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Georgetown Maine Water Quality Re-evaluation

University of New Hampshire Environmental Engineering Program

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Georgetown, Maine Water Quality Re-evaluation

Presented to the Georgetown, Maine Conservation Commission

Environmental Engineering Program
University of New Hampshire

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ABSTRACT

Seawater intrusion and septic contamination are two factors that can render a potable source of water undrinkable. The objectives of the study of Georgetown, Maine drinking water wells were to identify locations of seawater intrusion or septic contamination in the groundwater, compare current conditions to results found by Dr. Steve Mabee in 1989, compare results to Maine drinking water standards and to create GIS maps from data collected that will be given to Georgetown for future use. Nineteen wells were evaluated for seawater intrusion and septic contamination. Analysis for seawater intrusion was conducted by comparing the ratio of sodium to chloride and sulfate to chloride in the samples, resulting in the identification of two seawater intruded wells. Additionally, positive tests for E. coli bacteria in two different wells confirmed possible fecal contamination. Pump tests were performed to analyze the localized geology and attempt to obtain an estimate of well yield. Six wells were analyzed with a pump test and well yields of those ranged from 1.12-6.27 gallons per minute (gpm).

Further research should be conducted by a future University of New Hampshire senior project group. The sampling plan should occur in multiple seasons over a larger distribution of the island, as well as more overlap with the wells sampled in 1989. In addition, wells sampled in 2012 should also be sampled by next year's group.

To better identify septic contamination, the source of E. coli should be determined. Analysis for ammonia should be conducted to aid in the identification of septic contamination in wells. Pump tests may not provide relevant information, because pump tests of individual wells only provide localized information and cannot be extrapolated to the entire aquifer.

University Of New Hampshire
Environmental Engineering Program

Special thanks to:

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I. Introduction

Historically, human civilization has been based around easily accessible sources of clean drinking water (i.e., surface water). As technology progressed, it became possible to pump potable water from underground aquifers deep below the surface. Wells are drilled into the bedrock and are supplied water from fractures. Typically, 100 feet to 500 feet deep, bedrock wells can yield a wide range of flows from very low (≤2 gpm) to very high (15-20 gpm). Yield is determined by the number and sizes of the fractures in the bedrock. Higher yield means better interconnection among fractures and a large number or size of fractures, which can also mean more links to the surface. Groundwater is treated by the natural biological and physical filtering processed that the underlying soil and bedrock provide.

Unlike public water supplies, private wells are not regulated by local, state, or federal authority. There are regulations regarding the installation of wells, but monetary water quality and any treatment is at the discretion of the well owner. Some people with wells have treatment processes installed such as ion exchange, granular activated carbon, filtering, and others. These systems can be used to remove silt, hardness, or other constituents such as iron, nitrates, or hydrogen sulfide. These constituents can stain clothing, have adverse taste, or have health effects that are undesirable.

A. Location

Georgetown, Maine is an island located on the coast of Maine in Sagadahoc County, near the City of Bath. The island is connected to the main land by the Route 127 bridge that allows access by motor vehicle. It lies between the mouth of the Sheepscot and Kennebec Rivers. Georgetown has been inhabited twice; the first time from 1649-1689 when it was abandoned after several Native American attacks. It was then resettled in 1713. The town has an area of approximately 32 square miles, of which approximately 41% is water. According to 2010 census data, there were 1020 people living in 441 households on the island with a population density of about 54.4 people per square mile. Like most of southern Maine, the island has a large summer population and attracts tourists, which greatly increases the population, primarily in July and August. The island includes the villages of Five Islands, Georgetown, Marrtown, West Georgetown, Bay Point, and Robinhood. Reid State Park and several conservation lands are also present.

B. Seawater Intrusion and Septic Contamination

The freshwater aquifers on Georgetown are separated from the ocean by physical and chemical barriers. The aquifers on the island are furnished by surface water runoff which flows downhill, from the highest points to the lowest points on the island, both above and below ground. The physical pressure of the freshwater flowing against the sea current creates a boundary that limits the mixing of the two waters. Additionally, freshwater is less dense, and floats on top of seawater.

Seawater intrusion into the freshwater aquifer can be detrimental. In high concentrations, seawater is non-potable and not fit for human consumption. The ions in seawater also create issues for household plumbing. Seawater intrusion in a well occurs demand exceeds the rate at which the freshwater can flow into the well. When this occurs, seawater is able to enter the freshwater aquifer and can contaminate the well. This can be caused by several factors, the foremost including drought and high demand. Two indicators of seawater intrusion were used in this study: sodium to chloride and sulfate to chloride rates, based on their abundance in seawater.

Although the quality of household water supplies is not monitored by state or federal agencies, there are guidelines and regulations regarding the installation of such wells. For example, the Maine Department of Human Services recommends distances between a well and a septic system to be at least 100 feet apart to avoid contamination. There are several indicators of septic contamination in drinking water including nitrates, total coliform bacteria and fecal coliform bacteria.

The presence of nitrates may indicate septic contamination due to the breakdown of ammonia (NH_3) which is present in urine. Ammonia, in the presence of nitrifying bacteria and oxygen, breaks down into nitrite and nitrate. Nitrate can also be caused from sources such as fertilizers or erosion of natural deposits. Total coliforms are bacteria which are naturally occurring in the environment. There are two types of coliforms, non-fecal which can be found in the soil and vegetation, and fecal coliforms which are found in the guts of warm blooded animals (eg., bird and mammal).

C. Research by Dr. Steve Mabee

In the late 1980s, Maine was experiencing a large influx of population to the lakes and coastal regions. This led to a higher demand for potable water and a greater stress on the state's bedrock aquifers. In 1991, the Maine Geological Survey reported between 2000 and 5000 new bedrock wells drilled every year (Mabee, 1989).

Dr. Mabee's dissertation research used the physical characteristics of the Georgetown bedrock aquifers (fractures, or lineaments) to predict zones of high water yield. He used aerial photography, physical testing, and chemical analysis of well water to map the fractures and lineaments running through the aquifer. He theorized that the wells connected to fractures with higher permeability had different chemistry than those surrounding because of the shortened contact time the water had with the local bedrock. Although he collected water quality data on the 82 wells he sampled, the chemical analysis was not the primary focus of his dissertation.

Dr. Mabee concluded that Georgetown is divided along an axis running NNE-SSW by a deep bedrock valley. Much of this rift is below sea level and effectively separates the island into two different "hydrogeologic units" (Mabee, 1989). In 1989, the average annual rainfall was approximately 41 inches, of which 50% flowed overland and 30-40% was evapotranspired. The remaining 10-15% was recharged into the groundwater (Mabee, 1989).

All of the potable water on Georgetown comes from wells, of which nearly 75% are drilled into bedrock; the remaining 25% are dug wells. Bedrock wells are dependent upon the physical features in the bedrock, such as fractures, lineaments and veins to provide water. There are four distinct aquifers on Georgetown which appear to operate independently of each other. The wells are generally six inches in diameter and were air rotary percussion or cable tool drilled. Around 75% of the wells have a yield of 2 gpm or greater, while 28% have a yield of 10 gpm or greater. The majority of the bedrock wells are between 100 and 200 feet deep, and the water table is within 15 to 20 feet of the ground surface (Mabee, 1989).

In order to gauge the effect that the location of lineaments has on well productivity, Mabee conducted pump tests of 60 wells. Each pump test lasted 20 minutes long, during which the water levels were measured within the well casing. While short term pumping could not sufficiently stress the aquifer to specifically located lineaments, he believed it would be evident if wells were closer to a higher transmissivity area (Mabee, 1989). While proximity of a well to surface water was not be a major influence on productivity, the topography of the area had significant influence as did the bedrock and soil type (Mabee, 1989).

Dr. Mabee used the chemical composition of 105 domestic wells to study the differences in water quality as a function of distance from a lineament. He assumed lineament wells would have different chemistry because of the shortened contact time between the water and bedrock and the greater connection to other groundwater sources. However, Dr. Mabee's data indicated little difference in water quality between lineament and non-lineament wells. Once again, the yield data, bedrock and soil type influenced water chemistry. Mabee found that for the Georgetown wells, there is little geochemical evidence that location of a well with respect to a lineament enhances productivity. For example, sulfate, which shows a strong positive correlation with well productivity, showed no correlation with proximity to lineaments (Mabee, 1989). His data also show that the bedrock type and contact area (fracture wall area) affect groundwater quality more than residence time or flow rate (Mabee, 1989).

In his chemical analysis, Dr. Mabee identified wells afflicted by possible road salt or seawater intrusion by plotting Na:Cl ratios versus chloride. "All wells within 100 meters of any salted roadway with a Na:Cl ratio of 0.65 ± 20% ...and chloride concentration of >10mg/l were considered contaminated and removed from the water quality data base..." (Mabee, 1989). This was also done with wells within 100m of the shoreline with a ratio of 0.56±20% to determine possible seawater intrusion (Figure 1).

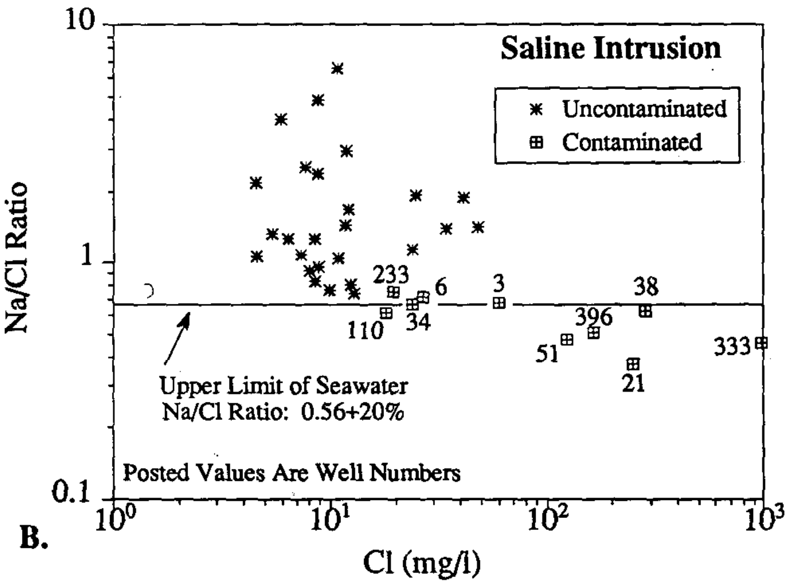


Figure 1. Na:Cl ratios versus Cl concentrations from 1989. Wells identified as contaminated were eliminated from Dr. Mabee's data base.

Mean values for sodium, magnesium, and chloride were very high compared to water from similar rock formations in non-saline environments. This may have been due to the location and physical characteristics of the island. Several factors, including pH, sodium, manganese, and potassium, had lower concentrations in wells closer (<30m) to mapped lineaments than in those further away. However, this was not related to the well productivity, suggesting that the chemical signature of the water was more dependent on flow path and length and not necessarily to well productivity. However, low productivity did not necessarily imply longer residence times; it could be fed by a smaller fracture network (Mabee, 1989).

Further investigation of the relationship between transmissivity and geochemistry was conducted by comparing the wells with the highest and lowest transmissivities, with the rationale being that the extremes would demonstrate more significant differences. This held true for chloride, manganese and sulfate, where higher transmissivity wells contained higher concentrations of these constituents. However, these levels could also be explained by their proximity to salted roadways. Two wells did fit the sodium to chloride ratio of road salt, one of which was a positive result for seawater intrusion.

The results from the geochemical analysis suggest that water quality is greatly affected by the composition of the overburden (covering over the bedrock) as well as the bedrock type. Higher chloride levels were found where there was a thinner silt/clay overburden. Mabee proposed that marine aerosols affected groundwater recharge especially on shorelines with high wave activity (Mabee, 1989). He noted that without further analysis and testing it was difficult to draw any conclusions as to the relationship between chemical signature and lineament versus non lineament wells.

