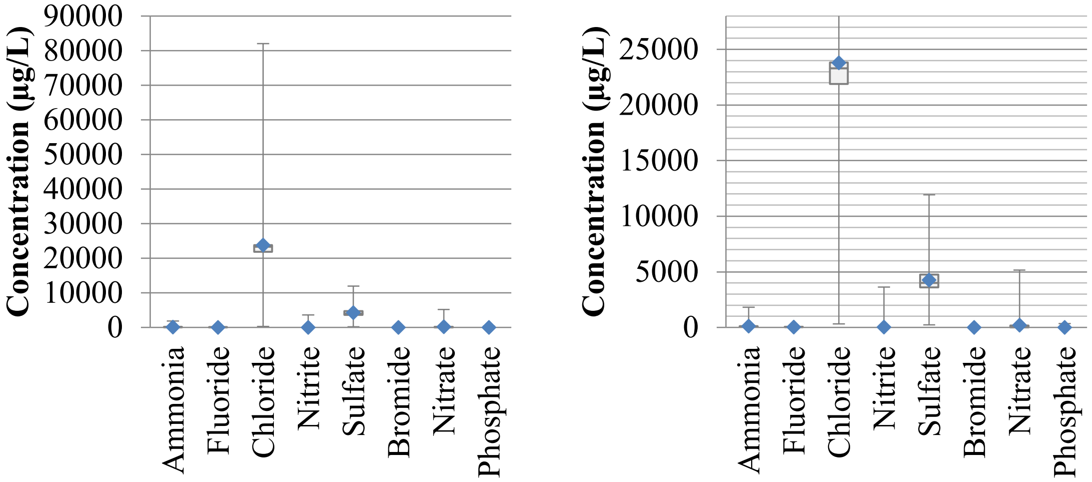

Figure 4-3A (left) and Figure 4-3B (right): Anion Concentrations

Figures 4-4A through 4-4C show box and whisker plots for the three bacterial indicators. Figure 4-4A shows the maximum detected values ranging from 10,300 MPN/100 mL for *E. coli* to 74,000 MPN/100 mL for total coliforms. Figure 4-4B shows the range of total coliform concentrations for the first to third quartiles. Similarly, Figure 4-4C shows the range of *E. coli* and enterococci concentrations for the first to third quartiles.

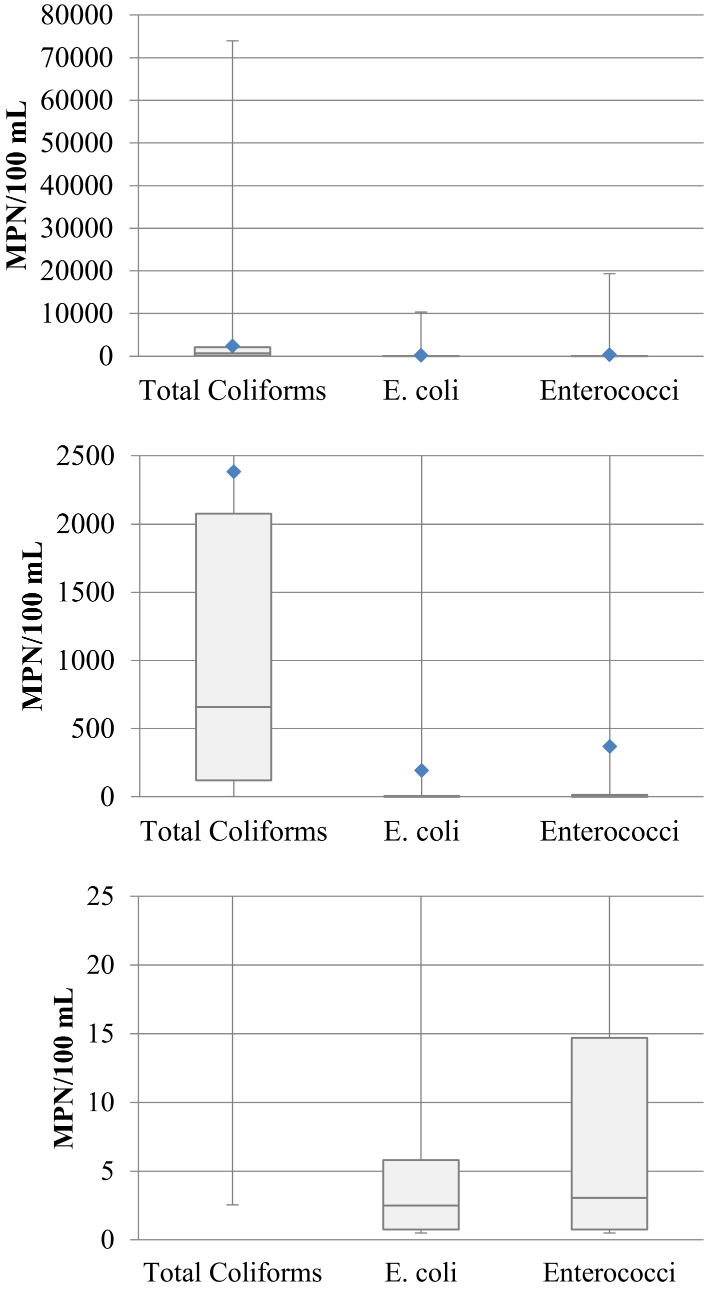

Figure 4-4A (top) through Figure 4-4C (bottom): Bacterial Indicator Concentrations

4.4 Statistical Data Summary

The following sub-sections describe the results of the statistical analyses performed on the analytical data including normality tests, correlation analyses, and one-way ANOVA. The implications of these findings are discussed further in Section 4.5.

4.4.1 Normality

The data sets for each water quality parameter were analyzed for normality using the Shapiro-Wilk test. The null-hypothesis of this test is that the data are normally distributed. Therefore, if the *p*-value is less than 0.05, the null hypothesis is rejected and the data are not normal; and if the *p*-value is greater than 0.05, the data are from a normally distributed population. The analyses indicated that only dissolved oxygen (n=199, *p*=0.080) and fluoride (n=199, *p*=0.097) data were normal for the conditions tested. Bacterial indicator data were log transformed and tested for normality using the same method; however, the log transformed data also were not normal. Based on the lack of normal data sets, non-parametric correlation analyses were performed as described in Sub-section 4.4.2.

4.4.2 Spearman Non-Parametric Correlation Analyses

Spearman non-parametric correlation analyses were run to compare all water quality parameters to each other and to inches of rainfall in the 24 hours preceding sampling. In addition, correlations were also analyzed for certain anion ratios compared to other water quality parameters. Tables showing the full results of correlation analyses are included in Appendix B.

Certain physical and chemical water quality analyses can be performed in the field or can be run in less time, for less cost, and/or with less technical expertise than microbial analyses. Since bacterial indicators such as *E. coli* and enterococci are commonly measured and regulated to determine recreational water quality, it can be beneficial to find significant correlations between bacterial indicators and other water quality parameters that could be used as screening tools to predict bacterial concentrations. Table 4-4 provides correlation data including *p* and R values for each water quality parameter relative to the bacterial indicators.

Significant correlations were defined by *p* values <0.05 and are highlighted in green in Table 4-4. As shown in Table 4-4, many water quality parameters were significantly correlated with all three bacterial indicators, and all parameters except for ammonia were correlated with at least one of the bacterial indicators.

Correlation coefficients indicate the strength of correlations. Taylor (1990) states that moderate correlations are those with correlation coefficients between 0.36 and 0.67, and strong correlations yield correlation coefficients between 0.68 and 1.0. In Table 4-4, moderate correlations are italicized and strong correlation are shown in bold. As shown, 14 of the 19 parameters are moderately to strongly correlated with total coliforms; however, only 6 parameters were moderately correlated with *E. coli,* and no strong correlations were found for *E. coli*. For enterococci, 4 or the 19 parameters were moderately correlated and no strong correlations were observed. Since total coliforms exist and grow in the environment, whereas *E. coli* and enterococci are indicators of fecal contamination, moderate to strong correlations with *E. coli* and enterococci are of particular interest.

Table 4-4: Summary of Correlation Data

Parameter	**Total coliforms**		***E. coli***		**Enterococci**	
	p	R	*p*	R	*p*	R
Rainfall	*0.000*	*0.492*	*0.000*	*0.531*	*0.000*	*0.367*
Temperature	**0.000**	**0.707**	*0.000*	*0.365*	0.001	0.224
DO	**0.000**	**-0.676**	0.000	-0.339	0.024	-0.160
Conductivity	*0.000*	*0.672*	*0.000*	*0.422*	0.000	0.262
pH	*0.000*	*0.395*	0.002	0.222	0.006	0.195
Turbidity	*0.000*	*0.457*	0.002	0.221	0.000	0.254
Alkalinity	*0.000*	*0.404*	0.162	0.144	0.782	-0.029
TOC	*0.000*	*0.617*	0.000	0.320	0.000	0.295
DOC	*0.000*	*0.530*	0.000	0.307	0.002	0.219
Ammonia	0.510	0.047	0.445	-0.054	0.107	-0.115
Fluoride	*0.000*	*0.510*	0.000	0.289	0.015	0.172
Chloride	0.000	0.331	0.000	0.286	0.000	0.258
Nitrite	0.000	-0.265	0.002	-0.214	0.239	-0.084
Sulfate	*0.000*	*-0.566*	0.000	-0.317	0.127	-0.109
Bromide	0.013	0.175	0.893	0.010	0.087	0.122
Nitrate	**0.000**	**-0.738**	*0.000*	*-0.537*	*0.000*	*-0.367*
Phosphate	0.047	0.141	0.067	0.130	0.016	0.170
Total coliforms	--	--	*0.000*	*0.643*	*0.000*	*0.451*
E. coli	*0.000*	*0.643*	--	--	*0.000*	*0.464*
Enterococci	*0.000*	*0.451*	*0.000*	*0.464*	--	--

4.4.3 ANOVA Analyses

A one-way analysis of variance was performed for each water quality parameter relative to the categories of site location (10 sites), site type (3 types - background, septic, culvert), season (4 seasons), and rainfall (3 groups). For the analysis of variance, rainfall in the 24 hours prior to sampling was separated into three categories: (1) no rain, (2) rain less than 0.5 inches, and (3) rain greater than 0.5 inches. Table 4-5 presents the *p* values for the ANOVA analyses. A water quality parameter was determined to vary by a specific category for $p \leq 0.05$. Significant variances are highlighted in green in Table 4-5.

Table 4-5: Summary of ANOVA Data including Site 6

Parameter	***p*-Value**			
	Site	**Site Type**	**Season**	**Rain**
Temperature	0.957	0.791	0.000	0.000
DO	0.000	0.157	0.000	0.000
Conductivity	0.975	0.317	0.000	0.000
pH	0.036	0.313	0.000	0.000
Turbidity	0.011	0.019	0.156	0.979
Alkalinity	0.002	0.171	0.000	0.577
TOC	0.067	0.022	0.122	0.248
DOC	0.003	0.062	0.000	0.019
Ammonia	0.000	0.005	0.049	0.787
Fluoride	0.408	0.915	0.000	0.000
Chloride	0.000	0.005	0.641	0.374
Nitrite	0.535	0.400	0.432	0.293
Sulfate	0.129	0.372	0.000	0.000
Bromide	0.895	0.988	0.536	0.635
Nitrate	0.170	0.755	0.000	0.040
Phosphate	0.000	0.027	0.015	0.098
Total coliforms	0.000	0.010	0.016	0.001
E. coli	0.000	0.012	0.028	0.002
Enterococci	0.000	0.009	0.013	0.093
Coliphages	0.582	0.680	0.147	0.030

Again considering the bacterial indicators, total coliforms and *E. coli* were found to vary by site location, site type, season, and rainfall, and enterococci were found to vary by all but rainfall. This highlights the importance of determining where and when to collect samples in order to obtain an accurate representation of overall water quality.

Additionally, the ANOVA analyses were performed on the data excluding Site 6, which was sampled directly from the culvert only when water was flowing. Since Site 6 was the only sampling location that was not within the lake, the data was excluded and the ANOVA analyses were rerun. The results are presented in Table 4-6.

As shown in Table 4-6, the results for variations by rainfall category were not significantly affected showing that variations in water quality within the lake occur with rainfall. Similarly, for seasonal variation, only phosphate, *E. coli*, and enterococci no longer varied with season when Site 6 data were excluded. In contrast, the parameters found to vary by site decreased from 11 to 5 of 20 parameters, and parameters found to vary by site type decreased from 8 to 2 of 20 parameters.

These finding showed that variations observed by site and site type were largely biased by the inclusion of the direct culvert sample at Site 6. While the culvert sampling location at Site 6 showed significant variations in parameter inputs, variations within the lake by site or site type were less pronounced likely due to the effects of dilution and mixing.

Table 4-6: Summary of ANOVA Data Excluding Site 6

Parameter	**Site**	**Site Type**	**Season**	**Rain**
Temp	1.000	0.966	0.000	0.000
DO	0.001	0.127	0.000	0.000
Cond	0.972	0.358	0.000	0.000
pH	0.044	0.369	0.000	0.000
Turb	0.038	0.078	0.068	0.561
Alkalinity	0.856	0.585	0.000	0.356
TOC	0.264	0.070	0.638	0.568
DOC	0.456	0.076	0.000	0.022
Ammonia	0.110	0.038	0.000	0.093
Fluoride	0.447	0.694	0.000	0.000
Chloride	0.018	0.107	0.581	0.948
Nitrite	0.475	0.421	0.445	0.323
Sulfate	0.324	0.270	0.000	0.000
Bromide	0.877	0.967	0.562	0.641
Nitrate	0.149	0.427	0.000	0.000
Phosphate	0.056	0.231	0.092	0.749
Total coliforms	0.028	0.037	0.000	0.000
E. coli	0.073	0.185	0.418	0.034
Enterococci	0.331	0.075	0.391	0.117
Coliphages	0.509	0.672	0.094	0.041

4.5 Discussion of Results

This section describes the significance of the results including relationships to published literature, spatial and temporal variances, climatic and land use impacts, and parameter correlations.

4.5.1 Site Influences

As shown previously in Table 4-5, 11 of the 20 water quality parameters were found to vary by sampling site location. These parameters included DO, pH, turbidity, alkalinity, DOC, ammonia, chloride, phosphate, total coliforms, *E. coli*, and enterococci. Table 4-7 presents average parameter values by sampling location for the parameters found to vary by location.

TABLE 4-7: Average Water Quality Parameter Values by Location

Parameter	Units	Sampling Site									
		1	4	5	6	7	8	9	10	11	16
DO	mg/L	6.5	9.4	9.4	11.2	9.0	9.3	7.3	9.2	9.0	9.5
pH		6.6	6.8	6.8	6.7	6.9	6.9	6.8	6.9	6.9	6.9
Turbidity	ntu	0.8	1.1	2.0	18.6	17.8	1.4	2.3	1.3	1.1	1.3
Alkalinity	mg/L $CaCO_3$	12.9	11.8	11.2	3.6	12.9	11.4	11.2	11.0	13.2	11.1
DOC	mg/L	3.3	3.5	3.5	6.5	3.7	3.6	3.9	3.5	3.4	3.3
Ammonia	µg/L	99.5	90.5	85.2	483.0	188.6	73.3	132.9	77.1	70.5	69.5
Chloride	µg/L	22597	21777	22789	41592	28550	22222	21447	21617	22483	22113
Phosphate	µg/L	0.0	0.0	0.0	104.7	3.1	0.0	8.9	10.8	0.0	0.0
Total coliforms	cfu/ 100 mL	991	1016	1097	20529	1665	965	3616	1041	1033	1378
E. coli	cfu/ 100 mL	32.3	41.8	4.9	2070.6	13.0	5.6	736.8	2.8	2.3	8.8
Enterococci	cfu/ 100 mL	10.3	27.3	15.2	5204.5	412.9	21.0	513.3	5.2	3.8	18.0

It is clear from Table 4-7 that average parameter values for Site 6, which is the culvert discharge sample, showed the greatest variation from typical values measured at the other nine locations. Again, when ANOVA analyses excluded Site 6, far fewer parameters were found to vary by site location. Parameter averages for DO, turbidity, DOC, ammonia, chloride, phosphate, total coliforms, *E. coli*, and enterococci were higher at Site 6 than other locations. The average DO concentration at Site 6 was 11.2 mg/L as compared to 6.5 to 9.5 mg/L detected at the other 9 sampling sites. Similarly, DOC at Site 6 averaged 6.5 mg/L compared to 3.3 to 3.9 mg/L DOC detected at the other 9 sampling sites. The average chloride concentration at Site 6 (42,000 µg/L) was nearly double the average values observed at the other 9 locations (21,000-29,000 µg/L), and the average phosphate concentrations at Site 6 (105 µg/L) was an order of magnitude above average phosphate concentrations at the other sites (0-11 µg/L).

Bacterial indicator concentrations were also one to two orders of magnitude higher at Site 6 than at other locations. The average *E. coli* concentration at Site 6 was 2,070 MPN/100 mL compared to average concentrations of 2 to 737 MPN/100 mL at the other sites, and the average enterococci concentration at Site 6 was 5,200 MPN/100 mL compared to average concentrations of 4 to 510 MPN/100 mL for the other sampling sites. Additionally, the maximum detected total coliform concentration at any site was 74,000 MPN/100 mL detected at Site 6. The highest concentration detected at any other site was 19,000 MPN/100 mL detected at Site 9.

DO was found to vary significantly by site with a minimum concentration of 2.08 mg/L detected at Site 1 and a maximum concentration of 16.2 mg/L detected at Site 6. As shown in Table 4-7, average DO concentrations were relatively low at Site 1 (6.5 mg/L) and Site 9 (7.3 mg/L) and were elevated at Site 6 (11.2 mg/L).