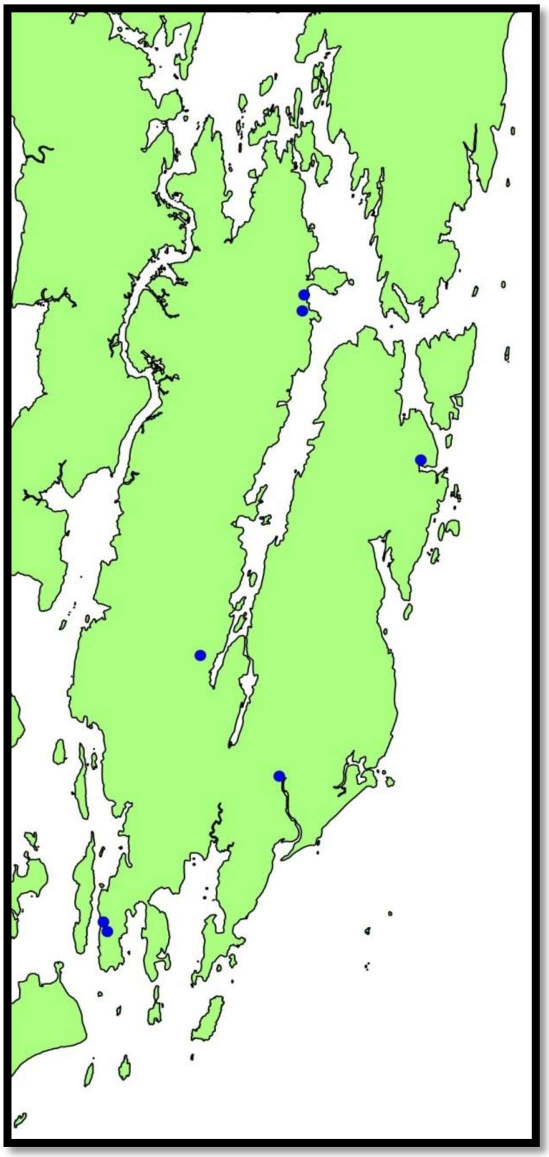
There are several sections of Dr. Mabee's data collection and conclusions that directly relate to the 2012 Georgetown well study. Wells within 100m of salted roadway with a Na:Cl ratio of $0.65 \pm 20\%$ or with Cl concentrations >10mg/L were assumed to be contaminated by road salt.

Mabee also concluded that short pump tests were effective at showing the transmissivity of the bedrock and overburden directly adjacent to the wells. However, actual aquifer characteristics could not be calculated or quantified using the pump test data.

II. Methods

A. Pump Tests

Six pump tests were conducted to determine the yield and recharge capabilities of the aquifer in immediate proximity to the well. Pump tests were performed to compare the aquifer capacity to that of 1989; the recharge rate of the aquifer could potentially aid in the identification of seawater intrusion or septic contamination.



Blue markers indicate where well yields were taken

To perform the pump tests, the initial water level was measured using a sounder (Model 101, Solinst, Georgetown, Ontario). A faucet was run for 10 minutes; each minute, the water level was measured as well as for 3 minutes after the test ended. During the pump test, the pressure tank gauge was observed; the time at which the pump went on and off was recorded. The capacity of the storage tank was also noted. Using all of these factors and a simple mass balance, the flow, in gpm could be determined.

B. Onsite Water Quality Parameters

Four water quality parameters were determined onsite, including: pH, specific conductivity, temperature and dissolved oxygen.

pH and Specific Conductivity

pH was analyzed using a probe **(model #, mnfct, city, state).** A measurement was taken once the pH value stabilized meaning the pH reading remained constant.

Dissolved Oxygen

The dissolved oxygen concentrations were determined using the (K7501 Oxygen CHEMets Kit, CHEMetrics, Calverton, Virginia) indigo carmine method. The oxygen in the water sample oxidizes the yellow-green colored leuco form of indigo carmine to form a blue dye. The blue color is proportional to the initial dissolved oxygen concentration. To determine the concentration, the ampule containing sample, unexposed to the atmosphere, is held next to the comparator to find the best color match. The comparator consists of a blue color gradient of tubes representing dissolved oxygen concentrations of 1 to 12 parts per million (ppm).

C. Water Quality Parameters Analyzed in the Laboratory

Nitrate, sulfate and phosphate were analyzing used a Hach photosphectrometer (DR 2400, Hach, Loveland, Colorado). Using powder pillows provided by Hach, the three constituents were measured. Chloride was also analyzed in the laboratory using manual titration.

1. Nitrate

Nitrate as nitrogen was analyzed by the cadmium reduction method. This method applies to water, wastewater and seawater. The applicable concentration range is 0.1 to 10 mg/L as N. The cadmium reduction method required a one minute shake time after the NitraVer 5 pillow packet (Hach 8171) was added to a 10 mL sample. A five minute reaction time must occur before the intensity of the color developed can be read. An amber color after the five minute reaction time indicates the presence of nitrate. Results can be reliably read within 24 hours, if stored at 4°C.

2. Sulfate

The USEPA SulfaVer 4 Method (Hach 8051) was adapted from *Standard Methods for the Examination of Water and Wastewater*. This method is applicable for water, wastewater and seawater. The applicable concentration range is 2 to 70 mg/L as SO_4^{2-}. After the addition of a SulfaVer pillow packet, the 10 mL sample is swirled before a 5 min reaction occurs. A milky white turbidity will form if sulfate is present. Samples analyzed for sulfate can be held for up to seven days at 4°C.

3. Phosphate

Reactive orthophosphate in the water was measured using the PhosVer 3 Ascorbic Acid Method (Hach 8048). This method is applicable for water, wastewater and seawater. The applicable concentration range is 0.02 to 2.50 mg/L as PO_4^{-3}. This method requires a 30 sec vigorous shake time after pillow packet addition and then a 2 min reaction time. Phosphate is present if the sample becomes very blue. The method suggests that samples be collected in a sample bottle rinsed with 1:1 Hydrochloric Acid Solution and deionized water. Hydrochloric acid was not available, so sample bottles were rinsed with 1:1 Nitric Acid and deionized water. Samples should be analyzed immediately for best results, but can be stored for 48 hours at 4°C if filtered.

4. Chloride

The Chloride Model 8-P test kit (Hach 1140-01) requires a manual titration for high range chloride concentrations (0 to 400 mg/L as Cl^-) and low range chloride concentrations (0 to 100 mg/L as Cl^-). For the low range test, 23 mL of sample is added to the mixing bottle. If the high range test is used, approximately 7 mL of sample is added to the mixing bottle (a measuring tube is provided for exact measurement). A chloride 2 indicator powder pillow is added to the sample and swirled. Silver nitrate is then added dropwise and swirled to obtain the chloride concentration. The equilibrium point is met when the water changes from yellow to orange, indicating the concentration in the sample. The number of drops must be multiplied by either 5 or 20 for low and high ranges, respectively.

5. *E. coli* and Total Coliform Bacteria

The Modified Colitag (Product 8888005, Hach, Loveland, Colorado) procedure detects presence or absence of total coliform bacteria and *E. coli* in drinking water. This method is approved by the USEPA for use under the Total Coliform Rule and Groundwater Rule. 100 mL of sample were collected in a sterile bottle and the Modified Colitag media was added. The sample bottle was then incubated for 16 to 48 hours at 35 °C ± 0.5 °C. The sample color is compared to standard provided by Hach. If the color is of equal or greater gradient of yellow, the sample is positive for total coliform bacteria. To detect *E. coli*, a long-wavelength (365 nm) UV lamp is used to examine the sample for fluorescence. If bright blue fluorescence occurs, *E. coli* is present.

D. Water Quality Parameters Analyzed Using ICP-AES

ICP- AES is an abbreviation for inductively coupled plasma atomic emission spectroscopy. The ICP-AES technique detects a wide array of ions in water. It is based upon exciting electrons that emit energy at given wavelengths as they return to their ground state. Each element (e.g., iron, chloride) has a specific wavelength, allowing the identification of a chemical based upon their emission. The elements of interest in this study were Sodium (Na^+), Iron (Fe) and Manganese (Mn). The detection limits for sodium, iron, and manganese are 0.01mg/L, 0.001mg/L, and 0.00008mg/L, respectively. Other ions of interest included: calcium, copper, arsenic and aluminum. Calcium is a component of water hardness, has a detectable limit of 0.0009 mg/L. Copper, arsenic and aluminum are metals of concern in drinking water where detectable limits are 0.0007, 0.013836 and 0.002285 mg/L, respectively. It is important to note that the detectable limit for arsenic is above the regulatory limit of 0.01 mg/L.

E. Total Organic Carbon Analysis

Total organic carbon was measured using high temperature combustion (TOC-V, Shimadzu, Columbia, Maryland). The sample was acidifed with 2 mL of sulfuric acid before injection into the machine. All carbon present in the sample was converted into carbon dioxide. The amount of carbon dioxide emitted is detected and converted into mg/L of organic carbon. The lowest detectable limit is 0.6 mg/L. Total organic samples that have been acidifed have extremely long hold times.

F. Quality Assurance and Quality Control

To ensure the integrity of the results, proper quality assurance and quality control (QA/QC) procedures were followed. Replicate samples were taken for each analyte at every testing location. Laboratory blanks, composed of reverse osmosis water, were analyzed to determine laboratory cleanliness and the laboratory water background concentrations. In the analysis, the laboratory water was free of ions that were being analyzed. Trip blanks, reverse osmosis laboratory water sample taken out in the field, were analyzed to determine any contamination during traveling. There was found to be no contamination during work in the field.

When using the Hach Photospectrometer, a set of standards was analyzed before any samples were run to ensure proper machine calibration. The concentrations of standards run for each analyte were specified by the procedure specific to the analyte (APPENDIX LETTER). The only exception to the procedure was phosphate, because there was only one laboratory stock solution available. Once standards were run, a known concentration of standard solution was spiked into a sample to determine the percent recovery. Spiked samples were analyzed to determine the machine's accuracy and precision.

G. Maine Drinking Water Standards

Maine uses the primary and secondary EPA drinking water standards, also known as maximum contaminant levels (MCLs). Primary MCLs are implemented to protect public health and are federally enforceable for municipal water supplies. Although, household wells are not regulated, nitrate, E. coli and total coliform bacteria all have primary MCL's. Secondary MCLs are reasonable goals to protect aesthetic water quality, such as taste, odor and color. The standards are not federally enforceable. Chloride, sulfate, iron and manganese all have secondary MCLs. Sodium is neither a primary nor a secondary MCL, although it is recommended that persons with heart conditions do not consume drinking water with a concentration exceeding 80 mg/L.

Contaminant	Regulatory Limit
Nitrate (MCL)	10 mg/L as Nitrogen
E. Coli (MCL)	Positive result requires corrective action
Total coliform bacteria (MCL)	Positives must be less than 5% of total groundwater samples
Chloride	250 mg/L as Chloride
Sulfate	250 mg/L as Sulfate
Iron	0.3 mg/L as Total Fe
Manganese	0.05 mg/L as Total Mn

III. Results

Municipal water sources are regulated under EPA drinking water standards which consist of primary and secondary Maximum Contaminant Levels (MCLs). Primary MCLs protect public health, and secondary MCLs are aesthetic parameters that are good goals for water quality. The EPA primary MCLs that were tested for are as follows:

Inorganic Chemicals:

Arsenic	0.01 mg/L
Barium	2.0 mg/L
Cadmium	0.005 mg/L
Chromium	0.1 mg/L
Copper	1.3 mg/L
Lead	0.015 mg/L
Selenium	0.05 mg/L

Microorganisms

Total Coliforms	5.0% of tests positive in 1 month*
E. coli	Positive test

*if fewer than 40 samples are taken in a month, any positive sample must be resampled, and if that should test positive, the water is considered in violation.