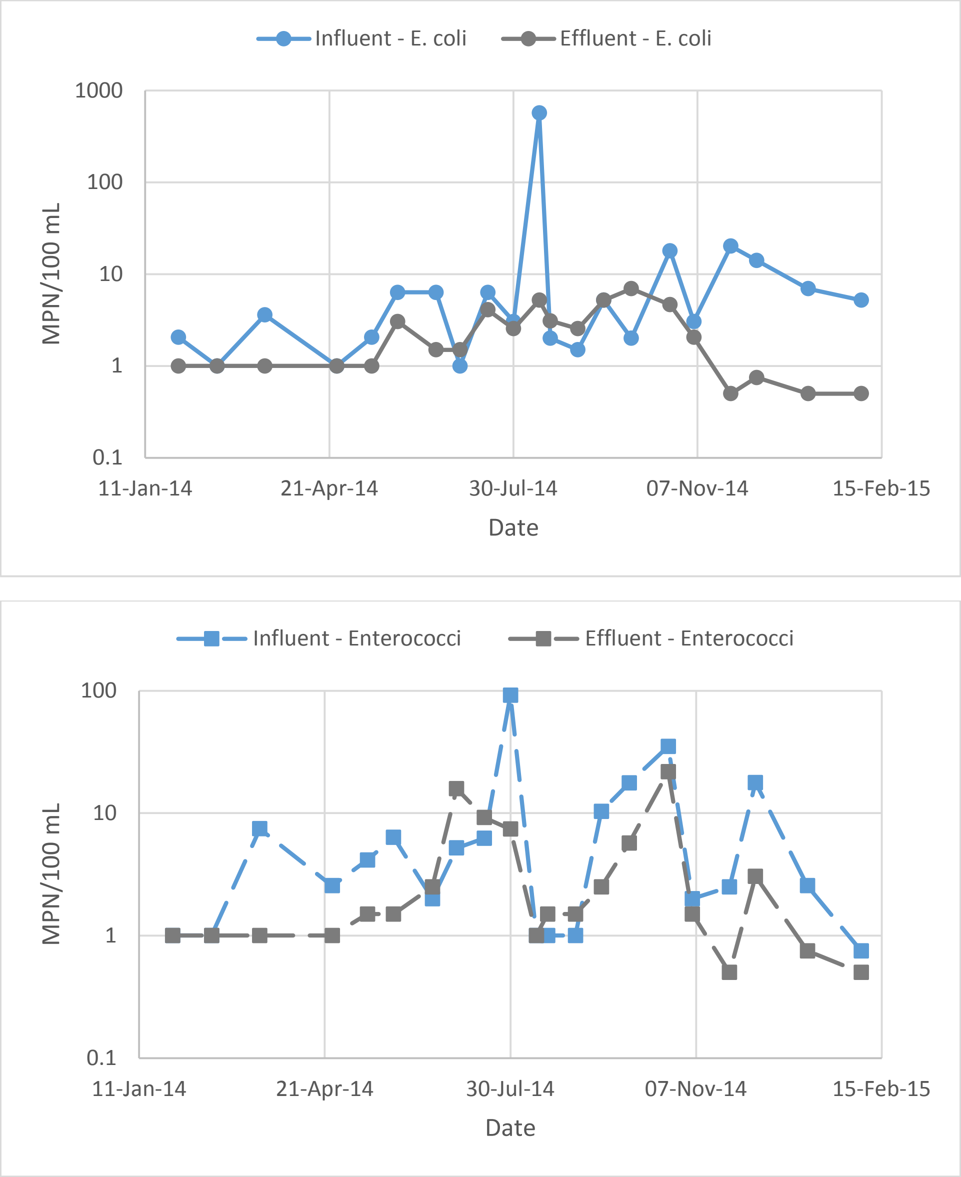

Figure 4-5A (top) and Figure 4-5B (bottom): Influent versus Effluent Bacterial Concentrations

To further assess variations by sampling location, *E. coli* concentrations at the lake influent and lake effluent were compared in Figure 4-5A, and enterococci concentrations at the lake influent and effluent were compared in Figure 4-5B. The results showed that concentrations for both bacterial indicators were typically higher at the lake influent than at the lake effluent, which could be explained by a combination of dilution, direct precipitation, bacterial die off, and predation within the lake. The influent and effluent concentrations of *E. coli* and enterococci were also compared statistically. Results indicated that effluent enterococci concentrations were significantly correlated ($p = 0.002$) with influent enterococci concentrations; however, effluent *E. coli* concentrations were not significantly correlated ($p = 0.661$) with influent *E. coli* concentrations. A full analysis of microbial fate and transport in the lake was outside the scope of this research, but may be an interesting future study to elicit significant factors in these correlations.

4.5.2 Site Type Influences

As shown in Table 4-5, eight parameters (turbidity, TOC, ammonia, chloride, phosphate, total coliforms, *E. coli*, and enterococci) were found to vary by sampling site type (background, septic, or culvert). Table 4-8 presents minimum, average, and maximum values for each of these parameters by sampling site type. These values include data from Site 6. Again, as shown in Table 4-6, when data from Site 6 were excluded, the parameters that varied by site type decreased significantly.

As shown in Table 4-8, average and maximum parameters values are highest for all parameters at the culvert sample locations compared to the background and septic locations. For example, *E. coli* and enterococci average and maximum values are one and two orders of magnitude greater at the culvert sampling sites than the background or septic sites. The maximum enterococci concentration detected at the culvert sampling sites was 19,400 MPN/100 mL detected at Site 6, while the maximum enterococci concentration detected at any non-culvert sampling site was 462 MPN/100 mL detected at the septic sampling location Site 4. This corresponds well to studies that show strong correlations between BOD, suspended solids, phosphates, and fecal coliforms and percent imperviousness (Mallin *et al*., 2009), since stormwater culverts are draining roadways and paved drives.

There was also more variability in the culvert sample data. For ammonia, culvert sampling sites show the lowest minimum value (10 μg/L) and the highest maximum value (1,800 μg/L), which was an order of magnitude greater than maximum values observed at the background or septic sites (160 and 280 μg/L, respectively). This same pattern was observed for turbidity, TOC, chloride, phosphate, *E. coli*, and enterococci. For example, turbidity at culvert sampling sites ranged from 0.25 to 180 NTU, while at non-culvert locations turbidity ranged from 0.51 to 6.7 NTU.

Table 4-8 shows phosphate concentrations were higher at septic sites (average and maximum values of 3.6 and 98 μg/L, respectively) than background (not detected). Kramer *et al*. (2006) and Ptacek (1998) showed septic systems as a significant source of phosphorus. In their study on 25 lakes in Minnesota, Kramer *et al*. (2006) found surface water phosphorus concentrations ranging from 42 and 282 μg/L with septic system contributions estimated to range from 1 to 64 percent. Similarly, Ptacek (1998) observed phosphorus concentrations between 300 and 1,500 μg/L in groundwater downgradient of septic systems in Ontario, Canada. Values observed at septic sites in Beaver Lake are on the lower side of these ranges at 0 to 98 μg/L. However, higher phosphate concentrations were observed at the culvert sites (0 to 351 μg/L).

Table 4-8: Water Quality Parameters by Site Type

Parameter	Value	Background	Septic	Culvert
Turbidity (NTU)	Minimum	0.505	0.658	0.254
	Average	1.06	1.27	8.90
	Maximum	1.88	6.67	183
TOC (mg/L)	Minimum	1.65	1.43	1.11
	Average	3.60	3.74	5.16
	Maximum	4.98	6.10	43.0
Ammonia (µg/L)	Minimum	30	20	10
	Average	80	80	183
	Maximum	160	280	1820
Chloride (µg/L)	Minimum	12307	8348.9	314.64
	Average	22397	21872	26636
	Maximum	26405	24514	82032
Phosphate (µg/L)	Minimum	0.00	0.00	0.00
	Average	0.00	3.59	17.8
	Maximum	0.00	98.1	351
Total Coliforms (MPN/100 mL)	Minimum	9.20	2.55	36.4
	Average	1134	1008	4647
	Maximum	4839	5234	73975
***E. coli* (MPN/100 mL)**	Minimum	0.50	0.50	0.50
	Average	14.5	16.8	501
	Maximum	569	797	10349
Enterococci (MPN/100 mL)	Minimum	0.50	0.50	0.50
	Average	10.7	17.8	984
	Maximum	246	462	19357

The background sampling sites typically show lower average and maximum concentrations than septic or culvert sites with the exception of the average total coliforms and average and maximum chloride. Interestingly, minimum concentrations for the background sites are often greater than those observed at the septic and culvert sites suggesting less variability in background data.

In a study focused on water quality in undeveloped, suburban, and urban rivers in North Carolina, Mallin *et al*. (2009) found that undeveloped land generally input higher concentrations of TOC than suburban or urban land uses. In contrast, Beaver Lake background sample data suggested slightly lower TOC concentrations that those observed at the septic and culvert sites. However, given the relatively small size of the lake and dense residential population, the background sampling locations at Beaver Lake are not completely undeveloped.

4.5.3 Seasonal Impacts

As shown in Table 4-5, 14 of the 21 water quality parameters were found to vary significantly by season. Figure 4-6 shows average temperature and DO concentrations over time. As shown in Figure 4-6, temperature increased from a low in winter of 0.4°C to a high of 26°C in summer and decreased from summer back to winter. Conversely, DO concentrations decreased with increasing temperatures. This inverse relationship corresponds to the expected saturation values for DO of approximately 14 mg/L at 0.4°C versus 8 mg/L at 26°C. Additionally, aerobic microbial respiration rates were likely higher in the summer than winter decreasing DO, because the bacterial indicator concentrations were significantly higher as discussed below. However, DO concentrations decrease from approximately 14 mg/L in December 2014 to 10 mg/L in February 2015 despite fairly stable temperatures (1.8 to 1.4°C). This trend could be explained by the lake freezing between December 2014 and January 2015 thus decreasing atmospheric reaeration.

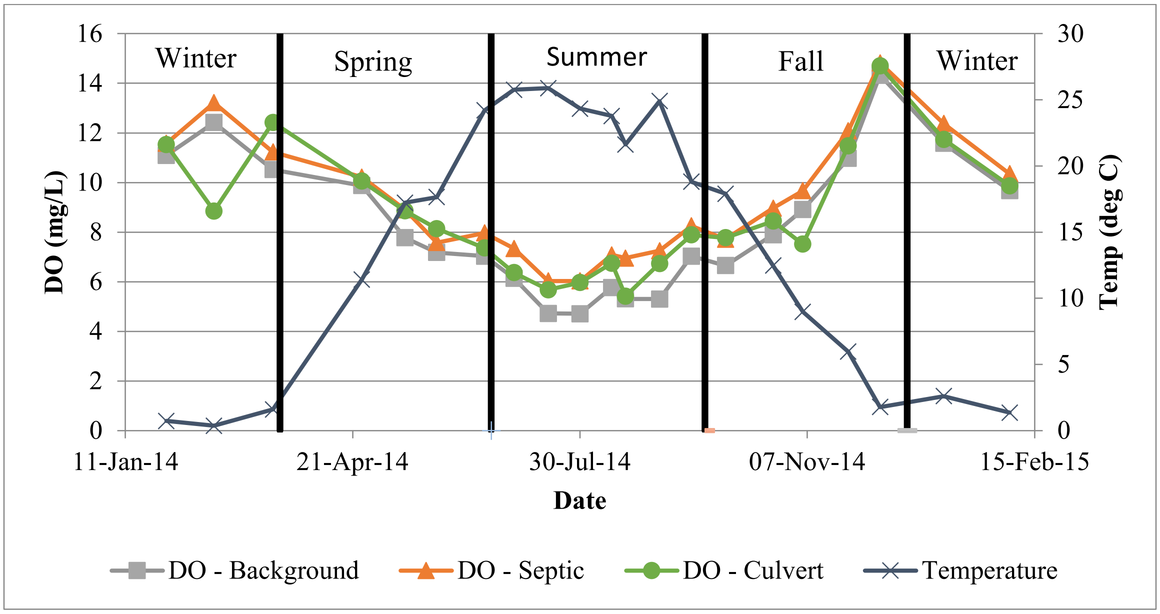

Figure 4-6: Temperature and Dissolved Oxygen Trends

Organic carbon was also plotted over time to consider seasonal trends as shown in Figure 4-7. Since the organic carbon at Beaver Lake is predominatly dissolved, only DOC is shown. TOC exhibited similar trends.

As shown in Figure 4-7, average DOC concentrations increased from the 2.6 mg/L in early spring to 4.4 mg/L in the summer. Large spikes in DOC concentrations up to 8 mg/L were observed during the fall at the culvert sampling locations. These spikes in DOC are likely attributed to fall leaf litter and debris being washed into the lake through the culverts. Also, a spike in DOC concentration up to 5 mg/L was observed at septic sampling locations in the spring. This may be due to flushing of septic systems caused by snowmelt and stormwater infiltration. Barber *et al.* (2006) showed similar results with organic carbon concentrations increasing significantly in surface water in the upper basin of the Boulder Creek Watershed due to flushing from soil and shallow groundwater. Lastly, DOC data observed in January and February 2014 showed a high level of variability with total concentrations ranging from 1.7 to 5.3 mg/L in January and 1.5 to

6.9 mg/L in February. This variability in the sampling data may be due to sampling methods. Samples were collected using a hand auger, which may have created turbulence in the water and re-suspended organic carbon in the lake bottom sediment.

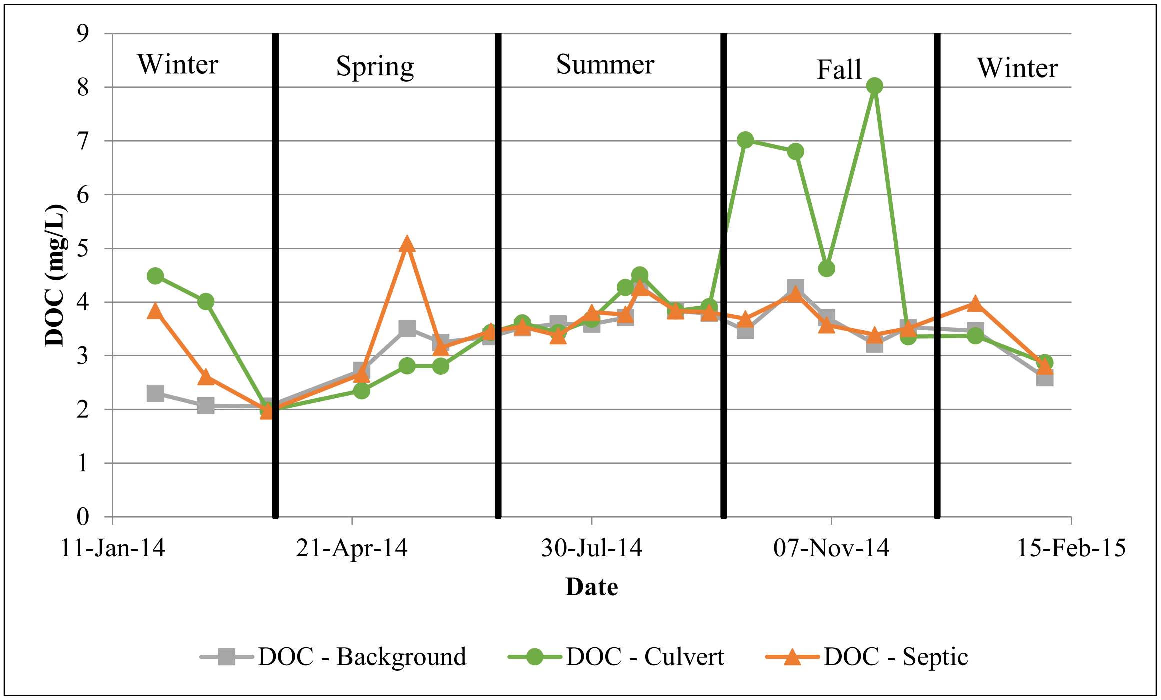

Figure 4-7: DOC Trends

As shown in Figure 4-8, anion concentrations were plotted over time for the most frequently detected anions. Average chloride concentrations increased through the winter of 2014 from 20 ppm in January to 29 ppm in March. Chloride concentrations then reduced and stabilized in spring and summer at approximately 23 ppm. In their study on the Boulder Creek Watershed, Barber *et al*. (2006) found that a wastewater treatment plant effluent accounted for approximately 75 percent of chloride in the watershed during baseline flow; however, during spring runoff, the same effluent accounted for only 38 percent of chloride due to the significant contributions from overland runoff. At Beaver Lake, chloride concentrations then increased from mid-fall (23 ppm) to winter (26 ppm). These increases in chloride were likely coinciding with road and driveway deicing. According to a 2013 Open Space and Recreation Plan, the Town of Ware applied 1,114 tons of road salt during the winter of 2011-2012. It is likely that similar or greater amounts of road salt were applied during the sampling program. The lake then froze during the winter, which would prevent much of the road salts from entering the water body. In the late winter to early spring, when the ice began to melt, there would be a flush of road salts accompanying the snowmelt that could account for the increase in chloride concentrations from January to March.

Sulfate (p=0.000, R= 0.495) and nitrate (p=0.000, R= 0.761) were inversely correlated to temperature much like DO. Sulfate and nitrate also varied by season (p=0.000 for both). As shown in Figure 4-8, average sulfate concentrations decreased from a maximum concentration of approximately 5,900 µg/L in the winter to a low of 3,000 µg/L in the summer. Concentrations of sulfate then increased from summer back up to approximately 5,000 µg/L in the winter of 2015 with few relative spikes and drops between. Similarly, average nitrate concentrations decreased from a high of 862 µg/L in the winter to a relatively low and consistent concentration of 0 to 12 µg/L through the summer. Concentrations of nitrate then increased from the summer back to approximately 400 µg/L in the winter of 2015. Fluoride concentrations remained relatively low and constant (16 to 33 µg/L) throughout the year.

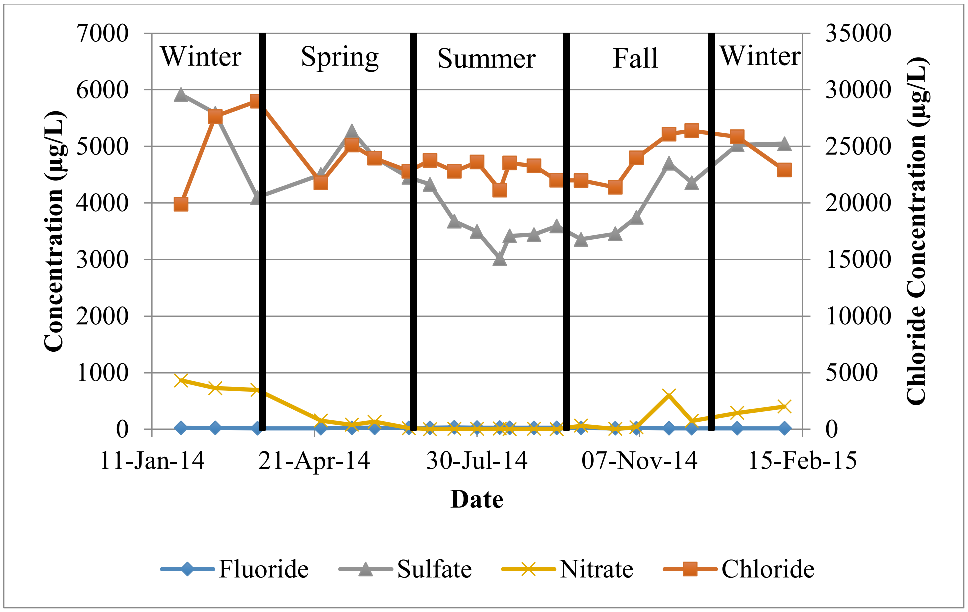

Figure 4-8: Anion Concentration Trends

Finally, bacterial indicators were plotted over time to evaluate seasonal trends in Figure 4-9. As shown in Figure 4-9, average total coliforms, *E. coli*, and enterococci show very similar trends with total coliform concentrations (maximum of 11,000 MPN/100 mL) much greater than *E. coli* (2,000 MPN/100 mL) or enterococci (2,400 MPN/100 mL) concentrations. Total coliform concentrations generally increased with temperature, increasing from a low of 97 MPN/100 mL in the winter of 2014 to a high of 11,000 MPN/100 mL in the fall and decreasing back to 160 MPN/100 mL in the winter of 2015. *E. coli* and enterococci followed similar trends. These findings correspond well to studies by Duris *et al.* (2013) and Long *et al.* (2006). In a two-year study on 27 surface water sampling locations in Pennsylvania, Duris *et al.* (2013) found that *E. coli* and enterococci concentrations were positively correlated with temperature with order of magnitude increases from winter (295 and 322 cfu/100 mL, respectively) to summer (1,186 and 1,330 cfu/100 mL, respectively). Similarly, Long *et al.* (2006) found that fecal coliform concentrations ranged from 100 to 2,500 cfu/100 mL in the summer and were typically less than 100 cfu/100 mL in the winter in a Wachusett Reservoir tributary study. Beaver lake average values for *E. coli* and enterococci were highest in October at approximately 2,000 and 2,400 MPN/100 mL respectively. The fecal indicator concentrations peaked in early fall rather than summer likely due to rain events captured in the October sampling round as described in Sub-section 4.5.4. Also, average water temperatures in early October were still between 12 and 17°C.

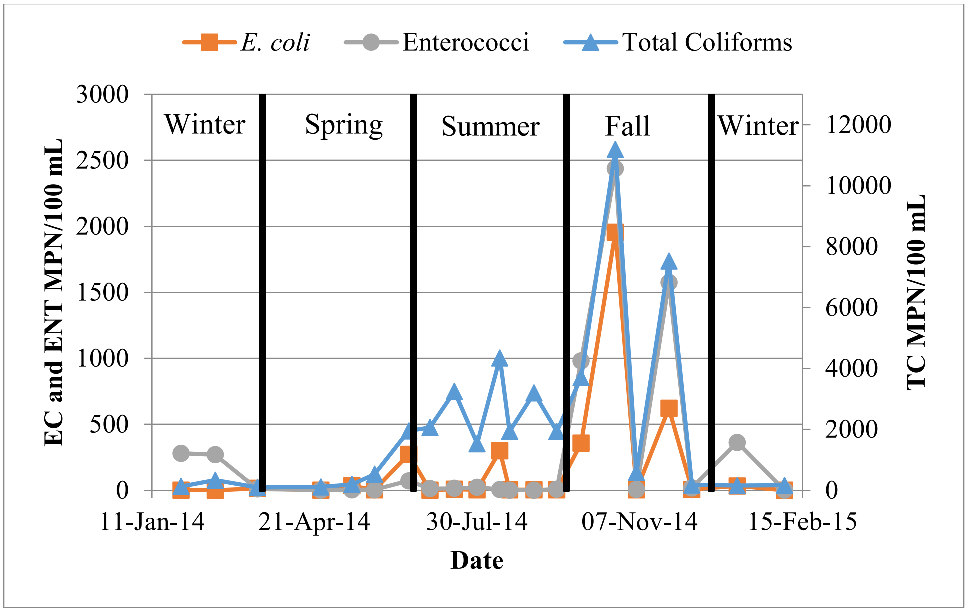

Figure 4-9: Bacterial Indicator Concentration Trends

4.5.4 Precipitation Influences

As shown in Table 4-5, 11 of the 20 water quality parameters varied with rainfall including total coliforms and *E. coli*. While enterococci were not found to vary significantly with rainfall at the 95% confidence level, this indicator did vary with precipitation at the 90% confidence level (p=0.09). Figure 4-10 shows average bacterial indicator concentrations for the three categories of rainfall used in the ANOVA analyses.

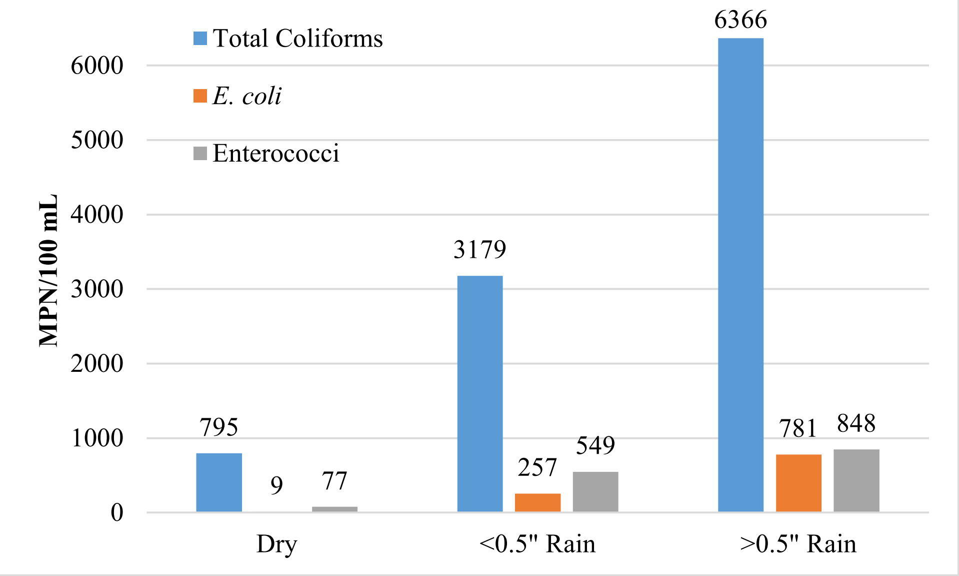

Figure 4-10: Bacterial Indicators and Rainfall

As shown in Figure 4-10, average concentrations for all three of the bacterial indicators increased with rainfall by one to two orders of magnitude. Total coliforms increased from an average dry weather concentration of 800 MPN/100 mL to a wet weather concentration of 6,400 MPN/100 mL, and *E. coli* increased from 9 to 780 MPN/100 mL. These results are consistent with those reported by Mallin *et al*. (2009), Staley *et al*. (2013), and Wilkes *et al*. (2009). Mallin *et al*. (2009) found order of magnitude increases for fecal coliforms between dry and wet weather sampling events in a study on river water quality in undeveloped, suburban, and urban land uses in North Carolina. The study found that dry to wet fecal coliform concentrations ranged from 300 to 1,500 cfu/100 mL in the undeveloped river and 500 to 3,500 cfu/100 mL in the urban river.

Staley *et al.* (2013) found that antecedent rainfall for two and seven days prior to sampling was positively correlated with enterococci concentrations, and concentrations generally exceeded regulatory standards after rainfall events. Similarly, average *E. coli* concentrations at Beaver Lake exceeded the regulatory limit of 126 cfu/100 mL for both rain conditions but not during dry conditions. Enterococci concentrations at Beaver Lake exceeded the regulatory limit of 33 cfu/100 mL during dry and wet conditions. Additionally, as shown, total coliform concentrations were greater than enterococci concentrations, and enterococci concentrations were greater than *E. coli* concentrations regardless of rainfall showing a relationship between the three indicators independent of rain conditions.

Figure 4-11 shows the bacterial indicator concentrations over time, and inches of rainfall in the 24 hours preceding sample collection are included as bars on the secondary y-axis. As shown in Figure 4-11, in addition to bacterial indicator concentrations varying temporally, localized concentration peaks generally correspond with antecedent rainfall events. As stated previously, all three indicators were correlated with rainfall and total coliforms and *E. coli* varied by the three rainfall categories. It should be noted that while the magnitude of concentration spikes corresponded to the magnitude of rainfall in some cases (July 16, August 13, and October 23), this was not always the case (September 3 and November 25). The largest spike in concentrations for all three indicators, total coliforms (11,000 MPN/100 mL), *E. coli* (2,000 MPN/100 mL), and enterococci (2,400 MPN/100 mL), occurred on October 23, 2014. This sampling event corresponds with the largest rain event of approximately 1.6 inches in the 24 hours preceding sampling. However, the second largest spike in concentrations for all three indicators, total coliforms (7,500 MPN/100 mL), *E. coli* (620 MPN/100 mL), and enterococci (1,600 MPN/100 mL), occurred on November 25, 2014 corresponding with the third lowest rainfall event (0.21 inches).

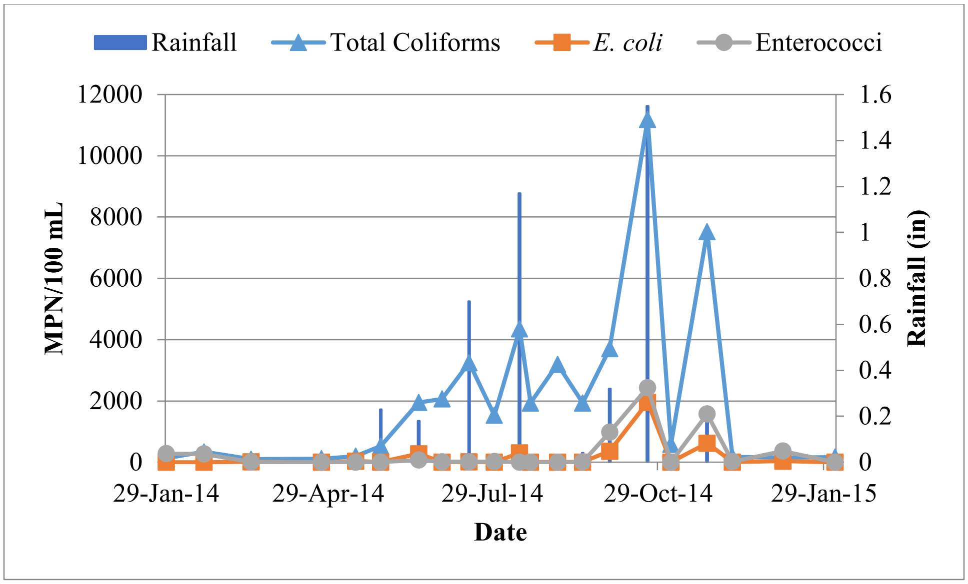

Figure 4-11: Bacterial Indicator Trends with Rainfall

Similarly, Figure 4-12 shows DOC concentrations over time with preceding rainfall shown as bars on the secondary y-axis. As shown in Table 4-5, DOC varies significantly with rainfall (p=0.019). While increased DOC concentrations did correspond to rainfall events for some sampling rounds, as shown in Figure 4-12, the magnitude of the rainfall did not appear to be a significant factor in the magnitude of the DOC spike. For example, the two largest spikes in DOC concentrations occurred on October 2, 2014 and November 25, 2014 at the culvert sampling locations. These sampling rounds corresponded with 0.32 and 0.21 inches of rainfall, respectively, which were not even included in the top rainfall category of greater than 0.5 inches.

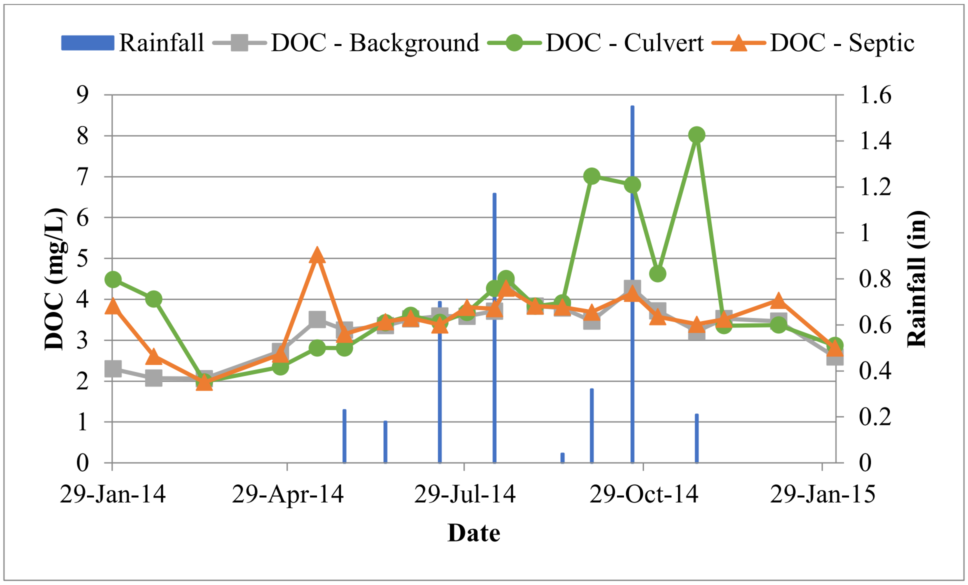

Figure 4-12: DOC Trends with Rainfall

Also, as discussed previously, non-culvert DOC contributions like septic systems may not be affected by overland runoff. These contributions may be related to other factors like snowmelt or rainfall preceding sampling by more than the 24 hours shown here (i.e. 2 to 7 days preceding). There may be a lag between rainfall and concentration changes representing the time it takes rainfall to infiltrate the ground surface and travel into surface water. For example, the largest septic spike in DOC concentrations resulted on May 14, 2014 during dry conditions. However, 0.88 inches of rainfall were recorded on May 10, 2014, four days prior to the sampling event. Similar concentration-rainfall patterns were observed for the other physical and chemical parameters.

4.5.5 Key Parameter Correlations

As described in Section 4.4, the data sets for all water quality parameters except for DO and fluoride were found to be non-normal. Because of these findings, non-parametric Spearman rank analyses were performed on the data sets. The rank correlations determined using the Spearman analysis have a tendency to over-predict the strength of correlations. Hauke and Kossowski (2011) compared the Pearson's and Spearman's correlation analyses on the same sets of data and found that in multiple cases the Pearson analysis determined that a correlation was not significant, while the Spearman rank analysis determined that the same correlation was significant. The authors caution not to rely too heavily on the Spearman's rank correlation coefficient as a measure of the strength of associations between two variables.

Of the 210 correlations considered as part of this research, 140 correlations were determined to be significant ($p < 0.05$) based on the Spearman rank analysis. This supported the theory of Hauke and Kossowski (2011) that Spearman rank analyses tend to over-predict the significance between variables. With 140 significant correlations between water quality parameters, it was difficult to make use of the statistical data. However, it is worth considering a few of the key findings from the correlation analyses.

Because bacterial indicators are directly related to risks to public health and because bacterial indicators including *E. coli* and enterococci are regulated Recreational Water Quality Criteria, it is important to understand correlations between bacterial indicators and other water quality parameters and variables. As shown in Table 4-4 and described in Sub-sections 4.5.3 and 4.5.4, respectively, water temperature and rain were positively correlated with all three bacterial indicators. These positive correlations underscore the importance of designing surface water quality monitoring plans that target sampling times during warm and rainy periods.

Several correlations that were expected based on a combination of chemistry and/or microbiology were observed. These correlations included DO being negatively correlated with temperature, bacteria being positively correlated with temperature and negatively correlated with DO, and organic carbon being positively correlated with bacteria. As discussed previously, DO is negatively correlated with temperature in part because DO saturation concentrations increase with decreasing temperature. DO is negatively correlated with bacteria partly because bacteria are positively correlated with temperature, and partly because of increased bacterial concentration/activity consuming DO through aerobic respiration. Similarly, TOC and DOC are positively correlated with bacterial indicators, because higher concentrations of organic carbon allow microorganisms to grow, and microorganisms themselves contribute to the amount of organic carbon in the water. The fact that all of these correlations were observed during this study helps to strengthen the reliability of the data collected.

Turbidity and conductivity are commonly used as indicators of overall water quality. Turbidity is an aggregate measure of the suspended solids in a sample, as discussed previously. Bacterial particles can contribute to increased turbidity, and bacteria can sorb to particulate matter. Additionally, suspended solids and turbidity can originate from overland runoff or resuspension of bottom or bank sediments induced by turbulence, which are both potential sources of bacterial contamination. As such, bacterial indicators were expected to be positively correlated with turbidity. As presented in Table 4-4, turbidity was moderately correlated with total coliforms and weakly to moderately correlated with *E. coli* and enterococci, again, confirming the expected results. Conductivity is a gross measure of the sum of positive cations and negative anions in a sample. Anions such as chloride, nitrite, nitrate, and orthophosphate can be a result of overland runoff from road salts and fertilizers. Other studies (Katz *et al*., 2011; Ptacek, 1998) suggest that these anions and anions such as bromide may be a result of septic systems. Therefore, conductivity may also be positively correlated with bacterial indicators. As shown in Table 4-4, conductivity was strongly correlated with total coliforms, moderately correlated with *E. coli*, and weakly to moderately correlated with enterococci.

Katz *et al.* (2011) found that chloride to bromide ratios of 400 to 1100 in shallow groundwater were indicative of septic system influences. Their study looked at groundwater data from throughout the United States and used non-parametric (Spearman) correlation analyses to compare the data. For this research, as shown in Table 4-3, bromide was only detected in three percent of the total samples collected making the chloride to bromide ratio unsuitable. Anions are typically lower in surface waters than mineral rich groundwaters, and groundwater systems are typically in closer contact with septic systems. These results indicate that chloride to bromide ratios may only be useful predictors of septic system influence in groundwater systems where bromide is detectable.

Fluoride and chloride ions were both positively correlated with all three bacterial indicators. As discussed previously, chloride at the site is likely associated with road salt. The positive correlation between chloride and bacterial indicators can be interpreted to signify that stormwater, which carries chloride from the roadways through storm drains and culverts to Beaver Lake, also carries bacteria. This is further supported by the fact that all three bacterial indicators are positively correlated with antecedent rainfall.

Conversely, sulfate and nitrate were moderately to strongly negatively correlated with total coliforms. Common sources of high sulfate concentrations are bedrock and deep groundwater aquifers. Therefore, increases in sulfate concentration could signify increased connectivity between groundwater and surface water. If groundwater is not a significant source of bacteria, hydrologic conditions when groundwater is strongly contributing to the lake could serve to dilute bacterial concentrations. Other anions had varying correlations with one or more of the bacterial indicators, as shown in Table 4-4.

Lastly, all three bacterial indicators were positively correlated with each other. As shown in Figure 4-9 through 4-11, the three bacterial indicators follow similar temporal or seasonal trends and are similarly influenced by precipitation. Also, as discussed in Sub-section 4.5.4, the three bacterial indicators keep fairly constant relationships (i.e. total coliforms > enterococci > *E. coli*). These facts indicate that it is likely appropriate to monitor for only one bacterial indicator.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the conclusions of this research and the recommendations for Beaver Lake and general water quality monitoring.

5.1 Conclusions

Between January 2014 and February 2015, 21 sampling events were performed to capture season and precipitation impacts to surface water quality at Beaver Lake in Ware, Massachusetts. Samples were collected from ten sampling locations that were selected to target potential inputs from septic systems, stormwater culverts, and background areas such as the lake influent, the lake effluent, and a private beach. Physical, chemical, and microbiological analyses were performed on surface water samples, and the data were statistically analyzed to determine correlations and variances between water quality parameters and land use and climatic variables. In general, water at Beaver Lake had low alkalinity (11 mg/L as $CaCO_3$) and relatively neutral pH (6.8). Turbidity values were typically less than 1.1 NTU (median), and average TOC and DOC concentrations were 4.2 and 3.7 mg/L, respectively. Fluoride, chloride, and sulfate were present throughout the lake, and other anions were detected intermittently.

Data collected as part of this research contributes additional water quality parameter values and ranges to the data already published and available. These data may also be useful to others conducting research at small rural/residential lakes or looking at water quality patterns in New England. By looking at a wide range or water quality parameters (20) over a full year of relatively frequent sampling (approximately twice per month), this research presents new information on variations in water quality, parameter correlations, and contaminant inputs and trends.

Results from this study show that 11 of the 20 water quality parameters varied by site location (p=0.000 to p=0.036) and 8 of the 20 water quality parameters varied by site type (p=0.005 to p=0.027). The three bacterial indicators varied with both site location (p=0.000) and site type (p=0.009 to p=0.012). These findings highlight the importance of sample site selection.