Secondary MCLs:

Aluminum	0.2 mg/L
Chloride	250 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
pH	6.5-8.5
Sulfate	250 mg/L
Zinc	5.0 mg/L

Results for the inorganic chemicals were largely either below primary MCLs or below detection levels. There were some cases where constituents that we tested for had MCLs below the detection levels of the ICP-AES. Several wells were high for chloride, iron, manganese, and aluminum, all secondary MCLs; high concentrations of chloride, iron and manganese can be seen in figures 2,3 and 4, respectively.

Sixteen maps of Georgetown were created to compare individual parameters; a map was generated for each parameter relevant to the study. The maps were created using an Open Source Geographic Information System (QuantumGIS). The maps show the spatial relationship of the concentrations of calcium, chloride, coliform, *E. coli*, iron, manganese, nitrate, phosphate, sodium, sulfate, and total organic carbon. The remaining maps include: Dr. Steve Mabee's seawater intrusion results, pH, specific conductance, the ratio of sodium to chloride, and the ratio of sulfate to chloride.

Maps with four legend items are annotated to indicate locations where the water quality standard was exceeded. Maps with just three legend items are non-regulated and are simply divided evenly among the results. Additional maps created can be found in Appendix A. While sodium is not regulated, concentrations were shown relative to the 80 mg/l known to be important for individuals with heart disease (Robin Collins, University of New Hampshire).

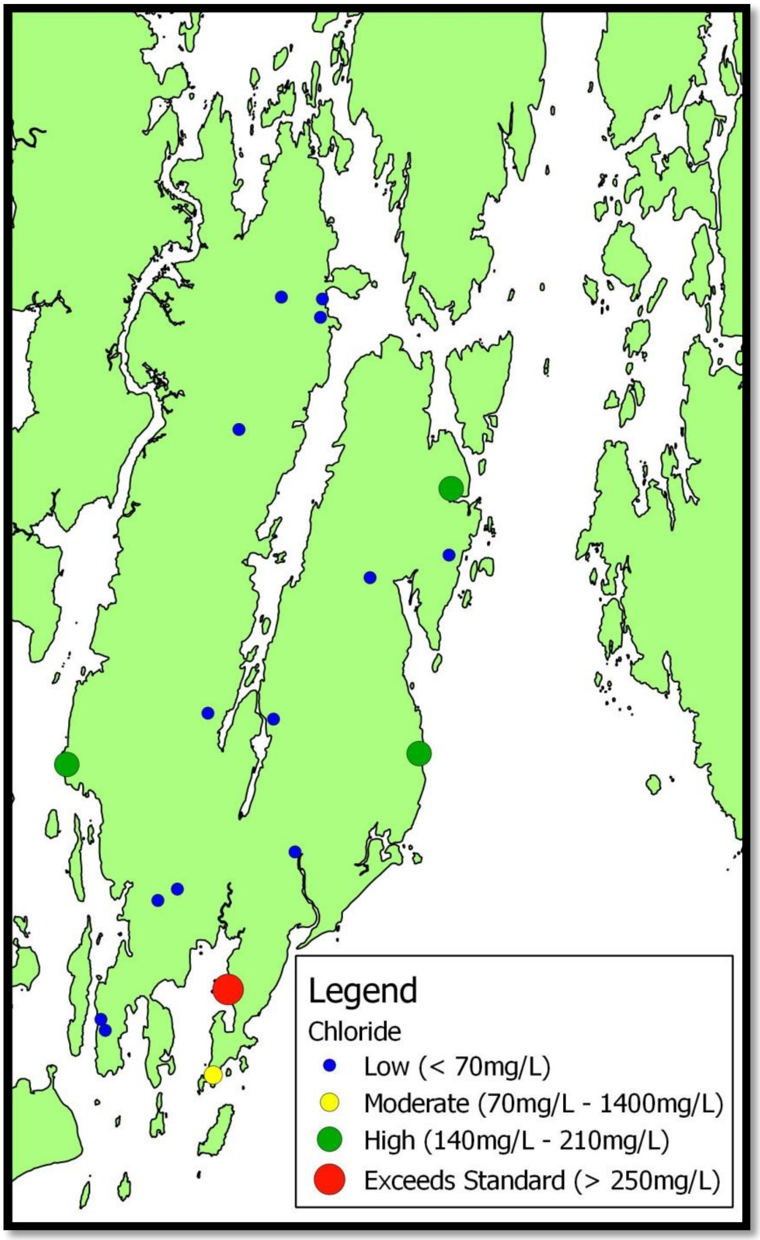


Figure 2: Chloride concentrations at locations in Georgetown

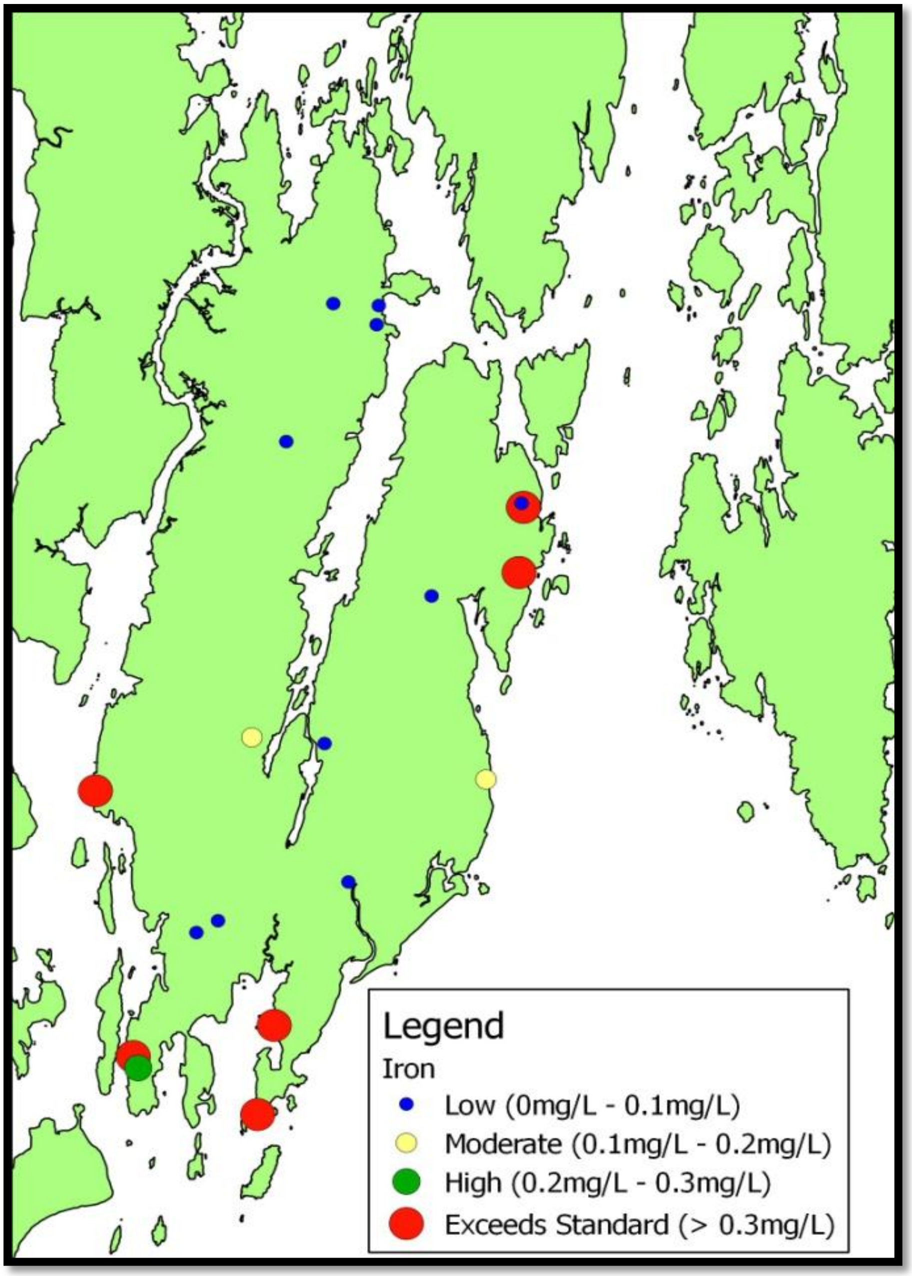


Figure 3:Iron concentrations at locations in Georgetown

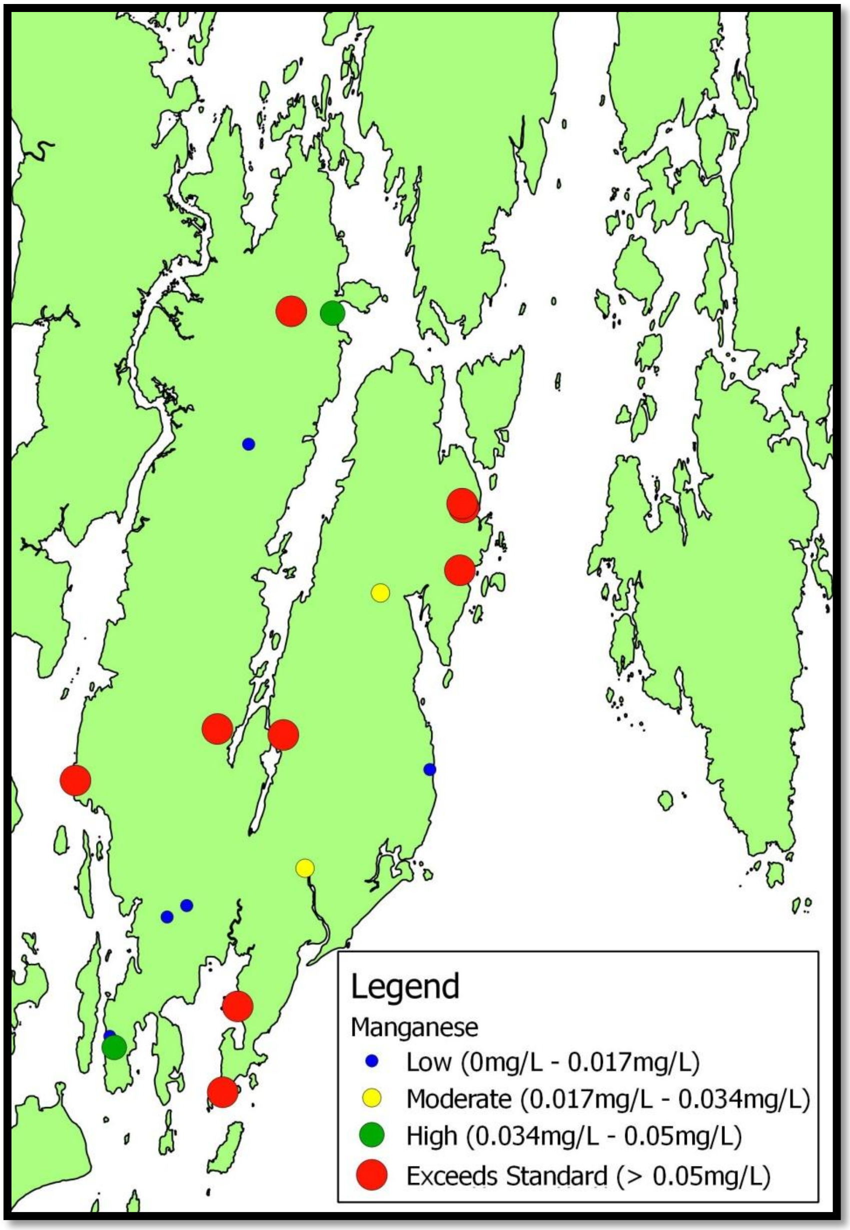


Figure 4: Manganese concentrations at locations in Georgetown

Chloride was the leading indicator for seawater intrusion in this study. Out of the wells tested, only one was in violation of the secondary MCL of 250 mg/L. Three other wells approached this MCL but did not exceed. In addition to chloride, sodium was also looked at as a seawater indicator. There were no standards for sodium but it is recommended that individuals with a heart condition avoid water with a concentration of 80 mg/L or greater. There were five wells that exceeded this recommendation, and two that were over 250 mg/L. Sulfate was another seawater intrusion indicator. No wells exceeded the MCL for sulfate and none approached the 250 mg/L mark (Figure 5).