The greatest variations in water quality were observed at Site 6, which is the direct culvert sample. Site 6 was the sampling location where the minimum concentration was detected for 11 out of 20 parameters, and the maximum concentration was detected for 10 of the 20 parameters. Additionally, the average and maximum values for all parameters were greatest at the culvert sampling locations compared to the septic and background locations. Lastly, when Site 6 data were excluded from ANOVA analyses, far fewer parameters were found to vary by site location or site type. This indicates that storm water flow through culverts was a major source of contaminant inputs, but water quality variations at the study site were dampened due to dilution and mixing effects.

Results showed that 14 of the 20 water quality parameters varied by season (p=0.000 to p=0.049), including the three indicator bacteria. In general, water quality parameters such as DO, organic carbon, chloride, and bacteria followed the seasonal and temporal trends outlined in the literature. Average DO values were lowest in the summer (approximately 5 mg/L) and highest in the late fall and winter (approximately 14 mg/L). Organic carbon concentration spiked (7 – 8 mg/L) at culvert locations in the fall likely due to leaf litter and organic debris, and average chloride concentrations were greatest in the late fall and winter (> 25,000 μg/L).

Similarly, 11 of the 20 water quality parameters varied by antecedent rainfall (*p*=0.000 to *p*=0.040), including total coliforms and *E. coli*. All three bacterial indicators were also positively correlated with rainfall (*p*=0.000). Average bacteria concentrations in the lake increased significantly after rainfall events as highlighted by one to two order of magnitude increases. Similarly, peaks in bacteria concentrations corresponded to rainfall events. This is particularly significant in that average *E. coli* concentrations were below the regulatory standard of 126 MPN/100 mL for dry weather conditions, but *E. coli* concentrations exceeded the standard for sampling rounds with antecedent rainfall. Enterococci exceed the regulatory standard for dry and wet weather conditions. DOC was also correlated with rainfall (*p*=0.019); however, peaks in DOC concentrations were not found to correspond to rainfall events indicating that DOC might be contributed by septic systems or other sources not directly affected by overland transport. For both bacteria and DOC, the magnitude of concentration spikes was not always found to correspond to the magnitude of antecedent rainfall. These findings highlight the importance of sample schedule in accurately characterizing surface water quality.

5.2 Recommendations

As discussed, average *E. coli* and enterococci concentrations exceeded the recreational water quality criteria. This is a regulatory problem and presents a potential risk to public health. Based on the analytical and statistical data, the *E. coli* and enterococci concentrations were increased by rainfall and increased temperature. Also, the largest *E. coli* and enterococci inputs appeared to be from the stormwater culverts. While temperature and precipitation conditions cannot be changed, stormwater management could be improved. Currently, the Ware Department of Public Works has not mapped the Beaver Lake culverts or storm drains. The storm drains and drainage areas could be mapped and investigated to help determine the source of fecal bacteria. If the source cannot be identified and mitigated, stormwater treatment could be employed prior to discharge to the lake.

Similarly, the greatest variability in data was observed at the culvert sampling location Site 6. This was the only location where water was collected directly from the culvert, and this site demonstrated the potential to input the highest contaminant loads. There are seven other culverts that discharge directly to Beaver Lake, and these locations could be investigated. These data could help determine if culverts are a primary source of pollution, or if Site 6 could be an anomaly.

While identifying or narrowing in on the source of the fecal bacteria is important, it would also be very useful to understand the nature of the contamination. Coliphages were measured with the intent to isolate potential human fecal inputs from other environmental fecal contamination; however, due to a lack of detections, the coliphage data were not particularly useful. Using other microbial source tracking markers such as caffeine or sucralose could help to identify the nature and origin of the fecal contamination.

Beaver Lake is a relatively small and shallow surface water body that appears to be well mixed. For example, analytical data from Site 7, immediately downstream of the culvert sample at Site 6, typically matched conditions observed throughout the lake more closely than the analytical data from Site 6. The small well mixed nature of the study site makes differentiating between contaminant sources and types very challenging. Different results might be expected from a larger lake with coves and discontinuities in mixing. Also, no hydraulic data were collected as part of this research. Understanding the turnover rates and flushing effects at the study site could be very helpful in interpreting the water quality data.

In general, for any environmental professional implementing a water quality monitoring plan, the site selection, sampling schedule, and analyte list are very important. Care should be taken to characterize water seasonally, in dry and wet conditions, and adjacent to different land uses in order to accurately model surface water quality. In addition, in small, well mixed surface waters, it may be necessary to collect samples directly from potential sources (culverts, groundwater samples adjacent to septic systems, or tributaries) to better understand contaminant loadings.

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APPENDIX A: ANALYTICAL RESULTS

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Rain (in. 24 hr prior)	Temp (oC)	DO (mg/L)	Cond (µS/cm)	pH	Turb (ntu)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	DOC (mg/L)
29-Jan-14	Winter	1	Background	0	1.1	9	60.9	6.49	0.638		1.7195	1.7265
29-Jan-14	Winter	4	Septic	0	0.2	12.72	42.5	6.45	0.813		4.888	4.577
29-Jan-14	Winter	5	Culvert	0	0.1	13.28	13.2	6.42	16.5		5.5415	4.374
29-Jan-14	Winter	6	Culvert	0								
29-Jan-14	Winter	7	Culvert	0	0.1	12.45	10.2	6.55	183		11.17	5.265
29-Jan-14	Winter	8	Septic	0	0.5	10.41	11.3	6.62	6.67		4.6415	4.4195
29-Jan-14	Winter	9	Culvert	0	0.5	8.85	34.8	6.51	1.8		4.302	3.8235
29-Jan-14	Winter	10	Septic	0	1.1	11.6	10.4	6.57	1.08		2.7595	2.532
29-Jan-14	Winter	11	Background	0	2.1	10.59	52.1	6.45	0.631		3.2725	3.1975
29-Jan-14	Winter	16	Background	0	0.8	13.7	43.7	6.45	1.34		2.7595	1.98
19-Feb-14	Winter	1	Background	0	1	11.86	60.4	6.82	0.916	13.16	1.647	1.473
19-Feb-14	Winter	4	Septic	0	0.1	14.25	33.9	6.79	1.92	10.904	3.002	2.828
19-Feb-14	Winter	5	Culvert	0	0	13.3	7.1	6.57	2.42	10.904	3.354	2.7575
19-Feb-14	Winter	6	Culvert	0								
19-Feb-14	Winter	7	Culvert	0	0	5.45	4.5	6.62	165	29.704	43.04	6.851
19-Feb-14	Winter	8	Septic	0	0.2	13.09	6.5	6.62	0.896	13.16	2.176	2.158
19-Feb-14	Winter	9	Culvert	0	0.1	7.79	13.5	6.33	2.55	13.912	2.807	2.425
19-Feb-14	Winter	10	Septic	0	0.2	12.3	25.3	6.44	1.04	11.28	3.23	2.842
19-Feb-14	Winter	11	Background	0	1.5	12.15	59.5	6.53	0.505	11.656	2.1975	2.036
19-Feb-14	Winter	16	Background	0	0.1	13.24	58.9	6.51	1.35	10.152	2.8995	2.709
17-Mar-14	Winter	1	Background	0	2.2	11.33	64.5	6.91	0.582	10.44	2.2575	2.3035
17-Mar-14	Winter	4	Septic	0	0	13.64	7.8	6.58	0.658	4.68	2.176	2.293
17-Mar-14	Winter	5	Culvert	0	0	12.75	4.7	6.49	1.21	7.74	3.0835	3.316
17-Mar-14	Winter	6	Culvert	0	0.2	16.2	5.4	6.49	0.82	4.32	1.109	1.3795
17-Mar-14	Winter	7	Culvert	0	0.1	14.8	1.1	6.44	5.36	4.5	1.601	1.303
17-Mar-14	Winter	8	Septic	0	0.1	11.6	4.3	6.07	0.793	4.5	1.428	1.51
17-Mar-14	Winter	9	Culvert	0	2	5.95	14.6	6.15	1.21	14.58	1.9995	1.9305
17-Mar-14	Winter	10	Septic	0	4	8.45	70	6.04	2.22	11.16	1.8955	2.1135
17-Mar-14	Winter	11	Background	0	4.2	7.8	73.3	6.23	0.73	25.2	1.9015	2.0535
17-Mar-14	Winter	16	Background	0	3.1	12.42	62.8	6.16	1.1	14.328	1.656	1.824
25-Apr-14	Spring	1	Background	0	11.4	8.98	83.6	7.01	0.717	10.575	3.503	2.9905
25-Apr-14	Spring	4	Septic	0	12.4	10.18	77.9	7.04	0.724	15.975	2.8735	2.701
25-Apr-14	Spring	5	Culvert	0	12.2	9.98	78.9	6.95	0.757	8.1	2.735	2.677
25-Apr-14	Spring	6	Culvert	0	5.6	10.23	92	6.72	0.338	3.78	1.3735	1.3665
25-Apr-14	Spring	7	Culvert	0	11.9	9.95	80	6.88	0.758	7.56	2.7615	2.7325
25-Apr-14	Spring	8	Septic	0	12	10.16	76.9	6.91	0.86	7.2	2.688	2.5825
25-Apr-14	Spring	9	Culvert	0	11.9	10.05	100.7	6.85	1.1	6.885	2.652	2.6175
25-Apr-14	Spring	10	Septic	0	12.1	10.3	75.5	6.9	0.766	7.515	2.701	2.695
25-Apr-14	Spring	11	Background	0	12.1	10.25	75.5	6.94	0.924	7.425	2.57	2.5585
25-Apr-14	Spring	16	Background	0	12.6	10.39	80.9	6.87	0.938	7.56	2.789	2.6325
14-May-14	Spring	1	Background	0	17.5	6.54	92.5	6.65	0.778	11.25	3.656	3.563
14-May-14	Spring	4	Septic	0	18.1	8.7	92.1	6.75	1.05	8.55	3.383	3.2175
14-May-14	Spring	5	Culvert	0	18.1	8.9	92.8	6.55	0.851	8.1	3.3035	3.069
14-May-14	Spring	6	Culvert	0	10.2	9.8	128.1	6.56	5.52	3.375	1.6625	1.668
14-May-14	Spring	7	Culvert	0	17.5	8.15	92.3	6.65	1.02	8.325	3.2305	3.2035

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Rain (in. 24 hr prior)	Temp (oC)	DO (mg/L)	Cond (µS/cm)	pH	Turb (ntu)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	DOC (mg/L)
14-May-14	Spring	8	Septic	0	17.9	8.68	92	6.58	0.734	8.775	3.594	8.664
14-May-14	Spring	9	Culvert	0	17.8	8.57	91.8	6.51	1.04	8.1	3.428	3.3055
14-May-14	Spring	10	Septic	0	18.3	9.32	92.2	6.61	0.724	8.55	3.6815	3.3975
14-May-14	Spring	11	Background	0	18.1	8.4	92.8	6.54	0.887	8.325	3.4635	3.2895
14-May-14	Spring	16	Background	0	18.7	8.38	93.2	6.6	1.09	8.55	3.912	3.667
28-May-14	Spring	1	Background	0.23	17.3	5.76	87.2	6.8	0.924	11.025	3.573	3.425
28-May-14	Spring	4	Septic	0.23	18.4	7.2	92.6	7.04	1.06	10.35	3.344	3.318
28-May-14	Spring	5	Culvert	0.23	18.6	7.35	94.4	6.94	1.02	9.675	3.522	3.328
28-May-14	Spring	6	Culvert	0.23	10.5	10.04	1.4	7.2	2.54	4.95	1.781	1.571
28-May-14	Spring	7	Culvert	0.23	18.3	7.75	95.6	7	1.01	10.125	3.2355	3.1145
28-May-14	Spring	8	Septic	0.23	18.9	7.8	94.1	7.19	0.902	11.25	3.38	3.0845
28-May-14	Spring	9	Culvert	0.23	18.4	7.41	94	7.12	1.01	9.225	3.4515	3.214
28-May-14	Spring	10	Septic	0.23	18.7	7.74	94.1	7.22	1.2	9.225	3.5685	3.0475
28-May-14	Spring	11	Background	0.23	18.8	7.72	93.9	7.22	1.06	11.925	3.3385	3.1135
28-May-14	Spring	16	Background	0.23	18.5	8.05	93.6	7.22	1.36	1.125	3.4895	3.208
18-Jun-14	Spring	1	Background	0.18	21.9	4.6	113.5	6.84	0.994	15.3	3.645	3.3155
18-Jun-14	Spring	4	Septic	0.18	25.1	7.66	115	7.44	1.37	11.7	4.113	3.5335
18-Jun-14	Spring	5	Culvert	0.18	25.1	7.66	115.8	7.41	1.57	11.925	3.964	3.3575
18-Jun-14	Spring	6	Culvert	0.18								
18-Jun-14	Spring	7	Culvert	0.18	24.9	7.65	113.8	7.37	1.61	11.7	3.835	3.412
18-Jun-14	Spring	8	Septic	0.18	24.4	8.03	111.8	7.33	1.46	12.825	3.858	3.4325
18-Jun-14	Spring	9	Culvert	0.18	23.8	6.77	113.4	7.47	2.36	11.475	4.3795	3.5185
18-Jun-14	Spring	10	Septic	0.18	23.9	8.2	110	7.53	1.64	10.35	4.0235	3.4015
18-Jun-14	Spring	11	Background	0.18	23.8	8.58	109.9	7.6	1.35	11.475	4.022	3.3315
18-Jun-14	Spring	16	Background	0.18	24.9	7.9	114.8	7.47	1.86	11.925	3.867	3.4215
1-Jul-14	Summer	1	Background	0	23.7	4.13	124.9	6.62	0.85		3.811	3.389
1-Jul-14	Summer	4	Septic	0	26.5	7.31	124.3	6.9	1.52		4.035	3.5015
1-Jul-14	Summer	5	Culvert	0	26.3	7.28	123	6.91	1.32		3.946	3.598
1-Jul-14	Summer	6	Culvert	0								
1-Jul-14	Summer	7	Culvert	0	26	7.16	121.9	7.07	1.34		3.793	3.549
1-Jul-14	Summer	8	Septic	0	26	7.25	121.5	6.86	1.34		3.7705	3.494
1-Jul-14	Summer	9	Culvert	0	25	4.66	125.6	6.69	2.03		4.007	3.6765
1-Jul-14	Summer	10	Septic	0	25.8	7.45	120.1	6.84	1.36		3.6905	3.6235
1-Jul-14	Summer	11	Background	0	25.7	7.22	120	6.84	1.44		3.7405	3.517
1-Jul-14	Summer	16	Background	0	26.8	7.07	124.2	6.76	1.61		3.889	3.6595
16-Jul-14	Summer	1	Background	0.7	23.7	2.32	122.3	6.29	0.74		4.391	3.926
16-Jul-14	Summer	4	Septic	0.7	26.4	6.11	126.2	6.75	1.59		4.195	3.493
16-Jul-14	Summer	5	Culvert	0.7	26.4	6.15	123.1	6.85	1.64		4.003	3.351
16-Jul-14	Summer	6	Culvert	0.7								
16-Jul-14	Summer	7	Culvert	0.7	26.4	5.94	122.3	6.89	2.05		4.291	3.53
16-Jul-14	Summer	8	Septic	0.7	26.3	6.09	122.1	6.99	1.62		3.8925	3.215
16-Jul-14	Summer	9	Culvert	0.7	25.4	4.94	138.4	6.96	1.82		4.3625	3.4195
16-Jul-14	Summer	10	Septic	0.7	26	5.89	120.8	6.8	1.61		3.9365	3.4155
16-Jul-14	Summer	11	Background	0.7	26	5.8	120.7	6.81	1.79		4.128	3.4475
16-Jul-14	Summer	16	Background	0.7	26.3	6.04	122.9	6.88	1.7		3.773	3.4035

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Analytical Results

Date	Season	Site ID	Site Type	Rain (in. 24 hr prior)	Temp (oC)	DO (mg/L)	Cond (µS/cm)	pH	Turb (ntu)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	DOC (mg/L)
30-Jul-14	Summer	1	Background	0	21.1	2.24	113.7	6.43	0.645	15.525	3.603	3.569
30-Jul-14	Summer	4	Septic	0	24.7	6.27	121.1	6.8	1.65	14.175	3.9365	3.843
30-Jul-14	Summer	5	Culvert	0	24.8	6.24	121	7.05	1.86	14.4	3.8155	3.552
30-Jul-14	Summer	6	Culvert	0								
30-Jul-14	Summer	7	Culvert	0	24.8	6.01	120.9	6.88	1.71	15.075	4.097	3.75
30-Jul-14	Summer	8	Septic	0	24.9	5.86	120.7	6.99	1.81	14.175	4.071	3.727
30-Jul-14	Summer	9	Culvert	0	24.1	5.64	118.4	6.88	1.66	14.85	3.9885	3.7425
30-Jul-14	Summer	10	Septic	0	24.9	5.96	120.5	6.97	1.88	14.625	4.2265	3.851
30-Jul-14	Summer	11	Background	0	25	5.68	120.2	6.97	1.6	14.4	4.129	3.419
30-Jul-14	Summer	16	Background	0	24.7	6.2	121.2	6.94	1.76	14.85	3.9035	3.776
13-Aug-14	Summer	1	Background	1.17	21.6	3.72	122.6	6.61	0.795		3.6585	3.423
13-Aug-14	Summer	4	Septic	1.17	24.7	7.21	122.6	7	1.21		4.01	3.6185
13-Aug-14	Summer	5	Culvert	1.17	24.7	7.2	121.5	7	1.23		3.909	3.512
13-Aug-14	Summer	6	Culvert	1.17	21.6	7.8	7.9	6.65	17.5		6.488	5.025
13-Aug-14	Summer	7	Culvert	1.17	24	7.15	105.9	6.95	1.51		3.905	3.832
13-Aug-14	Summer	8	Septic	1.17	24.7	7.14	121.6	7.03	1.5		3.975	3.9035
13-Aug-14	Summer	9	Culvert	1.17	23.3	4.84	112.5	6.81	1.96		4.1535	4.7065
13-Aug-14	Summer	10	Septic	1.17	24.5	6.9	120.4	7.03	1.8		4.239	3.7905
13-Aug-14	Summer	11	Background	1.17	24.5	6.27	120.1	7.06	1.67		4.16	3.8105
13-Aug-14	Summer	16	Background	1.17	24.2	7.3	118.9	7.1	1.88		4.1325	3.898
19-Aug-14	Summer	1	Background	0	19	2.15	105.8	6.41	0.771		4.4635	4.4285
19-Aug-14	Summer	4	Septic	0	22.5	6.99	116.3	6.83	1.3		4.2765	4.4075
19-Aug-14	Summer	5	Culvert	0	22.4	7.01	115.9	6.85	1.25		4.35	4.2735
19-Aug-14	Summer	6	Culvert	0								
19-Aug-14	Summer	7	Culvert	0	22.6	6.86	116.2	6.83	1.24		4.3885	4.3855
19-Aug-14	Summer	8	Septic	0	22.7	7.04	116.5	7.02	1.41		4.1065	4.068
19-Aug-14	Summer	9	Culvert	0	17.2	2.38	102.6	7.03	1.23		6.7575	4.8555
19-Aug-14	Summer	10	Septic	0	22.8	6.82	116.5	6.96	1.47		4.3765	4.343
19-Aug-14	Summer	11	Background	0	23	6.48	116.2	6.95	1.4		4.5635	4.136
19-Aug-14	Summer	16	Background	0	22.4	7.3	115.8	7.04	1.38		4.9835	4.2875
3-Sep-14	Summer	1	Background	0	22.9	2.08	123.9	6.5	0.734	18.225	4.207	3.9485
3-Sep-14	Summer	4	Septic	0	25.2	7.29	125.1	6.92	1.13	15.435	3.6935	3.923
3-Sep-14	Summer	5	Culvert	0	25.2	7.12	124.8	6.93	1.03	15.165	4.122	3.76
3-Sep-14	Summer	6	Culvert	0								
3-Sep-14	Summer	7	Culvert	0	25.3	7.21	124.9	7.19	1.01	15.075	4.0405	3.7385
3-Sep-14	Summer	8	Septic	0	25.4	7.29	124.3	6.99	1.11	14.625	3.8	3.7665
3-Sep-14	Summer	9	Culvert	0	24.2	5.86	120.6	6.88	1.38	15.075	4.357	4.0065
3-Sep-14	Summer	10	Septic	0	25.3	7.17	124.1	6.93	1.27	14.4	4.167	3.816
3-Sep-14	Summer	11	Background	0	25.5	6.84	124.1	6.97	1.15	14.625	4.045	3.773
3-Sep-14	Summer	16	Background	0	25.1	6.98	125	6.89	1.27	15.075	4.2325	3.7865
17-Sep-14	Summer	1	Background	0.04	17.4	4.43	112.9	6.57	1.31		3.67	3.6665
17-Sep-14	Summer	4	Septic	0.04	19.1	8.2	113	6.95	1.23		4.1425	3.6795
17-Sep-14	Summer	5	Culvert	0.04	19	8.13	112.4	7.04	1.38		4.265	3.8635
17-Sep-14	Summer	6	Culvert	0.04								

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Analytical Results

Date	Season	Site ID	Site Type	Rain (in. 24 hr prior)	Temp (oC)	DO (mg/L)	Cond (µS/cm)	pH	Turb (ntu)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	DOC (mg/L)
17-Sep-14	Summer	7	Culvert	0.04	18.9	8.02	112.1	7.04	1.01		4.1445	3.876
17-Sep-14	Summer	8	Septic	0.04	19.5	8.32	112.2	7.18	1.05		5.0895	3.8565
17-Sep-14	Summer	9	Culvert	0.04	17.5	7.52	102.7	7.16	3.4		4.216	4.006
17-Sep-14	Summer	10	Septic	0.04	19.3	8.22	110.9	7.17	1.02		4.241	3.8885
17-Sep-14	Summer	11	Background	0.04	19.4	8.19	110.4	7.2	0.931		4.188	3.8275
17-Sep-14	Summer	16	Background	0.04	19.1	8.46	111.2	7.18	1.03		4.321	3.8655
2-Oct-14	Fall	1	Background	0.32	16.8	4.75	106.7	6.83	0.633		3.3915	3.451
2-Oct-14	Fall	4	Septic	0.32	18.4	7.77	111.1	6.93	0.91		3.9785	3.776
2-Oct-14	Fall	5	Culvert	0.32	18.5	7.77	110.9	7.09	0.941		3.9835	3.5935
2-Oct-14	Fall	6	Culvert	0.32	15.3	8.55	26.7	6.83	26.7		18.275	16.955
2-Oct-14	Fall	7	Culvert	0.32	18.5	7.75	110.6	6.99	1.13		4.0865	3.7805
2-Oct-14	Fall	8	Septic	0.32	18.5	7.69	110.5	7.17	0.9		4.255	3.6155
2-Oct-14	Fall	9	Culvert	0.32	17.6	7.02	108.5	7.03	4.86		5.112	3.736
2-Oct-14	Fall	10	Septic	0.32	18.6	7.68	110.6	7.12	0.827		4.1805	3.6755
2-Oct-14	Fall	11	Background	0.32	18.6	7.5	110.4	7.03	0.815		4.1695	3.6515
2-Oct-14	Fall	16	Background	0.32	18.2	7.7	110.1	7.14	0.823		4.18	3.301
23-Oct-14	Fall	1	Background	1.55	11.4	5.65	84.2	6.46	0.743	14.175	4.714	4.558
23-Oct-14	Fall	4	Septic	1.55	13.1	8.79	93	6.79	1.38	14.4	4.0755	3.661
23-Oct-14	Fall	5	Culvert	1.55	13.3	8.75	94.6	6.66	0.924	14.175	3.8015	3.5255
23-Oct-14	Fall	6	Culvert	1.55	9.9	10.69	69.8	6.42	36.8	2.475	14.07	10.935
23-Oct-14	Fall	7	Culvert	1.55	13.3	8.78	95.1	6.79	1	14.175	3.951	3.5135
23-Oct-14	Fall	8	Septic	1.55	13.4	9.06	147.5	6.88	0.981	14.175	3.866	3.45
23-Oct-14	Fall	9	Culvert	1.55	10.5	5.56	25.7	6.29	10.3	4.5	16.49	9.246
23-Oct-14	Fall	10	Septic	1.55	13.3	9.04	111	6.82	1.07	9.675	6.1035	5.339
23-Oct-14	Fall	11	Background	1.55	13.3	9.02	147.5	6.8	1.15	14.625	4.5335	4.3485
23-Oct-14	Fall	16	Background	1.55	13.2	9.01	120	6.81	0.998	14.4	4.2285	3.889
5-Nov-14	Fall	1	Background	0	7.2	7.2	82.5	6.41	0.72		4.587	4.3685
5-Nov-14	Fall	4	Septic	0	9.2	9.42	85.3	6.79	0.811		3.9185	3.71
5-Nov-14	Fall	5	Culvert	0	9.2	9.38	84.7	6.89	0.815		3.912	3.815
5-Nov-14	Fall	6	Culvert	0								
5-Nov-14	Fall	7	Culvert	0	9.3	9.45	84.3	6.99	1.17		3.832	3.6315
5-Nov-14	Fall	8	Septic	0	9.3	9.77	84.5	7.01	0.88		3.762	3.496
5-Nov-14	Fall	9	Culvert	0	8.5	3.71	83.5	6.73	0.956		6.781	6.428
5-Nov-14	Fall	10	Septic	0	9.3	9.81	84.4	7	1.02		3.722	3.5155
5-Nov-14	Fall	11	Background	0	9	9.81	83.7	7.11	1.11		3.958	3.41
5-Nov-14	Fall	16	Background	0	9.7	9.72	85.9	7.02	0.876		3.7335	3.365
25-Nov-14	Fall	1	Background	0.21	4.8	8.1	68.7	6.39	0.945		3.005	3.02
25-Nov-14	Fall	4	Septic	0.21	5.6	12.05	76.7	6.76	0.94		3.443	3.4265
25-Nov-14	Fall	5	Culvert	0.21	5.4	12.1	76.8	6.9	1.45		3.4145	3.2965
25-Nov-14	Fall	6	Culvert	0.21	11.1	10.42	204.5	7	95.1		26.21	22.105
25-Nov-14	Fall	7	Culvert	0.21	5.6	11.95	76.9	7.01	1.35		3.529	3.3305
25-Nov-14	Fall	8	Septic	0.21	5.5	12.18	76.1	7.04	1.04		3.5755	3.436
25-Nov-14	Fall	9	Culvert	0.21	5.2	11.45	75.6	6.86	1.39		3.446	3.366
25-Nov-14	Fall	10	Septic	0.21	5.5	12.02	75.6	7.06	1.04		3.478	3.3115
25-Nov-14	Fall	11	Background	0.21	5.1	12.42	74.6	7.06	1.11		3.4555	3.307

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Rain (in. 24 hr prior)	Temp (oC)	DO (mg/L)	Cond (µS/cm)	pH	Turb (ntu)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	DOC (mg/L)
25-Nov-14	Fall	16	Background	0.21	5.8	12.4	76.3	7.03	1.21		3.674	3.325
9-Dec-14	Fall	1	Background	0	2	12.57	56.1	6.54	0.753	9.675	3.879	3.917
9-Dec-14	Fall	4	Septic	0	2	14.11	62.9	6.7	0.817	11.7	3.9585	3.844
9-Dec-14	Fall	5	Culvert	0	1.9	14.1	63.6	6.72	1.14	11.925	3.89	3.772
9-Dec-14	Fall	6	Culvert	0	3.5	14.8	137.4	6.54	0.388	2.925	2.3255	2.4475
9-Dec-14	Fall	7	Culvert	0	1.8	14.31	65	6.76	0.953	12.375	3.748	3.626
9-Dec-14	Fall	8	Septic	0	1.5	15.06	66.3	6.92	0.975	12.825	3.483	3.39
9-Dec-14	Fall	9	Culvert	0	0.6	15.6	64	6.99	2.26	13.5	3.8225	3.582
9-Dec-14	Fall	10	Septic	0	1.5	15.3	65.8	6.93	1.11	12.825	3.6445	3.301
9-Dec-14	Fall	11	Background	0	1.5	15.26	65.9	7.05	1.1	12.825	3.554	3.2545
9-Dec-14	Fall	16	Background	0	1.4	15.16	66	6.97	1.01	13.05	3.6825	3.416
6-Jan-15	Winter	1	Background	0	3	9.2	61.3	6.59	0.65		2.8145	2.5995
6-Jan-15	Winter	4	Septic	0	3.4	11.5	63.3	6.61	0.71		3.7395	3.471
6-Jan-15	Winter	5	Culvert	0	3.1	11.56	63.3	6.58	0.944		3.9435	3.5915
6-Jan-15	Winter	6	Culvert	0	0.9	13.75	120.3	6.49	0.254		1.9295	1.9355
6-Jan-15	Winter	7	Culvert	0	2.6	11.92	66.7	6.58	0.756		3.7295	3.637
6-Jan-15	Winter	8	Septic	0	2.6	12.73	66.2	6.69	0.771		4.1235	3.769
6-Jan-15	Winter	9	Culvert	0	2	9.73	70	6.46	1.23		4.575	4.322
6-Jan-15	Winter	10	Septic	0	2.5	12.9	65.4	6.78	1.01		4.797	4.691
6-Jan-15	Winter	11	Background	0	3.4	12.5	66.7	6.77	0.837		3.9615	3.983
6-Jan-15	Winter	16	Background	0	2.5	13.03	67.9	6.62	1.25		4.0785	3.815
4-Feb-15	Winter	1	Background	0	0.6	9.19	64.6	6.59	1.07		2.07	1.8535
4-Feb-15	Winter	4	Septic	0	1	10.45	62	6.54	0.755		2.941	2.7675
4-Feb-15	Winter	5	Culvert	0	1.2	10.8	64	6.49	1.15		3.123	2.986
4-Feb-15	Winter	6	Culvert	0								
4-Feb-15	Winter	7	Culvert	0	1.6	10.81	64.4	6.42	0.688		2.9265	2.925
4-Feb-15	Winter	8	Septic	0	1.7	10.86	68.6	6.4	0.853		2.8225	2.729
4-Feb-15	Winter	9	Culvert	0	0.3	8	65.3	6.29	2.22		2.8635	2.6965
4-Feb-15	Winter	10	Septic	0	2	9.75	62.6	6.39	2.83		4.5	2.9265
4-Feb-15	Winter	11	Background	0	2.3	11.05	71.3	6.5	0.59		3.469	3.2215
4-Feb-15	Winter	16	Background	0	1.5	8.78	65.5	6.4	1.56		3.435	2.707

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Ammonia (µg/L)	Fluoride (µg/L)	Chloride (µg/L)	Nitrite (µg/L)	Sulfate (µg/L)	Bromide (µg/L)	Nitrate (µg/L)	Phosphate (µg/L)	Total coliforms (cfu/100 mL)	E. coli (cfu/100 mL)	Enterococci (cfu/100 mL)	Coliphages (pfu/100 mL)
29-Jan-14	Winter	1	Background	60	23.2272	23099.4242	0	5993.7181	0	484.5709	0	75.4	2.05	0.5	0
29-Jan-14	Winter	4	Septic	140	39.2571	20465.7922	0	6356.3544	0	588.2873	0	74.8	1.25	1.5	0
29-Jan-14	Winter	5	Culvert	220	27.4745	22276.0516	0	6236.0852	0	709.5434	0	167.45	1	98.6	0.5
29-Jan-14	Winter	6	Culvert												
29-Jan-14	Winter	7	Culvert	930	38.1417	26428.0271	0	6715.8548	0	623.7915	0	507.3	5.8	4839.2	0
29-Jan-14	Winter	8	Septic	200	37.191	20443.953	0	5571.9609	0	541.5667	0	62	0.75	0.5	0
29-Jan-14	Winter	9	Culvert	200	17.1325	19884.7771	0	4756.3551	0	597.3275	0	66.3	0.5	3.5	0
29-Jan-14	Winter	10	Septic	140	16.1138	15587.394	0	3643.7971	0	496.1879	98.0893	92.05	0.5	0.5	0
29-Jan-14	Winter	11	Background	130	20.9957	16779.5877	0	4470.4278	0	413.5938	0	12.75	0.5	0.5	0
29-Jan-14	Winter	16	Background	60	11.7161	14101.9186	0	9515.2026	0	3303.8665	0	100.1	0.5	0.5	0
19-Feb-14	Winter	1	Background	50	22.0374	20888.0059	0	5604.7562	0	486.5744	0	126.65	0.75	0.5	0
19-Feb-14	Winter	4	Septic	280	25.6715	17354.2951	0	6286.3823	0	791.3653	0	77.15	1.25	1.5	0.5
19-Feb-14	Winter	5	Culvert	130	24.9459	23560.7758	0	6454.3922	0	945.2246	0	78.25	1.25	2.8	0.5
19-Feb-14	Winter	6	Culvert												
19-Feb-14	Winter	7	Culvert	1680	40.9484	80808.7222	0	3587.6676	32.1473	37.2198	0	4839.2	0.75	3629.4	0
19-Feb-14	Winter	8	Septic	50	22.7515	20554.3091	0	6021.8129	0	843.9181	0	47.75	1.5	0.5	0
19-Feb-14	Winter	9	Culvert	310	18.9837	26129.0803	0	5189.5758	0	467.8868	0	110.35	0.5	1.25	0
19-Feb-14	Winter	10	Septic	130	21.926	19873.114	0	5416.5225	0	559.5688	78.6542	68.2	0.75	1.75	0
19-Feb-14	Winter	11	Background	60	22.5559	19522.2121	0	5329.3805	0	540.7359	0	48.45	0.5	0.5	0
19-Feb-14	Winter	16	Background	40	19.7825	20169.7299	0	6388.0016	0	1860.679	0	58.5	0.5	0.5	0
17-Mar-14	Winter	1	Background	80	20.0997	24620.9086	0	4728.3826	0	382.2978	0	170.1	3.6	7.45	0
17-Mar-14	Winter	4	Septic	130	14.8102	9150.0335	172.9119	3421.0682	0	1009.1604	0	2.55	0.5	3.6	0
17-Mar-14	Winter	5	Culvert	120	11.3418	18023.5331	0	3898.1456	0	1292.0079	0	192.65	0.5	62.05	0
17-Mar-14	Winter	6	Culvert	30	31.1327	82031.5957	0	5267.5892	0	98.2569	0	152.95	98.6	12.8	0
17-Mar-14	Winter	7	Culvert	30	29.1494	76116.743	0	5077.11	0	160.8613	0	135.35	51.7	14	0
17-Mar-14	Winter	8	Septic	110	7.0748	9660.5649	172.8123	2060.1201	0	1037.152	0	9.8	0.5	0.5	0
17-Mar-14	Winter	9	Culvert	260	16.4014	27378.8732	0	4895.6508	0	580.6573	0	207.1	0.5	0.5	0
17-Mar-14	Winter	10	Septic	110	7.356	8348.9214	175.9377	2110.9408	0	681.8111	0	45.3	0.5	0.5	0
17-Mar-14	Winter	11	Background	140	18.9881	22352.5936	0	5381.6992	0	614.7788	0	9.2	0.5	0.5	0
17-Mar-14	Winter	16	Background	110	13.8829	12307.2098	0	4130.379	0	1110.5793	0	42.5	0.5	0.5	0
25-Apr-14	Spring	1	Background	80	20.2951	20549.3269	176.5725	4606.9476	0	68.9999	0	445.8	0.75	2.3	0
25-Apr-14	Spring	4	Septic	70	18.0426	18858.4702	157.8721	4385.4559	0	138.266	0	42.95	1.25	1.25	0
25-Apr-14	Spring	5	Culvert	70	18.075	19006.0319	154.8569	4428.4448	0	145.4841	0	45.25	0.5	2.55	0
25-Apr-14	Spring	6	Culvert	10	22.3	47535.2685	0	5301.404	0	0	0	240.65	3.6	0.75	0
25-Apr-14	Spring	7	Culvert	60	17.6683	18878.5197	156.3862	4400.96	0	153.8729	0	56.45	1	3.05	0
25-Apr-14	Spring	8	Septic	50	17.2299	18617.7796	157.5377	4365.0257	0	156.1605	0	54.9	2	2.55	0
25-Apr-14	Spring	9	Culvert	60	16.8527	18171.6231	152.9296	4306.3969	0	148.1879	0	63.5	1.5	2.55	0
25-Apr-14	Spring	10	Septic	50	17.1588	18397.4717	148.8836	4357.3625	0	150.3546	0	65.75	0.5	0.75	0
25-Apr-14	Spring	11	Background	60	17.1211	18397.0385	146.0988	4355.0363	0	146.4365	0	58.5	1	0.5	0
25-Apr-14	Spring	16	Background	50	17.0817	19457.9777	158.9887	4527.9451	0	419.6557	0	91.65	0.75	0.75	0
14-May-14	Spring	1	Background	70	23.3602	23058.0799	0	5071.8262	0	50.4847	0	649.9	2.05	4.15	0
14-May-14	Spring	4	Septic	40	21.3206	22488.4101	0	5132.0151	0	100.2341	0	48.6	0.75	0.75	0
14-May-14	Spring	5	Culvert	60	21.4423	22777.0444	0	5168.3992	0	107.2469	0	79.25	1.8	2	0
14-May-14	Spring	6	Culvert	20	27.656	47224.2567	0	6382.8308	0	0	0	563.45	336.5	20.75	0
14-May-14	Spring	7	Culvert	50	21.3146	22490.414	0	5134.6245	0	94.1975	0	51.8	1.25	0.75	0