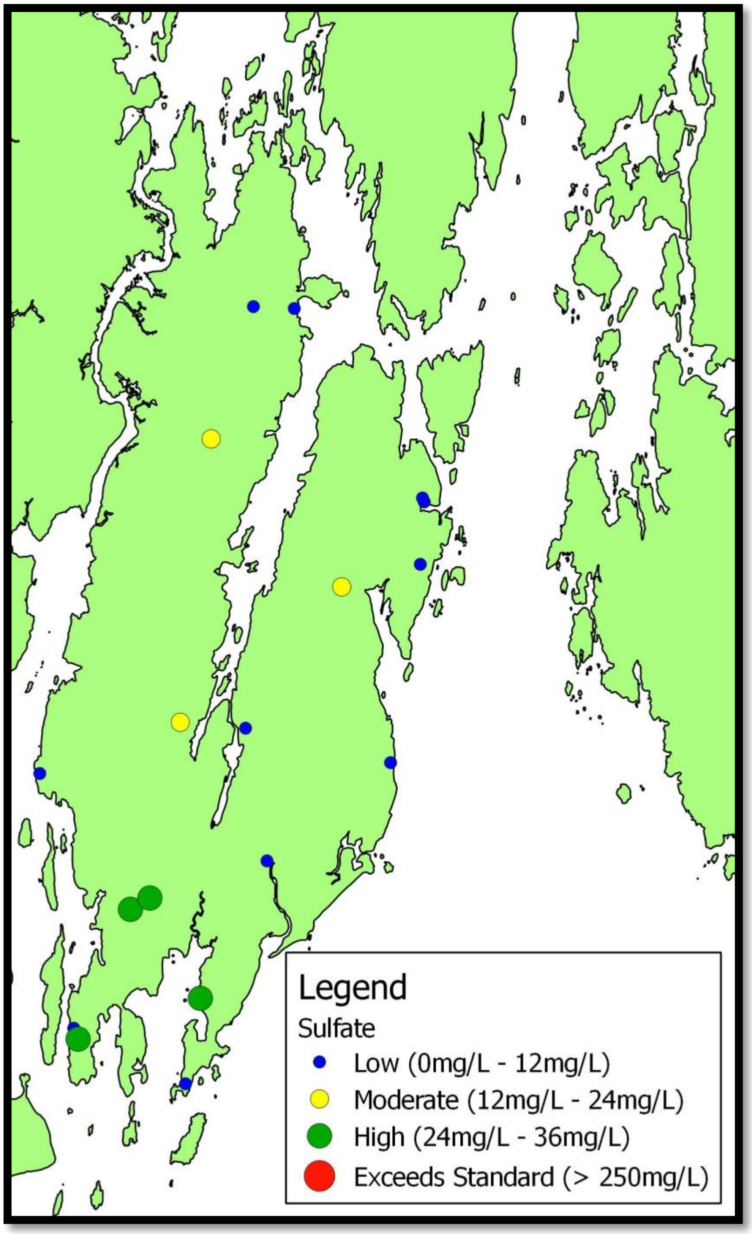


Figure 5: Sulfate concentrations at locations in Georgetown

The ratio of sodium:chloride and sulfate:chloride was studied to indicate possible seawater intrusion. In the ocean, the ratio of sodium:chloride is 0.56 +/- 20% and the ratio of sulfate:chloride is 0.1395 +/-10%. Sulfate:chloride had one possible positive for seawater intrusion (Figure 6), and sodium:chloride (Figure 7) also had a positive result, however these did not overlap. The sulfate:chloride point did correspond to a point Mabee highlighted for seawater intrusion (Figure 8).

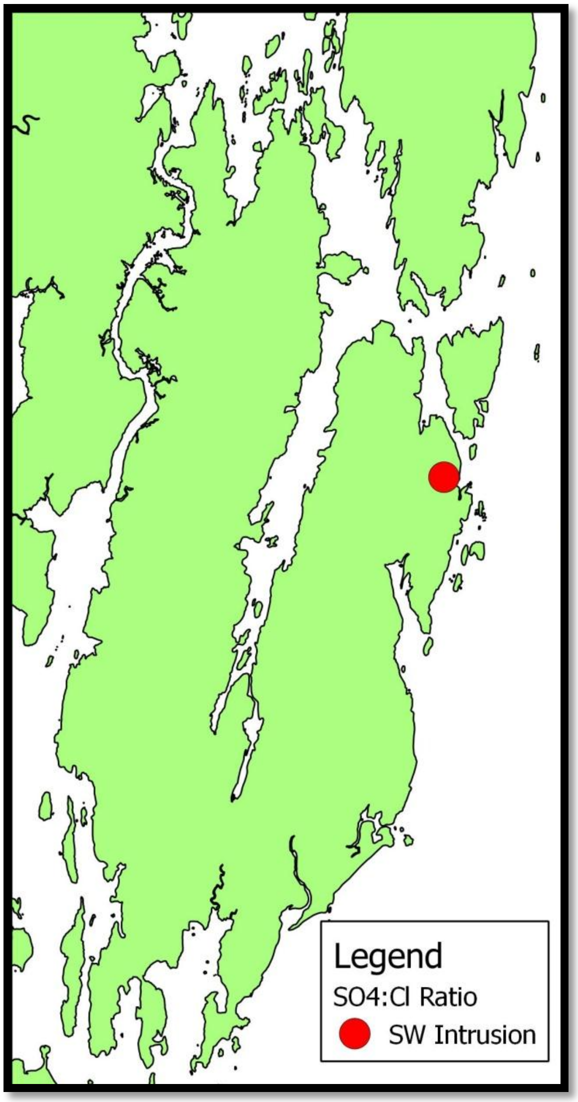


Figure 6: Sulfate to chloride concentrations at locations in Georgetown

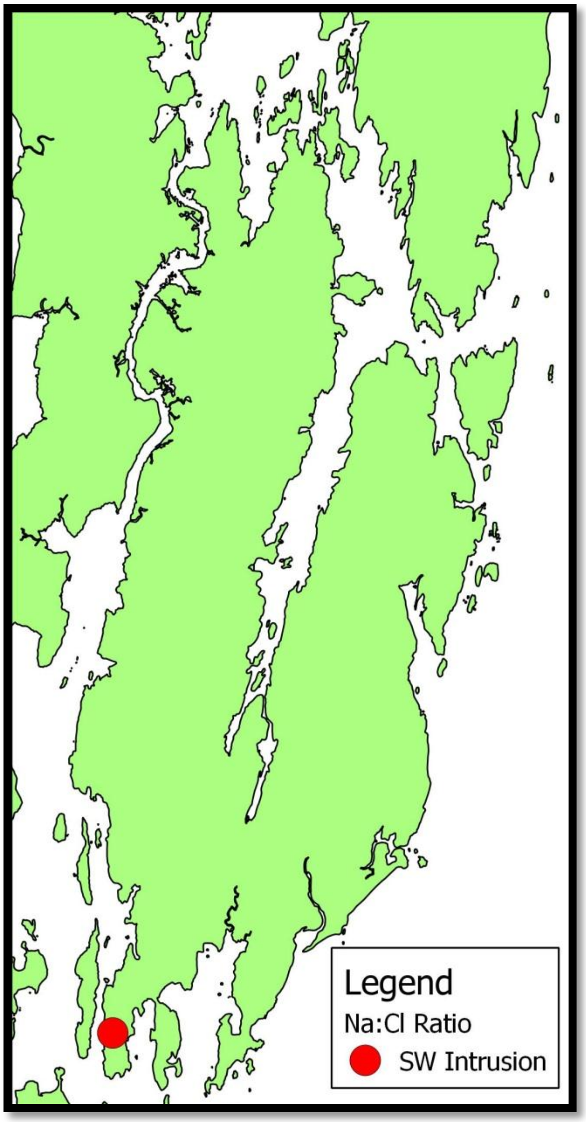


Figure 7: Sodium to chloride concentrations at locations in Georgetown

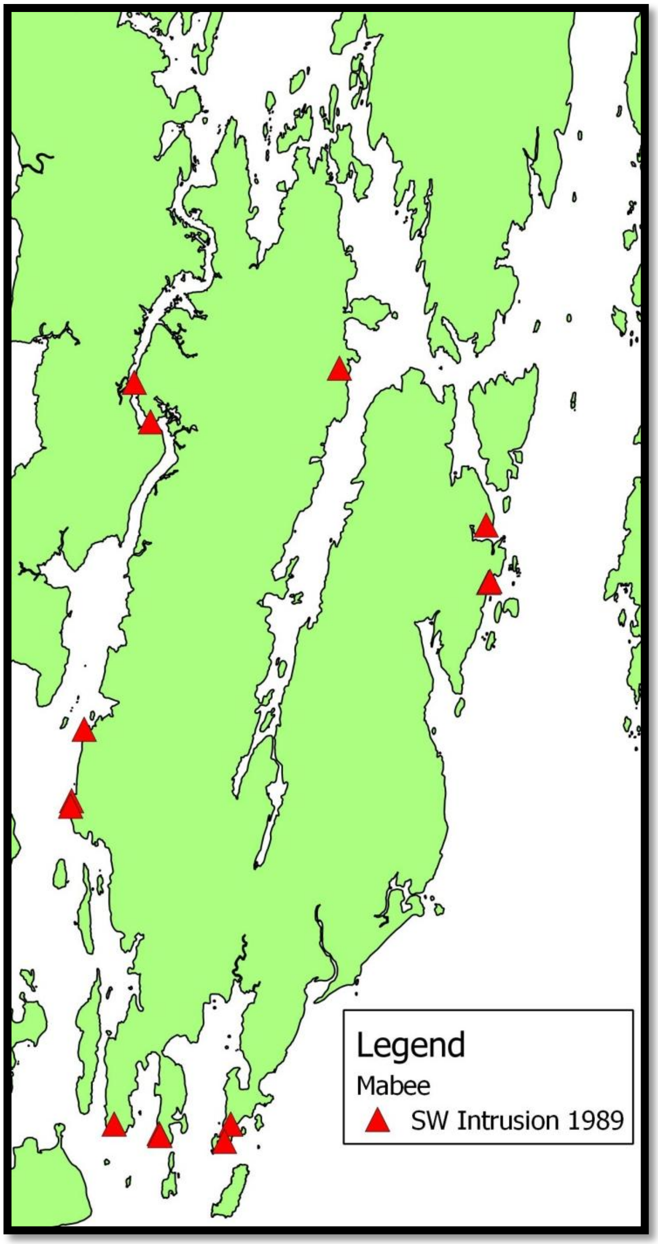


Figure 8: Seawater intrusion locations found by Mabee, 1989

Coliforms were the leading indicator for septic contamination in this study. Six wells were positive for total coliforms and two wells were inconclusive (Figure9). These were additionally analyzed for *E. coli* presence, for which two wells did test positive (Figure 10). In addition to coliforms, nitrate was used as an indicator for septic contamination. No wells approached the 10 mg/L MCL and the highest concentration was less than 3.0 mg/L (Figure 11). This positive did correspond to a positive for total coliforms and *E. coli*.