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Ammonia (µg/L)	Fluoride (µg/L)	Chloride (µg/L)	Nitrite (µg/L)	Sulfate (µg/L)	Bromide (µg/L)	Nitrate (µg/L)	Phosphate (µg/L)	Total coliforms (cfu/100 mL)	E. coli (cfu/100 mL)	Enterococci (cfu/100 mL)	Coliphages (pfu/100 mL)
14-May-14	Spring	8	Septic	20	21.4747	22696.865	0	5187.6229	0	94.1588	0	22.15	0.75	3.65	0
14-May-14	Spring	9	Culvert	80	30.8391	22779.5965	0	5130.2708	0	78.9583	0	326.05	0.5	5.75	0
14-May-14	Spring	10	Septic	20	30.5374	22559.0967	0	5153.7049	0	86.5097	0	65.75	0.5	0.5	0
14-May-14	Spring	11	Background	30	30.6303	22692.5147	0	5149.1878	0	90.1006	0	93.4	0.75	1.5	0
14-May-14	Spring	16	Background	30	31.2521	22584.6297	0	5196.9801	0	91.0678	0	61.15	0.5	0.75	0
28-May-14	Spring	1	Background	110	22.7924	19871.3414	0	4392.5548	0	90.927	0	980.4	6.35	6.35	0
28-May-14	Spring	4	Septic	80	22.5399	21229.1291	0	4655.393	0	149.3715	0	210.85	2	8.45	8
28-May-14	Spring	5	Culvert	80	22.0301	21651.1709	0	4744.1171	0	172.0206	0	448.55	4.65	1.5	0
28-May-14	Spring	6	Culvert	20	26.5858	47477.5454	0	5747.9636	0	0	0	3629.4	5.2	8	0
28-May-14	Spring	7	Culvert	70	28.8123	21698.074	0	4761.0253	0	156.7107	0	188.05	2.3	4.05	5.5
28-May-14	Spring	8	Septic	60	28.9296	21508.8922	0	4761.7981	0	148.939	0	134.4	0.75	2.05	0
28-May-14	Spring	9	Culvert	70	29.6749	21654.563	0	4752.165	0	147.3135	0	287.5	0.5	2	0.5
28-May-14	Spring	10	Septic	60	29.063	21533.8975	0	4762.4084	0	152.3447	0	162.75	3.05	2.3	0
28-May-14	Spring	11	Background	80	29.1134	21481.4621	0	4724.0194	0	145.2994	0	188.6	3.05	1.25	0
28-May-14	Spring	16	Background	70	29.6399	21479.0477	0	4752.2599	0	159.5353	0	259.55	0.5	7.8	1.5
18-Jun-14	Spring	1	Background	110	22.0153	21489.9016	0	4364.748	0	61.7862	0	1986.35	6.35	1.75	
18-Jun-14	Spring	4	Septic	70	22.709	22963.8727	0	4443.6537	0	0	0	1594.8	3.05	20	
18-Jun-14	Spring	5	Culvert	80	22.9376	23194.0277	0	4548.9883	0	0	0	2419.6	4.1	43.4	
18-Jun-14	Spring	6	Culvert												
18-Jun-14	Spring	7	Culvert	60	23.065	23048.2404	0	4449.8168	0	0	0	2076.25	5.75	29.25	
18-Jun-14	Spring	8	Septic	70	23.016	22806.6854	0	4433.0903	0	0	0	2076.25	5.2	25.4	
18-Jun-14	Spring	9	Culvert	80	23.5123	23127.9944	0	4486.7184	0	0	0	4839.2	4839.2	515.75	
18-Jun-14	Spring	10	Septic	80	23.064	22626.4022	0	4400.1978	0	0	0	1516.3	3.6	2.5	
18-Jun-14	Spring	11	Background	60	23.3662	22718.2181	0	4430.115	0	0	0	1062.05	1.5	2.5	
18-Jun-14	Spring	16	Background	80	30.9771	23282.2376	0	4506.4766	0	109.2589	0	4839.2	16.55	16.25	
1-Jul-14	Summer	1	Background	90	22.6948	24581.8093	0	4537.4636	0	37.4987	0	2859	1	5.2	0
1-Jul-14	Summer	4	Septic	50	24.3866	23997.2209	0	4438.1872	0	0	0	1751.4	0.5	14	0
1-Jul-14	Summer	5	Culvert	70	24.3526	23680.526	0	4383.3631	23.4429	0	0	2202.95	4.65	12.65	0
1-Jul-14	Summer	6	Culvert												
1-Jul-14	Summer	7	Culvert	50	24.2287	23551.0111	0	4306.1452	0	0	0	2202.95	3.4	23.65	0
1-Jul-14	Summer	8	Septic	60	24.4299	23643.2546	0	4330.1816	0	0	0	1643	0.5	7.95	0
1-Jul-14	Summer	9	Culvert	80	23.8221	23844.9742	0	4142.7922	23.4919	0	0	2682.2	1.25	22.95	0
1-Jul-14	Summer	10	Septic	50	24.1515	23335.9709	0	4274.3277	0	0	0	770.1	1.25	4.15	0
1-Jul-14	Summer	11	Background	60	24.3046	23391.6808	0	4255.3198	43.7446	0	0	1308.45	1.25	15.85	0
1-Jul-14	Summer	16	Background	60	29.228	23741.1097	0	4304.9153	0	0	0	3173	5.7	15.95	0
16-Jul-14	Summer	1	Background	120	20.5699	22518.152	0	3629.7311	0	46.5514	0	2612.8	6.35	6.25	0
16-Jul-14	Summer	4	Septic	90	34.3608	22860.0977	0	3720.3957	0	0	0	2202.95	10.55	15.9	0
16-Jul-14	Summer	5	Culvert	80	35.1406	22834.1516	0	3726.1746	0	0	0	2202.95	8.6	20.5	0
16-Jul-14	Summer	6	Culvert												
16-Jul-14	Summer	7	Culvert	90	35.0618	22775.004	0	3676.5385	0	0	0	3465.6	5.2	8.6	0
16-Jul-14	Summer	8	Septic	100	34.7136	22765.8258	0	3675.1353	0	0	0	2076.25	6.35	19.4	0
16-Jul-14	Summer	9	Culvert	90	34.8677	22829.3151	0	3643.1067	0	0	0	4184.8	19.55	20.35	0
16-Jul-14	Summer	10	Septic	80	35.5399	22800.6021	0	3665.5489	0	0	0	5233.8	17.1	20.15	0
16-Jul-14	Summer	11	Background	110	33.0987	22839.5528	0	3658.5778	0	0	0	4441	4.1	9.2	0
16-Jul-14	Summer	16	Background	90	35.3401	22880.6174	0	3694.1366	0	20.7138	0	2827.4	3.05	20.95	0

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Analytical Results

Date	Season	Site ID	Site Type	Ammonia (µg/L)	Fluoride (µg/L)	Chloride (µg/L)	Nitrite (µg/L)	Sulfate (µg/L)	Bromide (µg/L)	Nitrate (µg/L)	Phosphate (µg/L)	Total coliforms (cfu/100 mL)	E. coli (cfu/100 mL)	Enterococci (cfu/100 mL)	Coliphages (pfu/100 mL)
30-Jul-14	Summer	1	Background	90	20.9057	23467.1704	0	3938.1365	0	20.2451	0	1643	3.05	92.05	0
30-Jul-14	Summer	4	Septic	100	24.4741	23629.1884	0	3470.9825	0	0	0	1859.6	1.5	10.85	0.5
30-Jul-14	Summer	5	Culvert	100	24.7166	23741.6626	0	3489.9934	0	0	0	931.3	2.5	8.5	1
30-Jul-14	Summer	6	Culvert												
30-Jul-14	Summer	7	Culvert	100	24.8586	23693.5721	0	3460.9056	0	0	0	1986.35	2	5.75	1
30-Jul-14	Summer	8	Septic	110	25.0814	23613.3157	0	3415.752	0	0	0	1161.6	2.55	39.8	0
30-Jul-14	Summer	9	Culvert	120	25.2077	23672.6196	0	3420.0933	0	0	0	1769.75	5.8	18.15	0
30-Jul-14	Summer	10	Septic	120	25.1847	23564.0225	0	3401.9696	0	0	0	886.6	2.55	2	0
30-Jul-14	Summer	11	Background	100	39.1007	23360.564	0	3384.0927	0	0	0	1573.25	2.55	7.4	0
30-Jul-14	Summer	16	Background	110	39.1744	23796.055	0	3481.5971	0	33.0546	0	1986.3	20.45	21.7	0
13-Aug-14	Summer	1	Background	100	20.4548	24090.9339	0	4022.3529	0	0	0	3265.6	568.6	0.5	1.5
13-Aug-14	Summer	4	Septic	80	25.0851	23727.3126	0	3319.9929	0	0	0	2292.2	26.1	0.75	0
13-Aug-14	Summer	5	Culvert	80	36.1792	23475.1875	0	3292.72	0	0	0	3474.4	21.95	2	0
13-Aug-14	Summer	6	Culvert	440	0	314.6429	0	228.919	0	118.3444	112.046	19356.8	1986.3	57.6	0
13-Aug-14	Summer	7	Culvert	130	35.7335	23357.3199	0	3278.7724	0	0	0	8811.8	66.95	0.5	0.5
13-Aug-14	Summer	8	Septic	90	36.7055	23599.3089	0	3302.8944	0	0	0	2202.95	7.65	0.5	0.5
13-Aug-14	Summer	9	Culvert	130	35.7021	22936.9078	0	3079.3824	0	0	0	6212.4	216.55	0.75	0
13-Aug-14	Summer	10	Septic	100	36.737	23404.7209	0	3163.8782	0	0	0	1643	3.1	2	0
13-Aug-14	Summer	11	Background	100	36.8208	23311.879	0	3232.0424	0	0	0	2202.95	5.2	0.5	0.5
13-Aug-14	Summer	16	Background	110	36.8494	23233.9562	0	3264.6558	0	0	0	3693.6	95	0.5	0
19-Aug-14	Summer	1	Background	130	26.7923	22045.7081	0	3876.8791	0	0	0	1266.75	2	0.5	0.5
19-Aug-14	Summer	4	Septic	70	24.9738	23733.7451	0	3375.6855	0	0	0	1848.4	7.4	0.75	0
19-Aug-14	Summer	5	Culvert	80	25.0707	23727.1164	0	3372.4714	0	0	0	2143.6	9.8	1	1.5
19-Aug-14	Summer	6	Culvert												
19-Aug-14	Summer	7	Culvert	70	25.1796	23668.5465	0	3363.6849	0	0	0	2791.6	1	0.75	0
19-Aug-14	Summer	8	Septic	90	25.3004	23676.8628	0	3362.1509	0	0	0	2202.95	2.5	0.75	0
19-Aug-14	Summer	9	Culvert	70	25.4972	23832.7869	0	3362.0095	0	0	0	2202.95	6.9	0.5	0
19-Aug-14	Summer	10	Septic	70	25.8232	23691.4252	0	3333.1298	0	0	0	1594.8	2.05	3.05	0
19-Aug-14	Summer	11	Background	70	25.7133	23702.1337	0	3337.5944	0	0	0	1468.1	3.1	1.5	0
19-Aug-14	Summer	16	Background	70	25.5753	23696.0414	0	3357.7368	0	0	0	1904.8	2.55	0.75	0
3-Sep-14	Summer	1	Background	160	20.3824	22965.824	0	3682.137	0	46.3683	0	1643	1.5	0.5	0
3-Sep-14	Summer	4	Septic	80	24.866	23300.5971	0	3406.9438	0	0	0	2419.6	4.1	0.75	0
3-Sep-14	Summer	5	Culvert	80	25.1773	23434.8209	0	3414.6385	0	0	0	2419.6	4.7	0.5	0
3-Sep-14	Summer	6	Culvert												
3-Sep-14	Summer	7	Culvert	70	25.2076	23331.9566	0	3405.1174	0	0	0	2202.95	6.25	1.5	0
3-Sep-14	Summer	8	Septic	70	25.6548	23383.8727	0	3412.0367	0	0	0	1859.6	0.75	1.5	0
3-Sep-14	Summer	9	Culvert	80	25.2514	23164.8463	0	3401.06	0	0	0	19356.8	14.75	3.05	0
3-Sep-14	Summer	10	Septic	70	25.5764	23254.6013	0	3390.3286	0	0	0	2202.95	2.55	1.5	0
3-Sep-14	Summer	11	Background	70	25.5507	23179.4452	0	3404.1159	0	0	0	3365.6	2.55	1.25	0
3-Sep-14	Summer	16	Background	70	26.1141	23506.9109	0	3467.3207	26.5935	0	0	2994.2	10.45	0.5	0
17-Sep-14	Summer	1	Background	120	21.6889	25299.0348	0	3770.3254	0	18.2778	0	727	5.2	10.35	0
17-Sep-14	Summer	4	Septic	40	25.2836	24464.8916	0	3556.2957	0	0	0	1573.25	2	3.05	0
17-Sep-14	Summer	5	Culvert	30	25.6331	24628.1464	0	3583.2918	0	0	0	1666.4	2.85	10.35	0
17-Sep-14	Summer	6	Culvert												

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Ammonia (µg/L)	Fluoride (µg/L)	Chloride (µg/L)	Nitrite (µg/L)	Sulfate (µg/L)	Bromide (µg/L)	Nitrate (µg/L)	Phosphate (µg/L)	Total coliforms (cfu/100 mL)	E. coli (cfu/100 mL)	Enterococci (cfu/100 mL)	Coliphages (pfu/100 mL)
17-Sep-14	Summer	7	Culvert	30	25.6071	24399.2836	0	3568.963	0	0	0	1389.8	2.55	4.65	0
17-Sep-14	Summer	8	Septic	30	25.8597	24212.7948	0	3559.5119	0	0	0	2129.4	1.25	20.15	0
17-Sep-14	Summer	9	Culvert	60	26.3015	2444.4715	0	3612.3517	0	0	0	3006.2	5.8	15.7	0
17-Sep-14	Summer	10	Septic	30	26.1399	24089.8532	0	3541.2914	0	0	0	2419.6	1.75	5.25	0
17-Sep-14	Summer	11	Background	30	26.3014	24177.3907	0	3598.2967	0	0	0	2068.8	5.2	2.5	0
17-Sep-14	Summer	16	Background	30	25.9367	24326.7661	0	3536.626	0	0	0	2419.6	0.5	12.1	0
2-Oct-14	Fall	1	Background	80	20.5761	23369.3069	0	3911.256	0	27.0312	0	751.55	2	17.65	0
2-Oct-14	Fall	4	Septic	50	28.858	24514.2334	0	3637.9882	59.801	0	0	1643	5.25	16.05	0
2-Oct-14	Fall	5	Culvert	50	24.8654	24485.3031	0	3610.4668	0	0	0	1986.3	2.05	17.8	0
2-Oct-14	Fall	6	Culvert	1520	17.3749	1557.068	0	777.1193	0	597.3991	246.7768	34127.5	3553.5	19356.8	1
2-Oct-14	Fall	7	Culvert	50	25.2239	24404.9393	0	3596.2521	0	0	0	2076.25	9.7	24.6	0
2-Oct-14	Fall	8	Septic	50	24.9084	24262.4896	0	3577.2814	0	0	0	1356.65	4.15	10.9	0
2-Oct-14	Fall	9	Culvert	80	25.3584	24338.3599	0	3619.0767	0	0	0	2076.25	3.1	15.4	0
2-Oct-14	Fall	10	Septic	50	25.3908	24359.3875	0	3608.5861	0	0	49.3283	1859.6	2	8.55	0
2-Oct-14	Fall	11	Background	40	25.6545	24306.6073	0	3602.1304	0	0	0	1573.25	6.95	5.7	0
2-Oct-14	Fall	16	Background	30	25.5549	24356.0923	3624.3566	3624.3566	0	0	0	1699.95	1.25	22.1	0
23-Oct-14	Fall	1	Background	140	15.4289	21347.5869	0	3859.4736	0	35.5655	0	517.95	18	35.1	
23-Oct-14	Fall	4	Septic	50	19.1899	23478.3599	0	3709.2491	0	24.9903	0	2523.8	796.7	461.8	
23-Oct-14	Fall	5	Culvert	30	19.7852	23802.7777	0	3749.7657	0	0	0	1594.8	23.1	22.4	
23-Oct-14	Fall	6	Culvert	920	22.0789	23154.0354	0	4132.1411	0	0	351.2162	72290	8182.5	13084.5	
23-Oct-14	Fall	7	Culvert	40	19.7216	23817.7631	0	3713.2931	0	0	0	1124.75	94.2	66.45	
23-Oct-14	Fall	8	Septic	30	20.684	23843.8952	0	3623.7027	0	0	0	2135.6	58.2	269.15	
23-Oct-14	Fall	9	Culvert	480	8.8878	2778.362	0	776.198	0	0	82.4807	27510	10348.5	10133	
23-Oct-14	Fall	10	Septic	30	20.3967	23953.4468	0	3639.8817	0	0	0	1251.5	10.8	42.7	
23-Oct-14	Fall	11	Background	30	20.639	24125.8741	0	3670.0242	0	0	0	1308.45	4.65	21.8	
23-Oct-14	Fall	16	Background	50	20.2272	23566.3747	0	3676.2419	0	0	0	1643	20.75	245.95	
5-Nov-14	Fall	1	Background	150	16.0818	26404.8452	0	4127.1761	0	70.2062	0	162.75	3.05	2	
5-Nov-14	Fall	4	Septic	80	19.1553	23708.704	0	3762.8498	0	29.1186	0	709.45	1.5	2.5	
5-Nov-14	Fall	5	Culvert	70	19.1787	23717.6569	0	3761.1236	0	29.2339	0	476.2	2.55	1.5	
5-Nov-14	Fall	6	Culvert												
5-Nov-14	Fall	7	Culvert	70	19.3121	23656.2262	0	3704.8464	0	0	0	614.1	4.15	3.05	
5-Nov-14	Fall	8	Septic	60	19.7752	23816.8056	0	3673.9243	0	0	0	748.55	7.95	26.15	
5-Nov-14	Fall	9	Culvert	130	35.5397	23588.5871	0	3613.1317	0	0	104.5518	625.85	3.05	11.5	
5-Nov-14	Fall	10	Septic	60	19.7115	23650.1622	0	3637.5811	0	0	0	804.15	3.6	2.55	
5-Nov-14	Fall	11	Background	50	19.7344	23672.1964	0	3623.1817	0	0	0	489.15	2.05	1.5	
5-Nov-14	Fall	16	Background	50	19.198	23603.8548	0	3815.2687	0	215.5628	0	658.8	1.5	4.1	
25-Nov-14	Fall	1	Background	70	15.9211	20398.8605	0	4568.2738	0	100.4569	0	350.75	20.25	2.5	
25-Nov-14	Fall	4	Septic	70	18.2092	24095.2533	0	3921.3922	0	112.2117	0	143.75	2.55	2	
25-Nov-14	Fall	5	Culvert	50	18.2469	24154.3927	0	3930.0971	0	110.8795	0	130.85	3.6	2	
25-Nov-14	Fall	6	Culvert	1820	20.4071	48726.7269	168.8254	11921.0134	0	5159.544	336.4807	73975	6171	15732.5	
25-Nov-14	Fall	7	Culvert	60	18.0419	24170.9651	0	3876.4269	0	105.9985	0	164.7	4.65	4.6	
25-Nov-14	Fall	8	Septic	40	18.6124	23988.8564	0	3801.2742	0	91.3923	0	127.1	12.3	2.85	
25-Nov-14	Fall	9	Culvert	40	18.384	23937.8832	0	3775.1131	0	71.4839	0	103.5	2.05	1.5	
25-Nov-14	Fall	10	Septic	40	18.7115	23760.4702	0	3698.5841	0	61.6835	0	74.4	1.75	4.25	
25-Nov-14	Fall	11	Background	30	18.7346	23724.6218	0	3670.1304	0	58.682	0	110.5	0.5	0.5	

Appendix A
Analytical Results

Date	Season	Site ID	Site Type	Ammonia (µg/L)	Fluoride (µg/L)	Chloride (µg/L)	Nitrite (µg/L)	Sulfate (µg/L)	Bromide (µg/L)	Nitrate (µg/L)	Phosphate (µg/L)	Total coliforms (cfu/100 mL)	E. coli (cfu/100 mL)	Enterococci (cfu/100 mL)	Coliphages (pfu/100 mL)
25-Nov-14	Fall	16	Background	40	18.4293	24006.5048	0	3846.3356	0	105.1502	0	103.7	0.75	1.5	
9-Dec-14	Fall	1	Background	120	15.9226	20397.9305	0	4357.464	0	106.6885	0	284.45	14.15	17.8	
9-Dec-14	Fall	4	Septic	110	16.3992	21639.5901	0	4283.342	0	176.3627	0	153.25	5.25	5.8	
9-Dec-14	Fall	5	Culvert	100	16.4587	21738.312	0	4271.9252	0	174.2429	0	186.2	2.05	5.2	
9-Dec-14	Fall	6	Culvert	20	18.2192	60481.0069	0	6700.8457	0	0	0	504.3	43.45	141.45	
9-Dec-14	Fall	7	Culvert	100	16.5222	22676.3106	0	4251.6003	0	184.7694	0	122.45	1	4.65	
9-Dec-14	Fall	8	Septic	60	16.9009	23290.2412	0	3951.6035	0	168.0162	0	92	1.25	5.2	
9-Dec-14	Fall	9	Culvert	80	17.1623	23938.4895	0	4004.7234	0	165.9402	0	98.9	1.8	4.65	
9-Dec-14	Fall	10	Septic	70	17.3023	23123.827	0	3827.6659	0	142.776	0	118.45	0.75	3.1	
9-Dec-14	Fall	11	Background	60	17.2058	23238.9976	0	3851.8148	0	143.2617	0	123	0.75	3.05	
9-Dec-14	Fall	16	Background	70	17.1445	23370.7958	0	4089.9906	0	199.4731	0	90.3	1.5	4.1	
6-Jan-15	Winter	1	Background	80	16.1556	20153.0621	0	5316.0682	0	247.1934	0	162.8	6.95	2.55	
6-Jan-15	Winter	4	Septic	120	16.6403	20651.2335	0	5099.2506	0	273.8169	0	30.3	0.5	1.25	
6-Jan-15	Winter	5	Culvert	120	16.3392	20484.272	0	5066.8849	0	256.8181	0	36.35	0.5	0.75	
6-Jan-15	Winter	6	Culvert	30	17.1925	57414.7922	0	6121.2728	0	0	0	448.15	325.5	3629.4	
6-Jan-15	Winter	7	Culvert	130	16.4818	23304.2836	0	5229.5528	0	345.1571	0	39.45	1.5	0.5	
6-Jan-15	Winter	8	Septic	110	16.0796	23155.1452	0	4701.2523	0	405.3502	0	17.1	0.5	0.5	
6-Jan-15	Winter	9	Culvert	160	15.7042	25293.0052	0	4480.1679	0	258.7196	0	56.15	0.5	0.75	
6-Jan-15	Winter	10	Septic	110	15.9297	22405.4667	0	4494.8859	0	283.8196	0	461.1	0.5	0.5	
6-Jan-15	Winter	11	Background	90	15.6749	22090.7523	0	4422.9573	0	319.3018	0	144.3	0.5	0.75	
6-Jan-15	Winter	16	Background	120	16.6203	23515.2847	0	5339.5248	0	506.6191	0	165.95	0.5	0.5	
4-Feb-15	Winter	1	Background	80	16.131	23915.7156	0	5292.159	0	355.1659	0	133	5.2	0.75	
4-Feb-15	Winter	4	Septic	100	17.6399	21000.0194	0	6001.4159	0	347.3989	0	140.85	3.6	1	
4-Feb-15	Winter	5	Culvert	90	18.5852	24171.4394	0	5723.1792	0	336.9288	0	156.7	0.75	2	
4-Feb-15	Winter	6	Culvert												
4-Feb-15	Winter	7	Culvert	90	24.9681	23268.8475	0	5720.3779	0	334.2504	64.2996	114.35	1.25	1.5	
4-Feb-15	Winter	8	Septic	80	16.0183	23120.3194	0	5207.3502	0	340.9973	0	106.5	0.75	1	
4-Feb-15	Winter	9	Culvert	130	11.5811	24650.6572	0	4088.9307	0	553.2933	0	140.55	0.5	0.5	
4-Feb-15	Winter	10	Septic	150	12.534	19645.7219	0	3240.2521	0	229.9549	0	533.9	0.5	1.5	
4-Feb-15	Winter	11	Background	80	15.593	23079.8473	0	4819.5851	0	372.3564	0	47.1	0.5	0.5	
4-Feb-15	Winter	16	Background	120	15.5271	23380.5093	0	5338.0657	0	738.2526	0	129.15	0.75	0.5	

APPENDIX B: STATISTICAL RESULTS

Appendix B-1
Shapiro-Wilk Test for Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Rain	.512	67	.000	.426	67	.000
Temp	.183	67	.000	.868	67	.000
DO	.100	67	.094	.968	67	.080
Cond	.179	67	.000	.860	67	.000
pH	.140	67	.002	.953	67	.013
Turbidity	.479	67	.000	.122	67	.000
Alkalinity	.121	67	.016	.923	67	.000
TOC	.433	67	.000	.224	67	.000
DOC	.178	67	.000	.806	67	.000
Ammonia	.367	67	.000	.278	67	.000
Fluoride	.097	67	.195	.969	67	.097
Chloride	.399	67	.000	.541	67	.000
Nitrite	.499	67	.000	.480	67	.000
Sulfate	.128	67	.008	.953	67	.013
Bromide	.539	67	.000	.165	67	.000
Nitrate	.336	67	.000	.698	67	.000
Phosphate	.534	67	.000	.101	67	.000
Total Coliforms	.343	67	.000	.379	67	.000
E. coli	.441	67	.000	.202	67	.000
Enterococci	.475	67	.000	.114	67	.000
Coliphages	.460	67	.000	.254	67	.000

a. Lilliefors Significance Correction

Appendix B-2
Spearman Non-Parametric Correlations

		Rain	Temp	DO	Cond	pH	Turbidity	Alkalinity	TOC	DOC	Ammonia	Fluoride
Rain	Correlation Coefficient	1.000										
	Sig. (2-tailed)	.										
	N	210										
Temp	Correlation Coefficient	.353**	1.000									
	Sig. (2-tailed)	.000	.									
	N	199	199									
DO	Correlation Coefficient	-.301**	-.772**	1.000								
	Sig. (2-tailed)	.000	.000	.								
	N	199	199	199								
Cond	Correlation Coefficient	.305**	.872**	-.676**	1.000							
	Sig. (2-tailed)	.000	.000	.000	.							
	N	199	199	199	199							
pH	Correlation Coefficient	.366**	.524**	-.209**	.438**	1.000						
	Sig. (2-tailed)	.000	.000	.003	.000	.						
	N	199	199	199	199	199						
Turbidity	Correlation Coefficient	.205**	.279**	-.257**	.184**	.201**	1.000					
	Sig. (2-tailed)	.004	.000	.000	.009	.004	.					
	N	199	199	199	199	199	199					
Alkalinity	Correlation Coefficient	-.055	.366**	-.473**	.397**	.154	.149	1.000				
	Sig. (2-tailed)	.593	.000	.000	.000	.135	.148	.				
	N	96	96	96	96	96	96	96				
TOC	Correlation Coefficient	.302**	.416**	-.442**	.382**	.242**	.380**	.496**	1.000			
	Sig. (2-tailed)	.000	.000	.000	.000	.001	.000	.000	.			
	N	199	199	199	199	199	199	96	199			
DOC	Correlation Coefficient	.189**	.354**	-.388**	.336**	.151*	.260**	.478**	.887**	1.000		
	Sig. (2-tailed)	.008	.000	.000	.000	.034	.000	.000	.000	.		
	N	199	199	199	199	199	199	96	199	199		
Ammonia	Correlation Coefficient	-.106	-.134	-.194**	-.216**	-.398**	.249**	.346**	.235**	.240**	1.000	
	Sig. (2-tailed)	.137	.060	.006	.002	.000	.000	.001	.001	.001	.	
	N	199	199	199	199	199	199	96	199	199	199	
Fluoride	Correlation Coefficient	.262**	.569**	-.502**	.505**	.396**	.342**	.097	.349**	.275**	-.122	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.349	.000	.000	.087	.
	N	199	199	199	199	199	199	96	199	199	199	199

Appendix B-2
Spearman Non-Parametric Correlations

		Rain	Temp	DO	Cond	pH	Turbidity	Alkalinity	TOC	DOC	Ammonia	Fluoride
Chloride	Correlation Coefficient	.101	.113	-.135	.327**	.203**	.131	.336**	.206**	.204**	-.304**	.226**
	Sig. (2-tailed)	.156	.111	.057	.000	.004	.066	.001	.004	.004	.000	.001
	N	199	199	199	199	199	199	96	199	199	199	199
Nitrite	Correlation Coefficient	-.134	-.124	.174*	-.111	.034	-.190**	-.316**	-.255**	-.284**	-.036	-.257**
	Sig. (2-tailed)	.060	.082	.014	.117	.630	.007	.002	.000	.000	.615	.000
	N	199	199	199	199	199	199	96	199	199	199	199
Sulfate	Correlation Coefficient	-.315**	-.495**	.498**	-.436**	-.367**	-.275**	-.495**	-.536**	-.514**	-.054	-.213**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.447	.003
	N	199	199	199	199	199	199	96	199	199	199	199
Bromide	Correlation Coefficient	-.073	.127	-.165*	.125	-.009	.112	.224*	.108	.118	-.010	.133
	Sig. (2-tailed)	.308	.075	.020	.079	.899	.116	.028	.128	.096	.887	.062
	N	199	199	199	199	199	199	96	199	199	199	199
Nitrate	Correlation Coefficient	-.379**	-.761**	.619**	-.776**	-.507**	-.217**	-.281**	-.493**	-.434**	.331**	-.517**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.002	.006	.000	.000	.000	.000
	N	199	199	199	199	199	199	96	199	199	199	199
Phosphate	Correlation Coefficient	.138	-.102	.028	-.170*	-.135	.116	-.200	.175*	.166*	.276**	-.087
	Sig. (2-tailed)	.052	.151	.693	.017	.058	.102	.051	.014	.019	.000	.220
	N	199	199	199	199	199	199	96	199	199	199	199
Total Coliforms	Correlation Coefficient	.492**	.707**	-.676**	.672**	.395**	.457**	.404**	.617**	.530**	.047	.510**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.510	.000
	N	199	199	199	199	199	199	96	199	199	199	199
E. coli	Correlation Coefficient	.531**	.365**	-.339**	.422**	.222**	.221**	.144	.320**	.307**	-.054	.289**
	Sig. (2-tailed)	.000	.000	.000	.000	.002	.002	.162	.000	.000	.445	.000
	N	199	199	199	199	199	199	96	199	199	199	199
Enterococci	Correlation Coefficient	.367**	.224**	-.160*	.262**	.195**	.254**	-.029	.295**	.219**	-.115	.172*
	Sig. (2-tailed)	.000	.001	.024	.000	.006	.000	.782	.000	.002	.107	.015
	N	199	199	199	199	199	199	96	199	199	199	199
Coliphages	Correlation Coefficient	.157	.010	-.082	-.012	.074	.174*	-.009	.054	.115	.273**	.103
	Sig. (2-tailed)	.072	.910	.351	.889	.398	.046	.942	.541	.188	.002	.240
	N	132	132	132	132	132	132	67	132	132	132	132

Appendix B-2
Spearman Non-Parametric Correlations

		Chloride	Nitrite	Sulfate	Bromide	Nitrate	Phosphate	Total Coliforms	E. coli	Enterococci	Coliphages
Chloride	Correlation Coefficient	1.000									
	Sig. (2-tailed)	.									
	N	199									
Nitrite	Correlation Coefficient	-.283**	1.000								
	Sig. (2-tailed)	.000	.								
	N	199	199								
Sulfate	Correlation Coefficient	-.177*	.006	1.000							
	Sig. (2-tailed)	.012	.933	.							
	N	199	199	199							
Bromide	Correlation Coefficient	.148*	-.048	-.061	1.000						
	Sig. (2-tailed)	.037	.497	.391	.						
	N	199	199	199	199						
Nitrate	Correlation Coefficient	-.443**	.233**	.589**	-.148*	1.000					
	Sig. (2-tailed)	.000	.001	.000	.037	.					
	N	199	199	199	199	199					
Phosphate	Correlation Coefficient	-.115	.031	-.063	-.041	.088	1.000				
	Sig. (2-tailed)	.107	.662	.373	.570	.218	.				
	N	199	199	199	199	199	199				
Total Coliforms	Correlation Coefficient	.331**	-.265**	-.566**	.175*	-.738**	.141*	1.000			
	Sig. (2-tailed)	.000	.000	.000	.013	.000	.047	.			
	N	199	199	199	199	199	199	199			
E. coli	Correlation Coefficient	.286**	-.214**	-.317**	.010	-.537**	.130	.643**	1.000		
	Sig. (2-tailed)	.000	.002	.000	.893	.000	.067	.000	.		
	N	199	199	199	199	199	199	199	199		
Enterococci	Correlation Coefficient	.258**	-.084	-.109	.122	-.367**	.170*	.451**	.464**	1.000	
	Sig. (2-tailed)	.000	.239	.127	.087	.000	.016	.000	.000	.	
	N	199	199	199	199	199	199	199	199	199	
Coliphages	Correlation Coefficient	-.068	-.127	-.041	-.084	.042	.049	.069	.066	-.035	1.000
	Sig. (2-tailed)	.440	.148	.642	.340	.633	.574	.433	.453	.686	.
	N	132	132	132	132	132	132	132	132	132	132

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Site Location

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	293.235	9	32.582	.350	.957
	Within Groups	17589.059	189	93.064		
	Total	17882.294	198			
DO	Between Groups	259.109	9	28.790	3.873	.000
	Within Groups	1405.027	189	7.434		
	Total	1664.136	198			
Cond	Between Groups	3476.074	9	386.230	.297	.975
	Within Groups	246039.875	189	1301.798		
	Total	249515.948	198			
pH	Between Groups	1.439	9	.160	2.055	.036
	Within Groups	14.706	189	.078		
	Total	16.144	198			
Turbidity	Between Groups	7317.992	9	813.110	2.461	.011
	Within Groups	62436.382	189	330.351		
	Total	69754.374	198			
Alkalinity	Between Groups	445.309	9	49.479	3.153	.002
	Within Groups	1349.488	86	15.692		
	Total	1794.797	95			
TOC	Between Groups	214.326	9	23.814	1.817	.067
	Within Groups	2476.827	189	13.105		
	Total	2691.153	198			
DOC	Between Groups	93.210	9	10.357	2.937	.003
	Within Groups	666.380	189	3.526		
	Total	759.590	198			
Ammonia	Between Groups	1660817.854	9	184535.317	4.467	.000
	Within Groups	7807895.714	189	41311.618		
	Total	9468713.568	198			
Fluoride	Between Groups	428.453	9	47.606	1.042	.408
	Within Groups	8633.215	189	45.678		
	Total	9061.668	198			
Chloride	Between Groups	4141866872.262	9	460207430.251	6.397	.000
	Within Groups	13596836278.215	189	71940932.689		
	Total	17738703150.477	198			
Nitrite	Between Groups	541107.780	9	60123.087	.890	.535
	Within Groups	12770904.716	189	67570.924		
	Total	13312012.496	198			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Site Location

		Sum of Squares	df	Mean Square	F	Sig.
Sulfate	Between Groups	18754018.429	9	2083779.825	1.562	.129
	Within Groups	252161114.764	189	1334185.792		
	Total	270915133.192	198			
Bromide	Between Groups	176.787	9	19.643	.468	.895
	Within Groups	7935.097	189	41.985		
	Total	8111.884	198			
Nitrate	Between Groups	3162950.242	9	351438.916	1.449	.170
	Within Groups	45832394.175	189	242499.440		
	Total	48995344.417	198			
Phosphate	Between Groups	102146.666	9	11349.630	9.077	.000
	Within Groups	236318.302	189	1250.361		
	Total	338464.968	198			
Total Coliforms	Between Groups	3589546495.960	9	398838499.551	8.127	.000
	Within Groups	9275405975.180	189	49076222.091		
	Total	12864952471.140	198			
E. coli	Between Groups	46883834.729	9	5209314.970	4.946	.000
	Within Groups	199046891.494	189	1053158.156		
	Total	245930726.223	198			
Enterococci	Between Groups	252785756.384	9	28087306.265	7.965	.000
	Within Groups	666508739.007	189	3526501.265		
	Total	919294495.391	198			
Coliphages	Between Groups	5.901	9	.656	.838	.582
	Within Groups	95.423	122	.782		
	Total	101.324	131			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Site Type

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	42.668	2	21.334	.234	.791
	Within Groups	17839.626	196	91.019		
	Total	17882.294	198			
DO	Between Groups	31.127	2	15.564	1.868	.157
	Within Groups	1633.009	196	8.332		
	Total	1664.136	198			
Cond	Between Groups	2904.431	2	1452.216	1.154	.317
	Within Groups	246611.517	196	1258.222		
	Total	249515.948	198			
pH	Between Groups	.190	2	.095	1.168	.313
	Within Groups	15.954	196	.081		
	Total	16.144	198			
Turbidity	Between Groups	2765.597	2	1382.799	4.046	.019
	Within Groups	66988.776	196	341.779		
	Total	69754.374	198			
Alkalinity	Between Groups	66.887	2	33.443	1.800	.171
	Within Groups	1727.910	93	18.580		
	Total	1794.797	95			
TOC	Between Groups	102.974	2	51.487	3.899	.022
	Within Groups	2588.179	196	13.205		
	Total	2691.153	198			
DOC	Between Groups	21.265	2	10.632	2.823	.062
	Within Groups	738.325	196	3.767		
	Total	759.590	198			
Ammonia	Between Groups	491046.162	2	245523.081	5.360	.005
	Within Groups	8977667.406	196	45804.426		
	Total	9468713.568	198			
Fluoride	Between Groups	8.210	2	4.105	.089	.915
	Within Groups	9053.458	196	46.191		
	Total	9061.668	198			
Chloride	Between Groups	945051458.475	2	472525729.237	5.515	.005
	Within Groups	16793651692.002	196	85681896.388		
	Total	17738703150.477	198			
Nitrite	Between Groups	123828.318	2	61914.159	.920	.400
	Within Groups	13188184.177	196	67286.654		
	Total	13312012.496	198			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Site Type

		Sum of Squares	df	Mean Square	F	Sig.
Sulfate	Between Groups	2722766.380	2	1361383.190	.995	.372
	Within Groups	268192366.812	196	1368328.402		
	Total	270915133.192	198			
Bromide	Between Groups	.999	2	.499	.012	.988
	Within Groups	8110.885	196	41.382		
	Total	8111.884	198			
Nitrate	Between Groups	140368.798	2	70184.399	.282	.755
	Within Groups	48854975.619	196	249260.080		
	Total	48995344.417	198			
Phosphate	Between Groups	12215.416	2	6107.708	3.669	.027
	Within Groups	326249.552	196	1664.539		
	Total	338464.968	198			
Total Coliforms	Between Groups	591530768.910	2	295765384.455	4.723	.010
	Within Groups	12273421702.230	196	62619498.481		
	Total	12864952471.140	198			
E. coli	Between Groups	10879183.660	2	5439591.830	4.536	.012
	Within Groups	235051542.563	196	1199242.564		
	Total	245930726.223	198			
Enterococci	Between Groups	43445605.836	2	21722802.918	4.861	.009
	Within Groups	875848889.555	196	4468616.783		
	Total	919294495.391	198			
Coliphages	Between Groups	.604	2	.302	.387	.680
	Within Groups	100.720	129	.781		
	Total	101.324	131			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Season