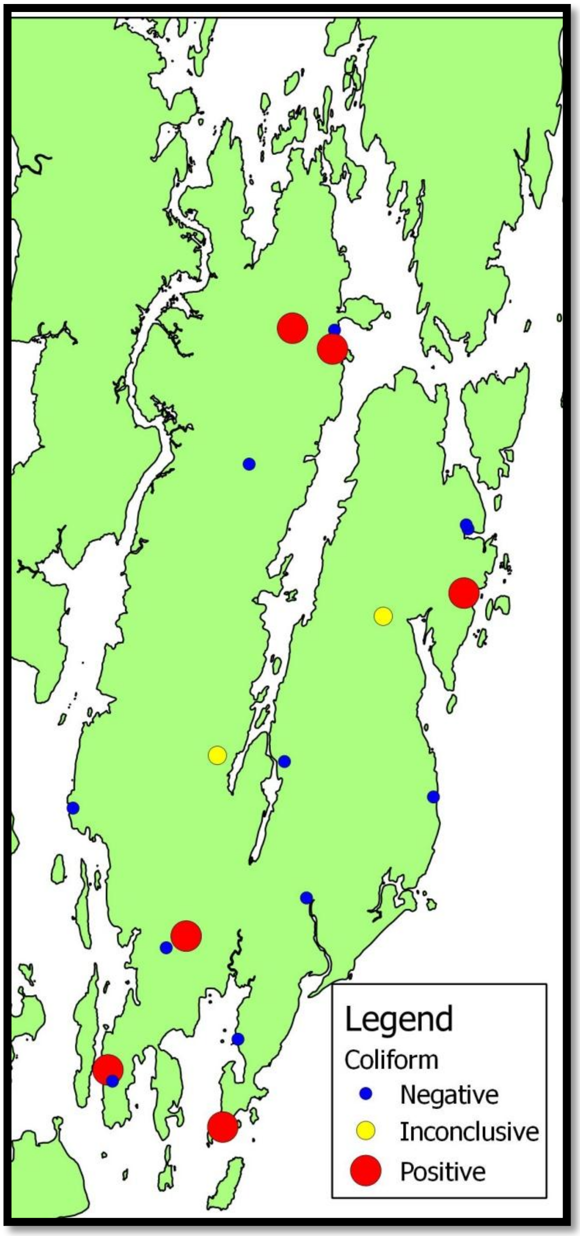


Figure 9:Coliform presence/ absence at locations in Georgetown

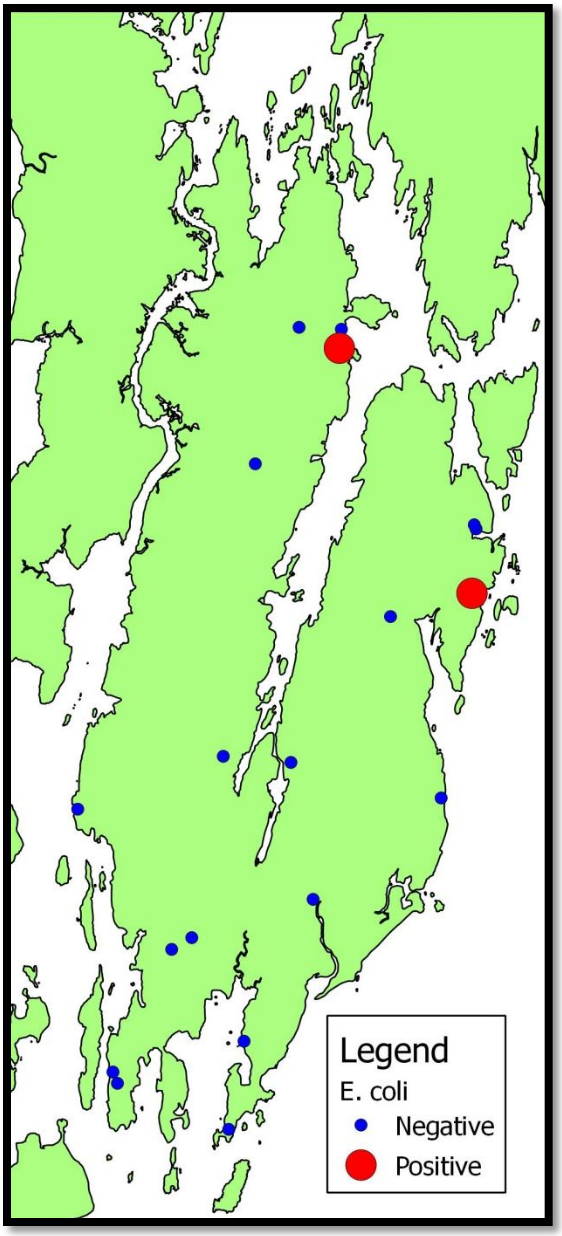


Figure 10: E. coli presence/ absence at locations in Georgetown

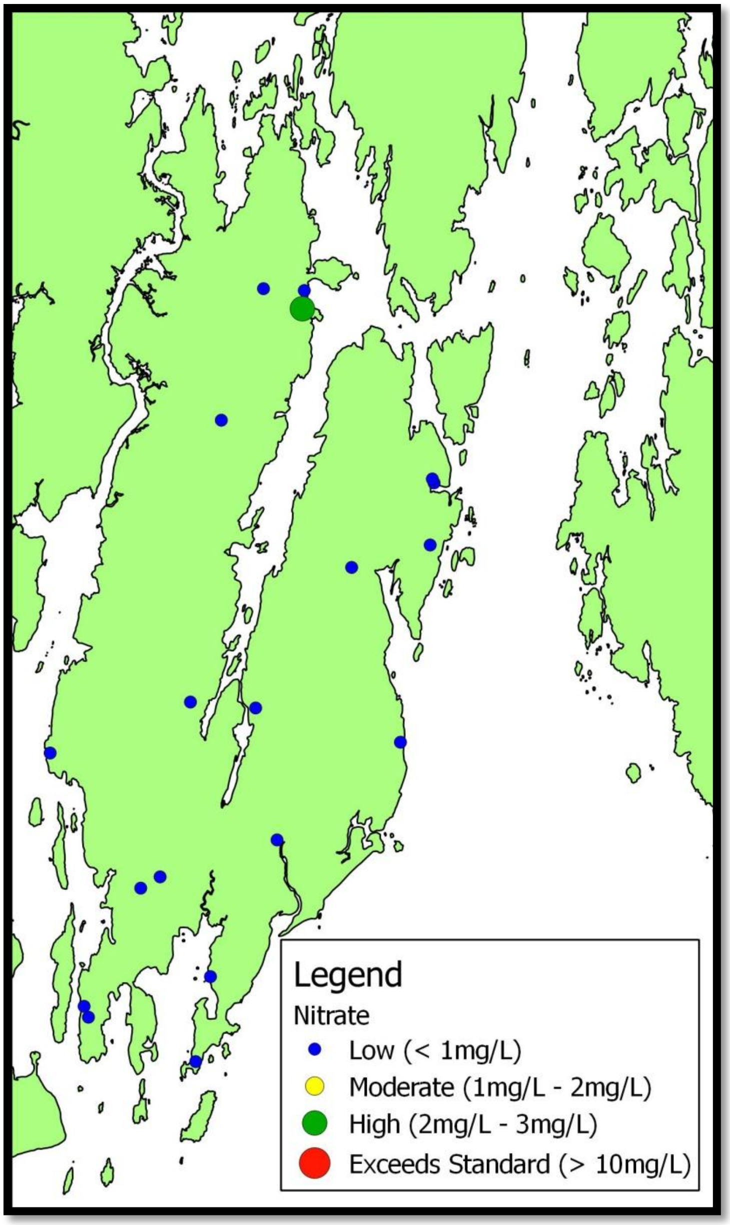


Figure 11: Nitrate concentrations at locations in Georgetown

Chemical composition of groundwater can be influenced by numerous factors including water table level, bedrock and overburden characteristics, precipitation, season, water demand, and weather. Of the 19 wells tested in 2012, only five had been previously tested in 1989 and could be compared to the current data. Changes in nitrate, sulfate, phosphate, and chloride were analyzed for significance using a Students t-test. The 2012 data had multiple data points, for each concentration which made it possible to use the mean and standard deviation of each constituent in comparison to the original single point 1989 data.

One problem arose when comparing the results to the previous values. Dr, Mabee may have used a different chemical analysis which was not specified in his report. It is possible that this accounts for variation in the data.

Nitrate was seen as a possible indicator for septic intrusion, but it was not a conclusive test. Nitrate levels can also be elevated from crop fertilization and natural sources. The regulations for nitrate in drinking water are 10 mg/L of nitrate-nitrogen. Nitrate exists for long periods of time in groundwater systems, but the presence of poorly drained soils or heavily wooded areas can reduce the concentrations of nitrate being transported into the aquifer (Nolan et al 1988). Additionally, these wells were tested in late February/early March and the precipitation, season, and water demand on the island may influence these concentrations as well.

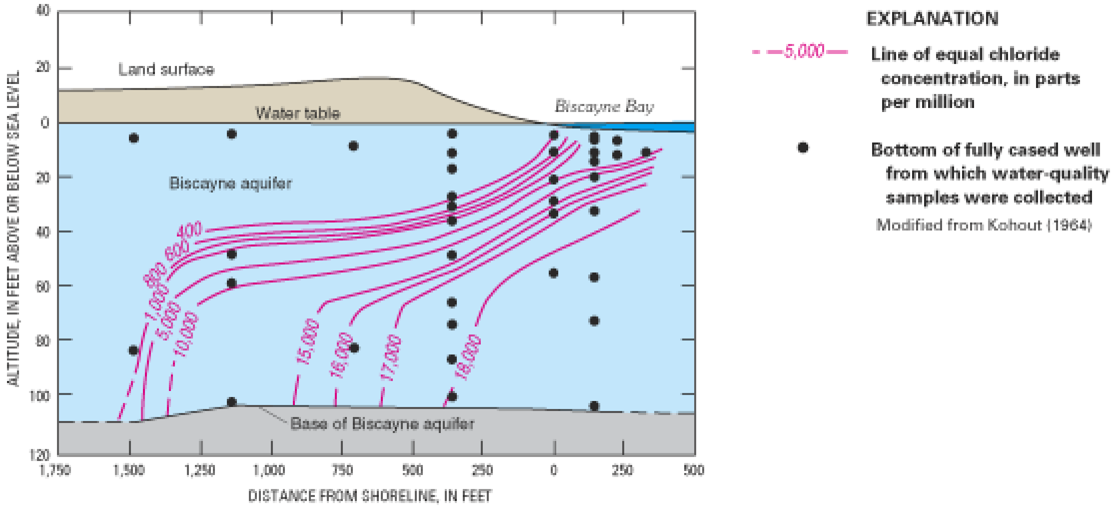
Sulfate and chloride levels both had significant change for the five wells with the 1989 data. The majority of the 5 wells showed a decrease in sulfate levels and increases in chloride. These constituents have an EPA secondary standard of 250 mg/L each, of which none of these five wells surpassed. These two constituents are also a possible indicator of seawater intrusion. Seawater contains a ratio of about 0.1395 SO_4:Cl, and when the results were evaluated for this ratio ±10%, well #99 was calculated to be positive for possible seawater contamination. Due to its proximity to the water and location in the Five Islands area, it is conceivable that there is some contamination occurring from the surrounding seawater. However, not all positives for seawater contamination necessarily equate to seawater in the aquifer. Wave action can cause dissolved constituents such as sulfate, chloride, and sodium to volatilize and be deposited into the soil via the air/soil interaction. Infiltration of surface water and precipitation can then carry these into the area of the well creating positive seawater characteristics without any real intrusion occurring.

Another ratio used to analyze for possible seawater contamination was an Na:Cl ratio of 0.56 ±20%. This is the approximate ratio of Na:Cl in seawater, so the presence of sodium and chloride in this ratio could be an indicator of seawater in the well. Only one well of the

19 tested came back positive for seawater intrusion with this ratio, but there was no correlation to the SO_4:Cl ratio, so it is difficult to definitively confirm or dispute the presence of seawater intrusion. Additionally, due to the elevation and bedrock exposure at this site, it is unlikely that seawater would be making it into the well.

The Atlantic Ocean is the primary source of seawater contamination of wells on the East Coast. However, factors such as precipitation, sea-spray contamination, tides, storm surges and dissolution of minerals in the overburden and bedrock are more likely to be the source of contamination than saline intrusion into the aquifer (Barlow, 2005). Precipitation and sea-spray both deposit chloride and sodium on the overburden which then percolates down to the groundwater.