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	14857.572	3	4952.524	319.283	.000
	Within Groups	3024.722	195	15.511		
	Total	17882.294	198			
DO	Between Groups	773.256	3	257.752	56.418	.000
	Within Groups	890.880	195	4.569		
	Total	1664.136	198			
Cond	Between Groups	139648.016	3	46549.339	82.618	.000
	Within Groups	109867.933	195	563.425		
	Total	249515.948	198			
pH	Between Groups	6.350	3	2.117	42.136	.000
	Within Groups	9.795	195	.050		
	Total	16.144	198			
Turbidity	Between Groups	1841.121	3	613.707	1.762	.156
	Within Groups	67913.252	195	348.273		
	Total	69754.374	198			
Alkalinity	Between Groups	411.354	3	137.118	9.118	.000
	Within Groups	1383.443	92	15.037		
	Total	1794.797	95			
TOC	Between Groups	78.481	3	26.160	1.953	.122
	Within Groups	2612.672	195	13.398		
	Total	2691.153	198			
DOC	Between Groups	75.588	3	25.196	7.183	.000
	Within Groups	684.001	195	3.508		
	Total	759.590	198			
Ammonia	Between Groups	372428.655	3	124142.885	2.661	.049
	Within Groups	9096284.913	195	46647.615		
	Total	9468713.568	198			
Fluoride	Between Groups	2206.530	3	735.510	20.922	.000
	Within Groups	6855.138	195	35.155		
	Total	9061.668	198			
Chloride	Between Groups	151828860.303	3	50609620.101	.561	.641
	Within Groups	17586874290.174	195	90189098.924		
	Total	17738703150.477	198			
Nitrite	Between Groups	185713.499	3	61904.500	.920	.432
	Within Groups	13126298.997	195	67314.354		
	Total	13312012.496	198			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Season

		Sum of Squares	df	Mean Square	F	Sig.
Sulfate	Between Groups	80884483.164	3	26961494.388	27.667	.000
	Within Groups	190030650.029	195	974516.154		
	Total	270915133.192	198			
Bromide	Between Groups	89.893	3	29.964	.728	.536
	Within Groups	8021.991	195	41.138		
	Total	8111.884	198			
Nitrate	Between Groups	10043195.252	3	3347731.751	16.759	.000
	Within Groups	38952149.166	195	199754.611		
	Total	48995344.417	198			
Phosphate	Between Groups	17738.904	3	5912.968	3.595	.015
	Within Groups	320726.065	195	1644.749		
	Total	338464.968	198			
Total Coliforms	Between Groups	660725173.342	3	220241724.447	3.519	.016
	Within Groups	12204227297.798	195	62585781.014		
	Total	12864952471.140	198			
E. coli	Between Groups	11148744.694	3	3716248.231	3.087	.028
	Within Groups	234781981.529	195	1204010.162		
	Total	245930726.223	198			
Enterococci	Between Groups	49208102.345	3	16402700.782	3.676	.013
	Within Groups	870086393.046	195	4461981.503		
	Total	919294495.391	198			
Coliphages	Between Groups	4.141	3	1.380	1.818	.147
	Within Groups	97.182	128	.759		
	Total	101.324	131			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Rainfall

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	5545.465	8	693.183	10.676	.000
	Within Groups	12336.829	190	64.931		
	Total	17882.294	198			
DO	Between Groups	344.342	8	43.043	6.197	.000
	Within Groups	1319.794	190	6.946		
	Total	1664.136	198			
Cond	Between Groups	37333.975	8	4666.747	4.179	.000
	Within Groups	212181.974	190	1116.747		
	Total	249515.948	198			
pH	Between Groups	6.483	8	.810	15.935	.000
	Within Groups	9.662	190	.051		
	Total	16.144	198			
Turbidity	Between Groups	710.810	8	88.851	.245	.982
	Within Groups	69043.564	190	363.387		
	Total	69754.374	198			
Alkalinity	Between Groups	69.233	3	23.078	1.230	.303
	Within Groups	1725.564	92	18.756		
	Total	1794.797	95			
TOC	Between Groups	119.943	8	14.993	1.108	.360
	Within Groups	2571.211	190	13.533		
	Total	2691.153	198			
DOC	Between Groups	81.846	8	10.231	2.868	.005
	Within Groups	677.743	190	3.567		
	Total	759.590	198			
Ammonia	Between Groups	325792.402	8	40724.050	.846	.563
	Within Groups	9142921.166	190	48120.638		
	Total	9468713.568	198			
Fluoride	Between Groups	2245.074	8	280.634	7.822	.000
	Within Groups	6816.594	190	35.877		
	Total	9061.668	198			
Chloride	Between Groups	308106333.392	8	38513291.674	.420	.908
	Within Groups	17430596817.084	190	91739983.248		
	Total	17738703150.477	198			
Nitrite	Between Groups	1182334.935	8	147791.867	2.315	.022
	Within Groups	12129677.560	190	63840.408		
	Total	13312012.496	198			

Appendix B-3
ANOVA Including Site 6

ANOVA - Variance by Rainfall

		Sum of Squares	df	Mean Square	F	Sig.
Sulfate	Between Groups	48665964.312	8	6083245.539	5.201	.000
	Within Groups	222249168.881	190	1169732.468		
	Total	270915133.192	198			
Bromide	Between Groups	320.652	8	40.081	.977	.455
	Within Groups	7791.232	190	41.006		
	Total	8111.884	198			
Nitrate	Between Groups	4003732.416	8	500466.552	2.113	.036
	Within Groups	44991612.001	190	236797.958		
	Total	48995344.417	198			
Phosphate	Between Groups	29463.396	8	3682.925	2.265	.025
	Within Groups	309001.572	190	1626.324		
	Total	338464.968	198			
Total Coliforms	Between Groups	1499603673.119	8	187450459.140	3.134	.002
	Within Groups	11365348798.021	190	59817625.253		
	Total	12864952471.140	198			
E. coli	Between Groups	39510793.173	8	4938849.147	4.546	.000
	Within Groups	206419933.050	190	1086420.700		
	Total	245930726.223	198			
Enterococci	Between Groups	96482951.704	8	12060368.963	2.785	.006
	Within Groups	822811543.687	190	4330587.072		
	Total	919294495.391	198			
Coliphages	Between Groups	20.527	5	4.105	6.402	.000
	Within Groups	80.796	126	.641		
	Total	101.324	131			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Site Location

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	54.096	8	6.762	.071	1.000
	Within Groups	17196.983	180	95.539		
	Total	17251.079	188			
DO	Between Groups	199.837	8	24.980	3.363	.001
	Within Groups	1336.875	180	7.427		
	Total	1536.712	188			
Cond	Between Groups	2539.296	8	317.412	.281	.972
	Within Groups	203280.930	180	1129.338		
	Total	205820.225	188			
pH	Between Groups	1.283	8	.160	2.043	.044
	Within Groups	14.135	180	.079		
	Total	15.418	188			
Turbidity	Between Groups	5076.345	8	634.543	2.098	.038
	Within Groups	54439.181	180	302.440		
	Total	59515.526	188			
Alkalinity	Between Groups	65.770	8	8.221	.495	.856
	Within Groups	1345.351	81	16.609		
	Total	1411.122	89			
TOC	Between Groups	99.169	8	12.396	1.265	.264
	Within Groups	1763.510	180	9.797		
	Total	1862.680	188			
DOC	Between Groups	6.692	8	.836	.976	.456
	Within Groups	154.254	180	.857		
	Total	160.945	188			
Ammonia	Between Groups	257228.571	8	32153.571	1.666	.110
	Within Groups	3474885.714	180	19304.921		
	Total	3732114.286	188			
Fluoride	Between Groups	350.208	8	43.776	.987	.447
	Within Groups	7980.438	180	44.336		
	Total	8330.646	188			
Chloride	Between Groups	803635581.434	8	100454447.679	2.393	.018
	Within Groups	7555156719.212	180	41973092.885		
	Total	8358792300.646	188			
Nitrite	Between Groups	539620.221	8	67452.528	.953	.475
	Within Groups	12745252.902	180	70806.961		
	Total	13284873.124	188			
Sulfate	Between Groups	8108714.061	8	1013589.258	1.164	.324
	Within Groups	156793525.001	180	871075.139		
	Total	164902239.062	188			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Site Location

		Sum of Squares	df	Mean Square	F	Sig.
Bromide	Between Groups	165.149	8	20.644	.468	.877
	Within Groups	7935.097	180	44.084		
	Total	8100.246	188			
Nitrate	Between Groups	1525133.915	8	190641.739	1.532	.149
	Within Groups	22399277.657	180	124440.431		
	Total	23924411.572	188			
Phosphate	Between Groups	3090.487	8	386.311	1.942	.056
	Within Groups	35813.475	180	198.964		
	Total	38903.962	188			
Total Coliforms	Between Groups	122492469.363	8	15311558.670	2.226	.028
	Within Groups	1238187310.314	180	6878818.391		
	Total	1360679779.677	188			
E. coli	Between Groups	9786968.593	8	1223371.074	1.834	.073
	Within Groups	120083226.724	180	667129.037		
	Total	129870195.317	188			
Enterococci	Between Groups	6691803.372	8	836475.422	1.151	.331
	Within Groups	130774325.550	180	726524.031		
	Total	137466128.922	188			
Coliphages	Between Groups	5.897	8	.737	.912	.509
	Within Groups	94.589	117	.808		
	Total	100.486	125			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Site Type

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	6.412	2	3.206	.035	.966
	Within Groups	17244.667	186	92.713		
	Total	17251.079	188			
DO	Between Groups	33.762	2	16.881	2.089	.127
	Within Groups	1502.950	186	8.080		
	Total	1536.712	188			
Cond	Between Groups	2262.677	2	1131.339	1.034	.358
	Within Groups	203557.548	186	1094.395		
	Total	205820.225	188			
pH	Between Groups	.164	2	.082	1.001	.369
	Within Groups	15.254	186	.082		
	Total	15.418	188			
Turbidity	Between Groups	1612.984	2	806.492	2.591	.078
	Within Groups	57902.542	186	311.304		
	Total	59515.526	188			
Alkalinity	Between Groups	17.292	2	8.646	.540	.585
	Within Groups	1393.830	87	16.021		
	Total	1411.122	89			
TOC	Between Groups	52.626	2	26.313	2.704	.070
	Within Groups	1810.054	186	9.731		
	Total	1862.680	188			
DOC	Between Groups	4.389	2	2.194	2.607	.076
	Within Groups	156.557	186	.842		
	Total	160.945	188			
Ammonia	Between Groups	129266.667	2	64633.333	3.337	.038
	Within Groups	3602847.619	186	19370.148		
	Total	3732114.286	188			
Fluoride	Between Groups	32.659	2	16.329	.366	.694
	Within Groups	8297.987	186	44.613		
	Total	8330.646	188			
Chloride	Between Groups	198698683.769	2	99349341.884	2.265	.107
	Within Groups	8160093616.877	186	43871471.058		
	Total	8358792300.646	188			
Nitrite	Between Groups	123122.045	2	61561.023	.870	.421
	Within Groups	13161751.078	186	70762.103		
	Total	13284873.124	188			
Sulfate	Between Groups	2307485.308	2	1153742.654	1.320	.270
	Within Groups	162594753.753	186	874165.343		
	Total	164902239.062	188			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Site Type

		Sum of Squares	df	Mean Square	F	Sig.
Bromide	Between Groups	2.959	2	1.479	.034	.967
	Within Groups	8097.287	186	43.534		
	Total	8100.246	188			
Nitrate	Between Groups	217893.366	2	108946.683	.855	.427
	Within Groups	23706518.207	186	127454.399		
	Total	23924411.572	188			
Phosphate	Between Groups	608.013	2	304.006	1.477	.231
	Within Groups	38295.949	186	205.892		
	Total	38903.962	188			
Total Coliforms	Between Groups	47245034.172	2	23622517.086	3.345	.037
	Within Groups	1313434745.505	186	7061477.126		
	Total	1360679779.677	188			
E. coli	Between Groups	2338696.376	2	1169348.188	1.705	.185
	Within Groups	127531498.941	186	685653.220		
	Total	129870195.317	188			
Enterococci	Between Groups	3770098.064	2	1885049.032	2.623	.075
	Within Groups	133696030.859	186	718795.865		
	Total	137466128.922	188			
Coliphages	Between Groups	.647	2	.323	.398	.672
	Within Groups	99.839	123	.812		
	Total	100.486	125			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Season

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	14564.936	3	4854.979	334.372	.000
	Within Groups	2686.143	185	14.520		
	Total	17251.079	188			
DO	Between Groups	712.605	3	237.535	53.323	.000
	Within Groups	824.107	185	4.455		
	Total	1536.712	188			
Cond	Between Groups	145184.405	3	48394.802	147.653	.000
	Within Groups	60635.820	185	327.761		
	Total	205820.225	188			
pH	Between Groups	6.315	3	2.105	42.775	.000
	Within Groups	9.104	185	.049		
	Total	15.418	188			
Turbidity	Between Groups	2245.589	3	748.530	2.418	.068
	Within Groups	57269.937	185	309.567		
	Total	59515.526	188			
Alkalinity	Between Groups	352.290	3	117.430	9.538	.000
	Within Groups	1058.832	86	12.312		
	Total	1411.122	89			
TOC	Between Groups	16.934	3	5.645	.566	.638
	Within Groups	1845.746	185	9.977		
	Total	1862.680	188			
DOC	Between Groups	22.223	3	7.408	9.879	.000
	Within Groups	138.722	185	.750		
	Total	160.945	188			
Ammonia	Between Groups	349169.524	3	116389.841	6.365	.000
	Within Groups	3382944.762	185	18286.188		
	Total	3732114.286	188			
Fluoride	Between Groups	2413.180	3	804.393	25.148	.000
	Within Groups	5917.466	185	31.986		
	Total	8330.646	188			
Chloride	Between Groups	87850874.431	3	29283624.810	.655	.581
	Within Groups	8270941426.215	185	44707791.493		
	Total	8358792300.646	188			
Nitrite	Between Groups	189855.213	3	63285.071	.894	.445
	Within Groups	13095017.911	185	70783.881		
	Total	13284873.124	188			
Sulfate	Between Groups	74270520.889	3	24756840.296	50.534	.000
	Within Groups	90631718.172	185	489901.179		
	Total	164902239.062	188			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Season

		Sum of Squares	df	Mean Square	F	Sig.
Bromide	Between Groups	89.130	3	29.710	.686	.562
	Within Groups	8011.115	185	43.303		
	Total	8100.246	188			
Nitrate	Between Groups	11311584.265	3	3770528.088	55.305	.000
	Within Groups	12612827.307	185	68177.445		
	Total	23924411.572	188			
Phosphate	Between Groups	1326.730	3	442.243	2.177	.092
	Within Groups	37577.232	185	203.120		
	Total	38903.962	188			
Total Coliforms	Between Groups	179605621.008	3	59868540.336	9.378	.000
	Within Groups	1181074158.669	185	6384184.641		
	Total	1360679779.677	188			
E. coli	Between Groups	1968440.703	3	656146.901	.949	.418
	Within Groups	127901754.614	185	691360.836		
	Total	129870195.317	188			
Enterococci	Between Groups	2210404.014	3	736801.338	1.008	.391
	Within Groups	135255724.909	185	731112.027		
	Total	137466128.922	188			
Coliphages	Between Groups	5.110	3	1.703	2.179	.094
	Within Groups	95.376	122	.782		
	Total	100.486	125			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Rainfall

		Sum of Squares	df	Mean Square	F	Sig.
Temp	Between Groups	2673.364	2	1336.682	17.055	.000
	Within Groups	14577.715	186	78.375		
	Total	17251.079	188			
DO	Between Groups	167.525	2	83.763	11.379	.000
	Within Groups	1369.187	186	7.361		
	Total	1536.712	188			
Cond	Between Groups	35685.142	2	17842.571	19.506	.000
	Within Groups	170135.083	186	914.705		
	Total	205820.225	188			
pH	Between Groups	4.683	2	2.342	40.573	.000
	Within Groups	10.735	186	.058		
	Total	15.418	188			
Turbidity	Between Groups	368.823	2	184.412	.580	.561
	Within Groups	59146.703	186	317.993		
	Total	59515.526	188			
Alkalinity	Between Groups	33.075	2	16.538	1.044	.356
	Within Groups	1378.047	87	15.840		
	Total	1411.122	89			
TOC	Between Groups	11.312	2	5.656	.568	.568
	Within Groups	1851.368	186	9.954		
	Total	1862.680	188			
DOC	Between Groups	6.465	2	3.233	3.892	.022
	Within Groups	154.480	186	.831		
	Total	160.945	188			
Ammonia	Between Groups	94116.793	2	47058.396	2.406	.093
	Within Groups	3637997.493	186	19559.126		
	Total	3732114.286	188			
Fluoride	Between Groups	986.768	2	493.384	12.496	.000
	Within Groups	7343.877	186	39.483		
	Total	8330.646	188			
Chloride	Between Groups	4838557.253	2	2419278.626	.054	.948
	Within Groups	8353953743.394	186	44913729.803		
	Total	8358792300.646	188			
Nitrite	Between Groups	160468.744	2	80234.372	1.137	.323
	Within Groups	13124404.380	186	70561.314		
	Total	13284873.124	188			
Sulfate	Between Groups	21529070.518	2	10764535.259	13.965	.000
	Within Groups	143373168.543	186	770823.487		
	Total	164902239.062	188			

Appendix B-4
ANOVA Excluding Site 6

ANOVA - Variance by Rainfall

		Sum of Squares	df	Mean Square	F	Sig.
Bromide	Between Groups	38.688	2	19.344	.446	.641
	Within Groups	8061.558	186	43.342		
	Total	8100.246	188			
Nitrate	Between Groups	2571415.338	2	1285707.669	11.199	.000
	Within Groups	21352996.234	186	114801.055		
	Total	23924411.572	188			
Phosphate	Between Groups	120.961	2	60.480	.290	.749
	Within Groups	38783.001	186	208.511		
	Total	38903.962	188			
Total Coliforms	Between Groups	183427619.362	2	91713809.681	14.490	.000
	Within Groups	1177252160.315	186	6329312.690		
	Total	1360679779.677	188			
E. coli	Between Groups	4638033.662	2	2319016.831	3.444	.034
	Within Groups	125232161.655	186	673291.192		
	Total	129870195.317	188			
Enterococci	Between Groups	3132605.181	2	1566302.591	2.169	.117
	Within Groups	134333523.741	186	722223.246		
	Total	137466128.922	188			
Coliphages	Between Groups	5.079	2	2.539	3.274	.041
	Within Groups	95.407	123	.776		
	Total	100.486	125			