In addition to this surface deposit of seawater, tidal swell and freshwater levels can affect the concentration of chloride and sodium in the groundwater. The transition zone between fresh and salt water periodically shifts in and out seasonally and annually depending on groundwater recharge rates and tidal levels. Due to the dynamic nature of the seawater/freshwater mixing zone, this transition zone shifts back and forth seaward and landward. This may have an impact on the concentrations of the seawater constituents in wells close to the water (Barlow)



Modified from Kohout (1964)

Figure : Biscayne aquifer

A study of the Biscayne aquifer (Florida) showed this transition zone, seen in Figure 3, extending just over 1500ft into the shoreline. The Biscayne aquifer has characteristics similar to the Georgetown aquifer and is made of porous limestone. It is possible for seawater to move fairly far inland in this transition zone. However, in a review of bedrock aquifers in Maine, it was found that, due to the orientation of the fractures in the crystalline bedrock structures, landward migration of seawater was largely prevented (Caswell, 1979a, B). Of a 60 well survey, the three wells that exhibited seawater intrusion were located near crosscut fractures that may short circuit seawater into the aquifer directly from the ocean (Caswell 1979a, B). These three wells are located in Harpswell, Maine, about 12 miles up the coast from Georgetown, and it is probable that the aquifers on Georgetown behave in a similar manner.

An important part of this 2012 study was looking at the contaminant levels in relation to the regulated drinking water standards for Maine. The secondary EPA standards were used as guidelines for the concentrations of constituents in the wells. Regulated constituents included nitrate, sulfate, chloride and fecal coliforms.

Nitrate is regulated under the EPA primary standards at a level of 10 mg/L as nitrate. Nitrate can be dangerous to children and infants especially, competing for oxygen in the blood stream and causing blue baby syndrome. Of the wells tested, none exceeded the standard, with the closest value 2.35 mg/L. Nitrate was also used as an indicator for possible septic contamination. However, with these results, using it as a tracer for septic contamination was inconclusive.

Sulfate has an EPA secondary standard of 250 mg/L. Sometimes an indicator of the presence of seawater in the right ratio with chloride, in high concentrations sulfate is thought to be a possible cause of diarrhea, acting as a natural laxative. No wells reported results approaching the standard, with the highest measured value being 34.50 mg/L. As stated earlier, sulfate had a statistically significant decrease from previous levels.

Chloride was the primary indicator of seawater intrusion used in this study. At levels above 250 mg/L (EPA secondary standard), it can have a noticeable effect on taste. Health effects are thought to be associated primarily with sodium chloride. Several wells approached the suggested maximum level with 195.625 mg/L, 172.5 mg/L, and 142.5 mg/L. However, one vastly surpassed the secondary standard, with a level of 1367 mg/L. It is suggested that this well retested and evaluated to further confirm these results. Removal of chloride in drinking water is possible through a reverse osmosis system and installation of a system should be considered as it may prove to be more cost effective than purchasing outside drinking water.

Total coliforms, as well as fecal coliforms in the form of *E. coli*, were tested by a positive/negative culture test. Total coliforms can occur from natural sources in soil and plants, and can be influenced by human and animal waste. While total coliforms are not regulated, they are an indicator that fecal coliforms may be present. EPA standards state that “No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E. coli* fecal coliforms, system has an acute MCL violation.”(EPA). Two samples tested positive for fecal coliforms and it is strongly suggested these wells be tested again according to EPA regulations.

IV. Conclusions

Water samples from wells on the island of Georgetown, ME were analyzed for water quality characteristics, specifically sodium, chloride, nitrate, sulfate and coliforms. These constituents are assumed to be possible indicators of seawater intrusion and septic contamination. The experimental plan was based Dr. Steve Mabee's study written in 1989 studying the aquifer characteristics of Georgetown through physical and chemical indicators in wells across the island. Data taken in the winter of 2012 was compared to Mabee's 1989 data in order to investigate possible changes in concentrations of constituents. Changes were thought to be caused by factors such as population growth and density, sea level change and precipitation.

It is difficult to determine which wells are at risk without a more in depth analysis of the physical aquifer characteristics. Comparing the location of wells along the coast that intersect with fractures running perpendicular to the water could give insight into future problem areas. Seawater intrusion in bedrock aquifers is largely due to these fractures that can be inlets for seawater. Vertical fractures were mapped by Mabee and have been mapped by other sources as well. Overlaying these maps onto the maps depicting sampled wells would help identify possible sites of contamination.

Wells were identified using both the sodium to chloride ratio and the sulfate to chloride ratio. However, the wells that were calculated positive did not overlap between the ratios. The well that fell within the range for sulfate to chloride was also a well that Dr. Mabee had identified as containing seawater using the same sodium to chloride ratio. Additionally, there was a well that had an extremely high concentration of chloride and it is suggested that this well is tested again as it also exceeds EPA standards for chloride. Elevated levels of sodium or chloride could be caused by deposition of sea spray onto the overburden. Wave action can volatilize seawater and the constituents can mix with the overburden where they are then transported into the groundwater. Seawater intrusion positives are not necessarily due to intrusion into the aquifer, but can be due to the infiltration of seawater constituents into the overburden and bedrock.

The leading indicators for septic intrusion were total coliforms and *E. coli* bacteria, with nitrate being a secondary indicator. Several positive results for total coliforms were found on the island. Total coliforms can be naturally occurring bacteria in the soil, or natural organic matter, as well as from the fecal matter of warm blooded animals (birds and mammals). Positive tests for total coliforms served to narrow down the sample size for possible septic contamination, which was then further tested for *E. coli*. Two wells tested positively for *E. coli*. One well was a very shallow, dug well and contamination could be from animal waste that is being washed into the well. Shallow wells do not have the same biodegradation that deeper bedrock wells have due to the shorter contact time in the soil. The other well's location with regards to the house and the septic tank suggested initially that septic contamination may be occurring. These results provided more evidence towards contamination, which was also backed up by a slightly elevated nitrate level, which was below the standard, but the highest value of the sampling group.

Out of the 19 wells we tested, five were in common with the wells that Mabee tested. We were able to analyze these wells statistically using a Student's t-test for significance. Using Mabee's data as the accepted mean and our data set as the experimental set, the significance of the changes were calculated (p=0.05). Nitrate, sulfate, phosphate and chloride were all tested for significant changes in data. Nitrate demonstrated significant change, however no pattern was detected between the five sample sites. Sulfate experienced significant decreases from 1989 to 2012. The cause for this was unclear, but it may be tied into the reduction of sulfate dioxide from the Clean Air Act of 1990 or the decrease in the use of sulfate in detergents. Phosphate had no noticeable patterns in change and only a couple of the wells experienced significant change. Chloride levels increased significantly between sampling periods and the cause of this is unclear as well.

With all of the comparisons done between Dr. Mabee's data and the 2012 data, it is important to keep in mind the difference in sampling time. Dr. Mabee's data was collected in the summer months when aquifer demand is at the highest and theoretically when the chances for seawater intrusion and septic contamination are at their highest. The 2012 data was collected during the winter months when groundwater infiltration is relatively low and demand on the aquifer is low. The stresses on the aquifer are very different between the winter and summer months due to the vast difference in population. Temperature and precipitation events are quite different as well, which can have an effect on recharge rates, groundwater levels, wave action, etc.

If this study is to be continued, several aspects of the experimental plan are suggested to be altered. Multiple sampling events should to be conducted. A sampling event while the island is near peak inhabitance is most important to allow for data comparisons between current and past data to be more cohesive. More wells overlapping with past data need to be sampled, as 5 out of 19 was not large enough of a sample size to find any solid patterns on the island. In order to study the effect that population density, population increase, sea level rise, and weather events have on the aquifer and the water quality, sampling needs to occur at as similar a time of year as when Dr. Mabee conducted his study. Additionally, when testing for septic contamination a test for specifically human waste needs to be implemented, such as ribotyping and using the PCR to identify bacterium types. This suggestion would help specify whether contamination found could be specifically from septic contamination.

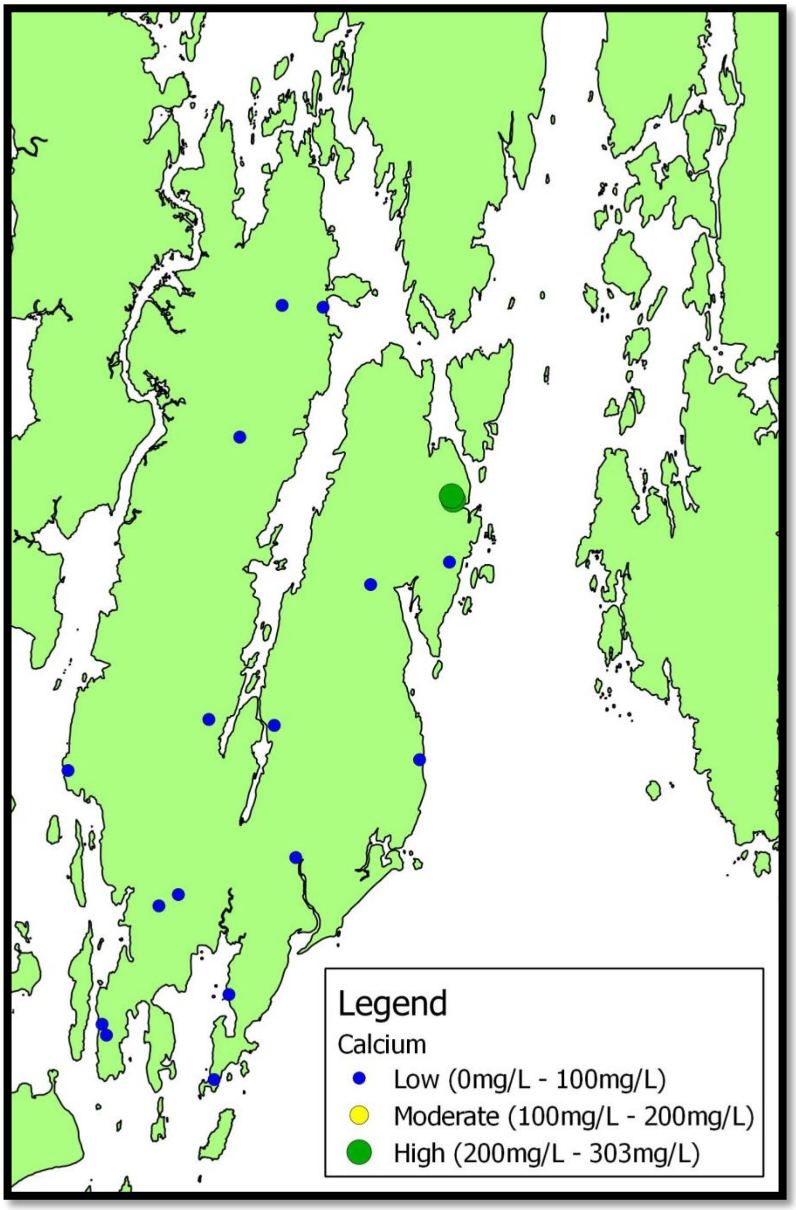
Pump tests should be eliminated from this study, as Dr. Mabee did not find his provided any helpful data that was pertinent to the transport and fate of constituents through the aquifer. It should be assumed that because the 2012 pump tests were conducted in the same fashion that his were, they too provide little useful data as well and should therefore be eliminated from the study.

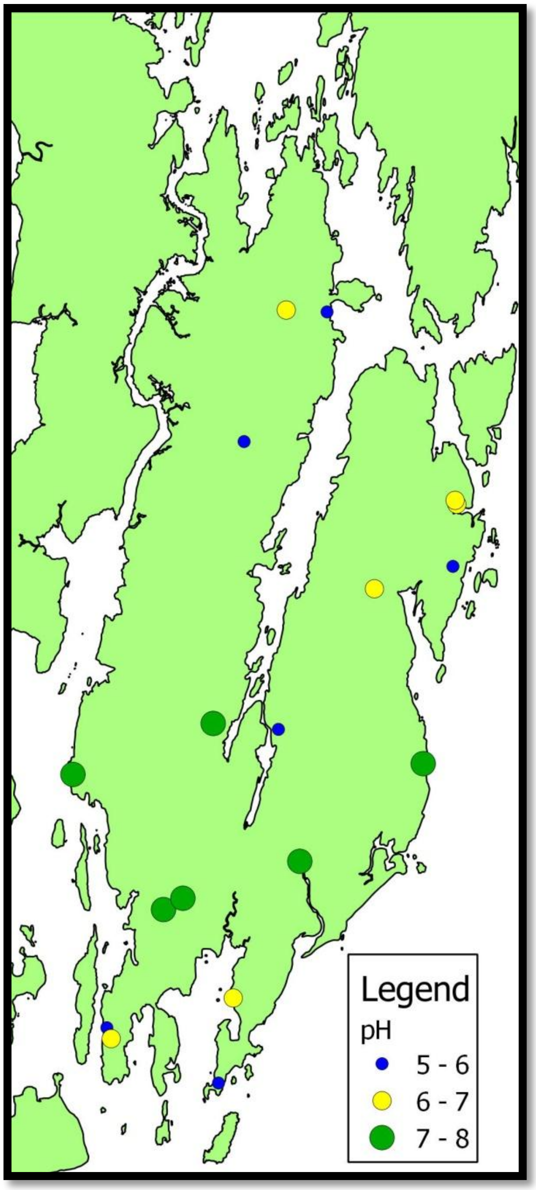
Replication of Dr. Mabee's wells and data should to be the biggest priority. Time of sampling events, number of sampling events, testing technique, and distribution of samples all played into the lack of connection between the two studies. Elimination of the pump tests would provide more time for sampling a larger number of wells and a larger number of common wells with the 1989 study. Wells that were identified as saline in 1989 should be retested and analyzed for seawater intrusion. Sampling only wells that Dr. Mabee sampled, or wells that were sampled during this study, would make the data more meaningful and make it easier to draw conclusions from the analysis.

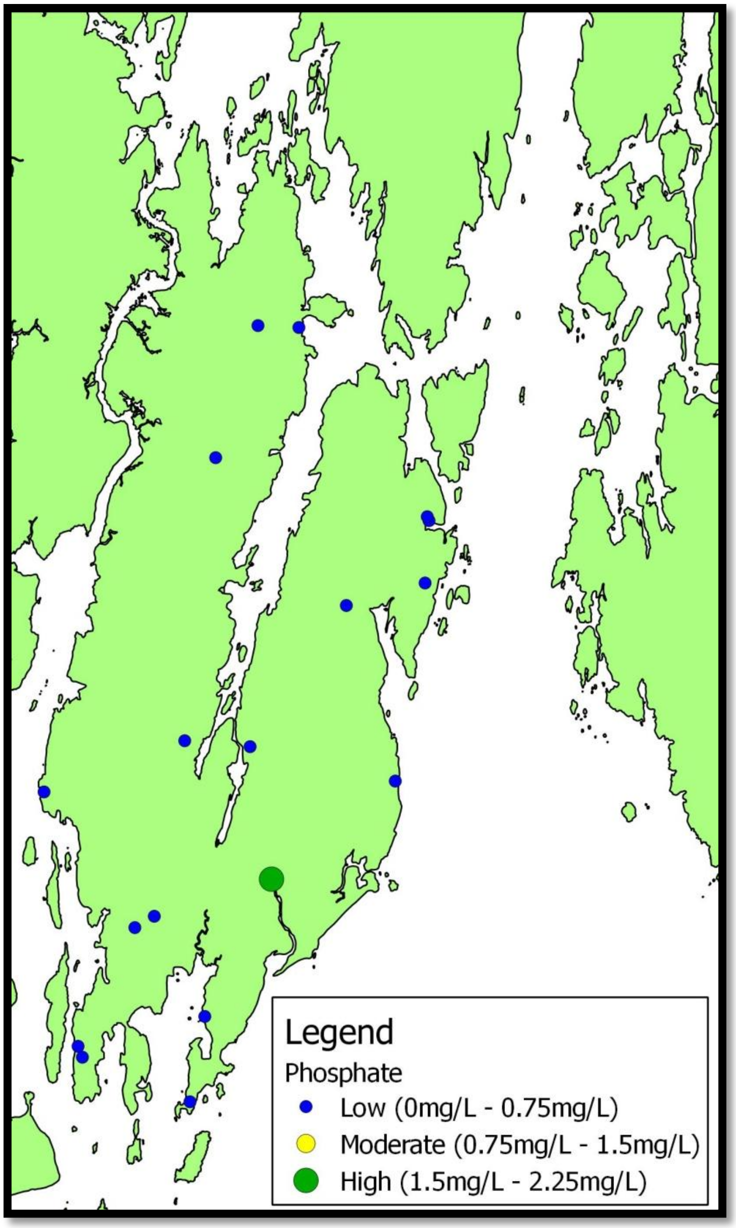
Works Cited

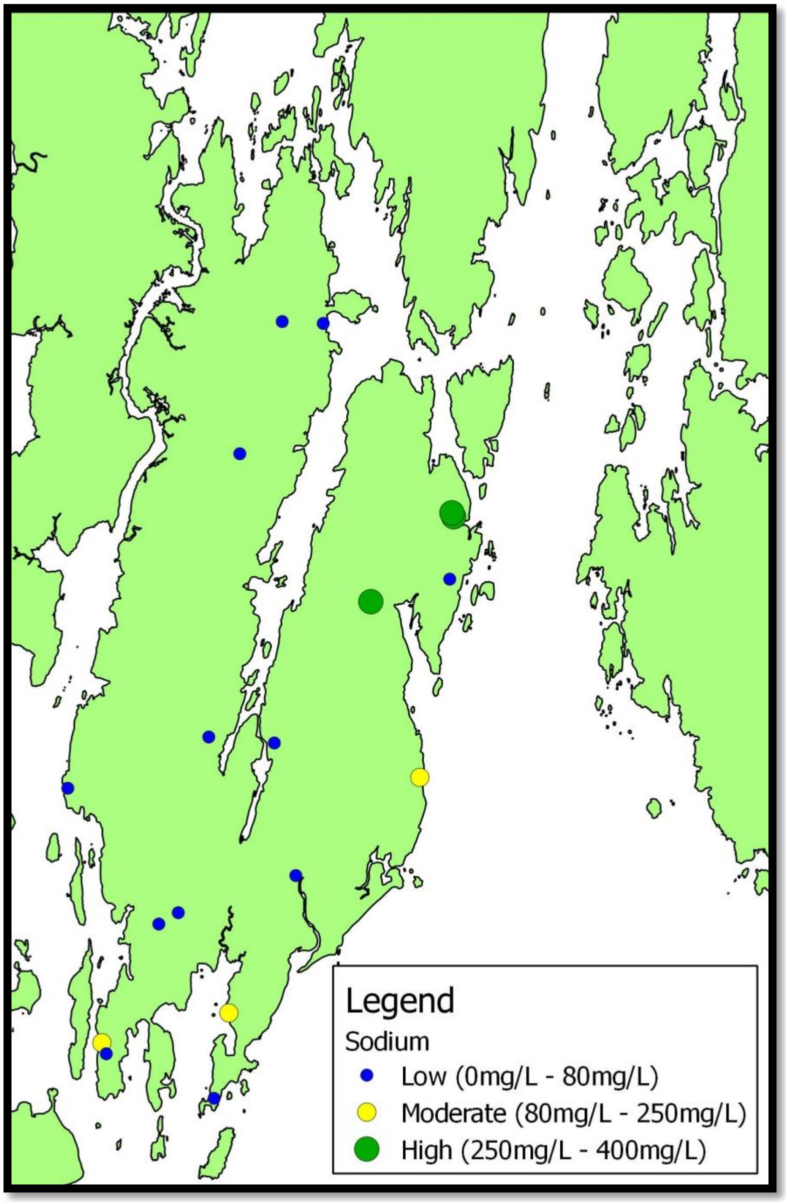
Figure 1 (http://pubs.usgs.gov/circ/2003/circ1262/images/fig08_opt.gif)
Figure 2 (http://pubs.usgs.gov/circ/2003/circ1262/images/fig07_opt.gif)

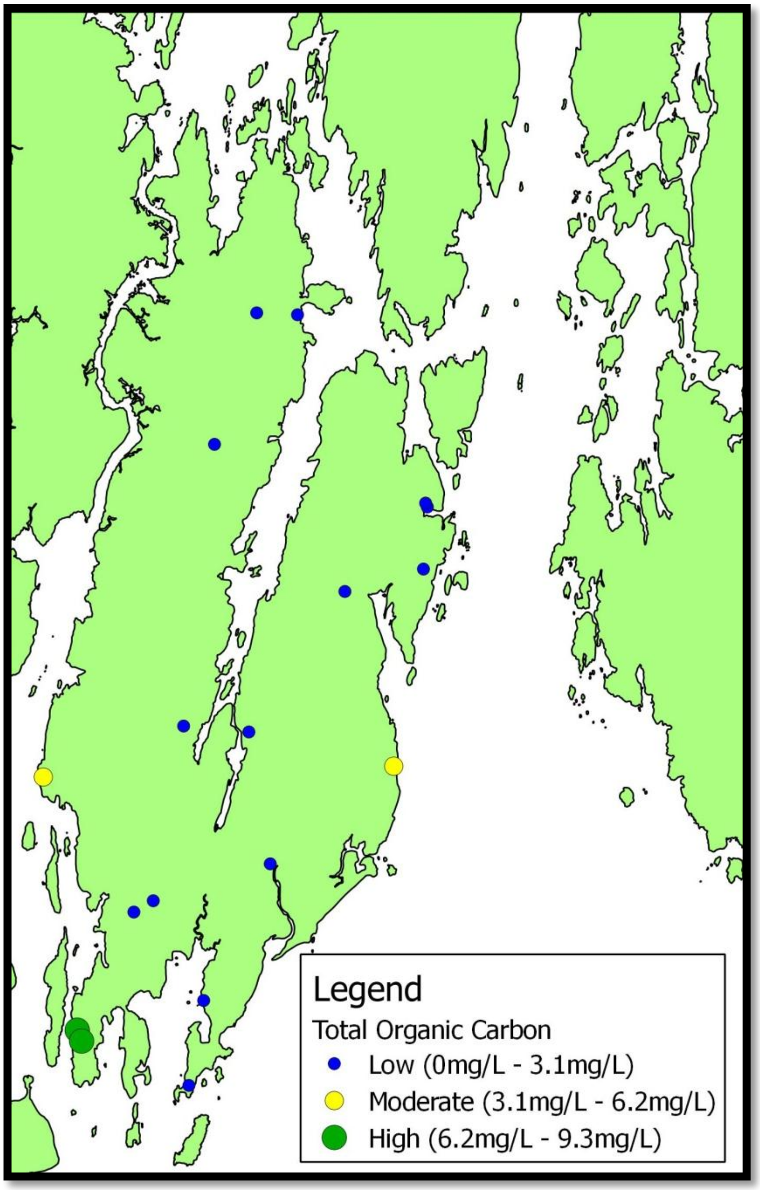
APPENDIX A


Legend
Calcium
Low (0mg/L - 100mg/L)
Moderate (100mg/L - 200mg/L)
High (200mg/L - 303mg/L)


Legend
pH
5 - 6
6 - 7
7 - 8


Legend
Phosphate
● Low (0mg/L - 0.75mg/L)
○ Moderate (0.75mg/L - 1.5mg/L)
● High (1.5mg/L - 2.25mg/L)

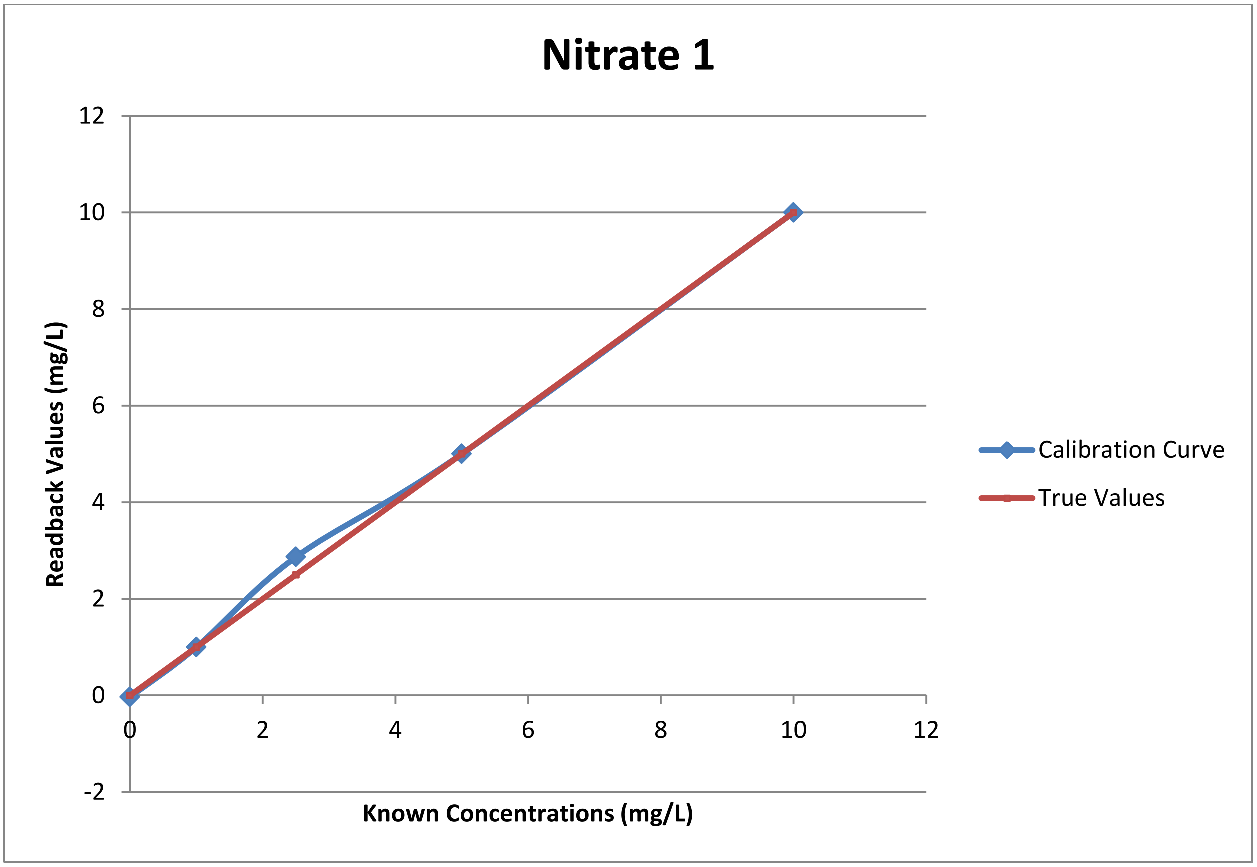

Legend
Sodium
● Low (0mg/L - 80mg/L)
○ Moderate (80mg/L - 250mg/L)
● High (250mg/L - 400mg/L)


Legend
Total Organic Carbon
Low (0mg/L - 3.1mg/L)
Moderate (3.1mg/L - 6.2mg/L)
High (6.2mg/L - 9.3mg/L)

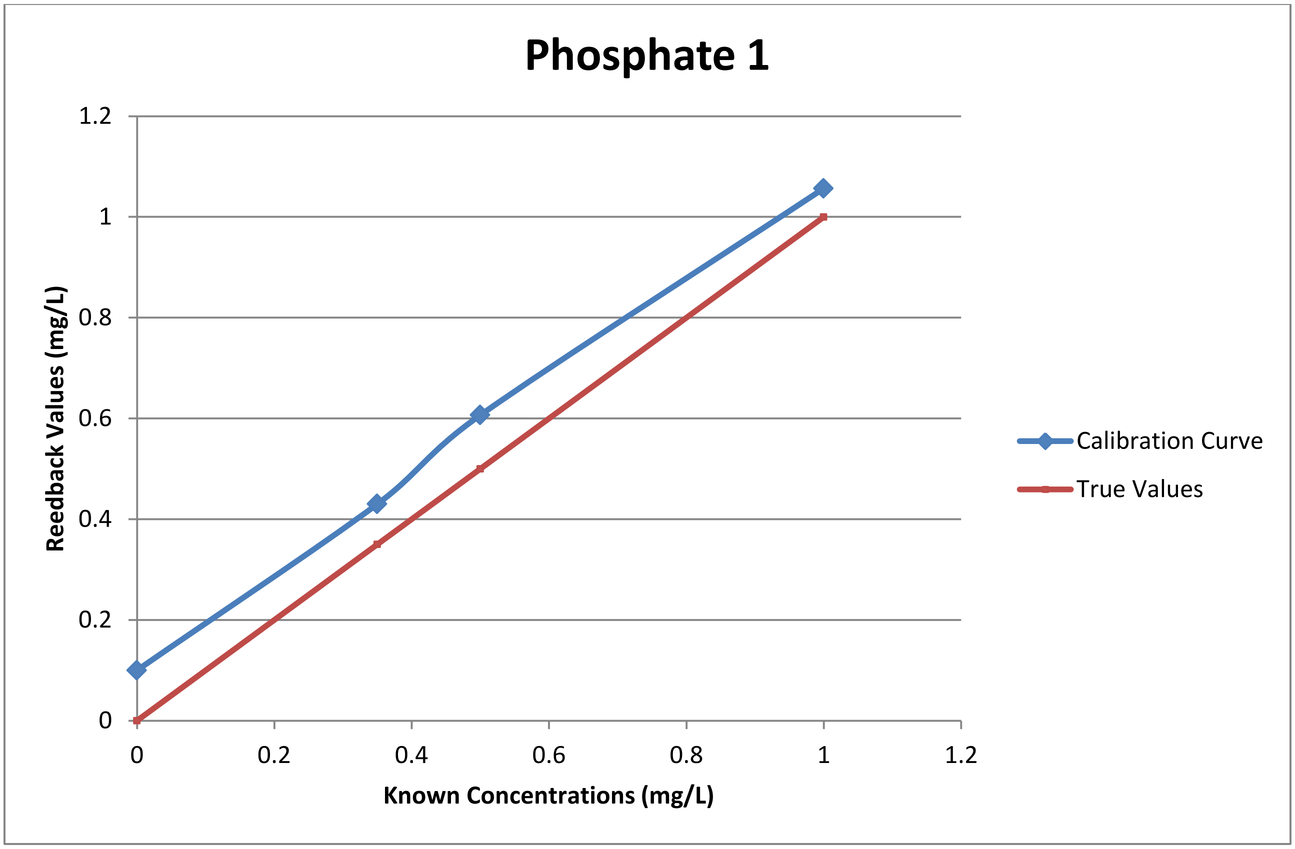
APPENDIX B

To ensure the accuracy and precision of the samples analyzed, standards and spikes were both run. Standards were prepared according to the appropriate method described by Hach to ensure accuracy. Sample spikes were prepared according to procedure described by Hach to ensure precision.

Two sets of samples were run in the home of Dr. Nancy Kinner in Georgetown, Maine. A set of samples was analyzed for nitrate; the graph below represents the known concentrations (standards) compared to the values given by the spectrometer. The same set of samples was analyzed in Georgetown for phosphate.

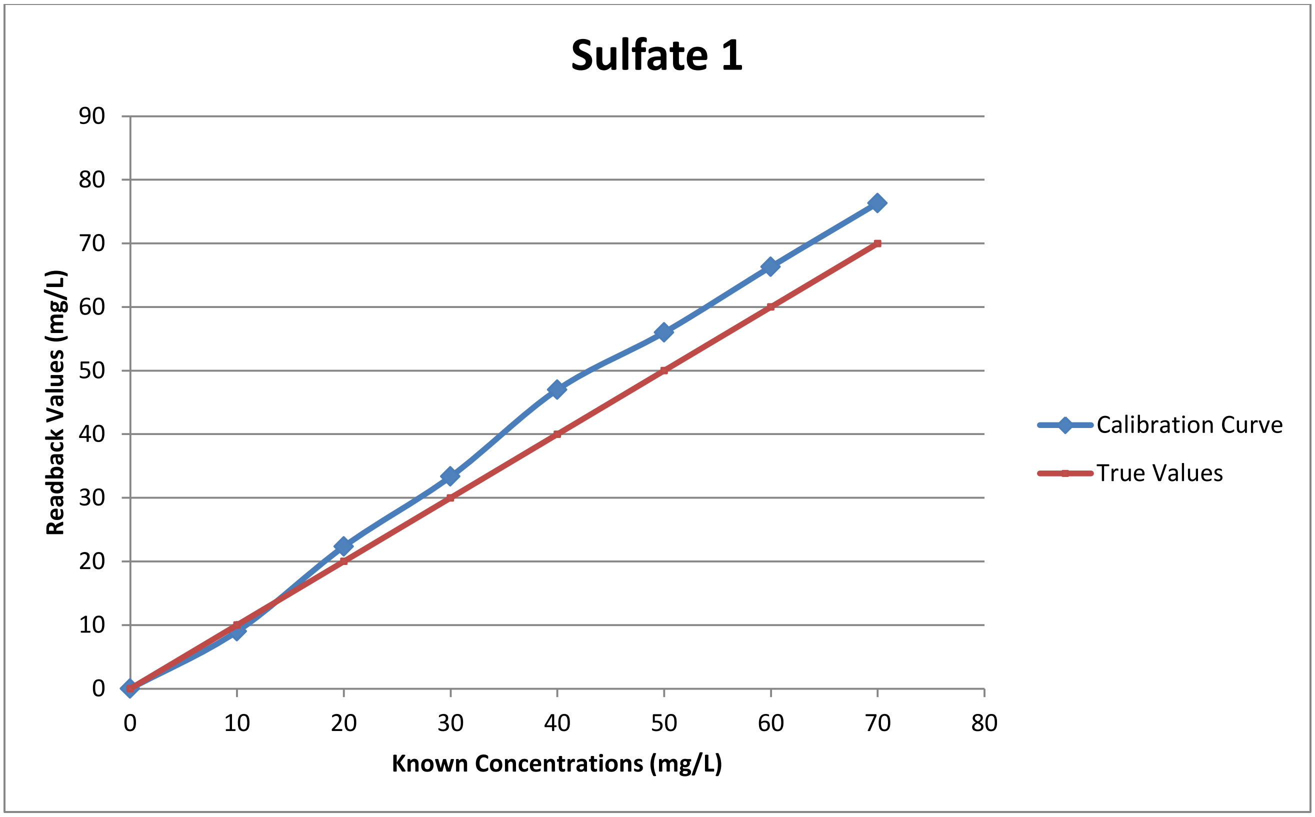


NITRATE 1			
Sample Name	Reading 1	Reading 2	Reading 3
10 mg/L standard	9.9	10	10.1
5 mg/L standard	5	5	5
2.5 mg/L standard	2.8	2.9	2.9
1 mg/L standard	1	1	1
Highfive-7-NLG	0.3	0.2	0.3
Highfive-7-NLG (1 ml spike)	1.3	1.3	1.2
	119.20%	115.60%	109.70%
Highfive-7-NLG (2 ml spike)	1.7	1.8	1.8
	93.10%	97.90%	97.80%
Highfive-7-NLG (3 ml spike)	2.3	2.3	2.4
	91.40%	92.90%	96.30%
RO Blank	0.3	-0.2	-0.2



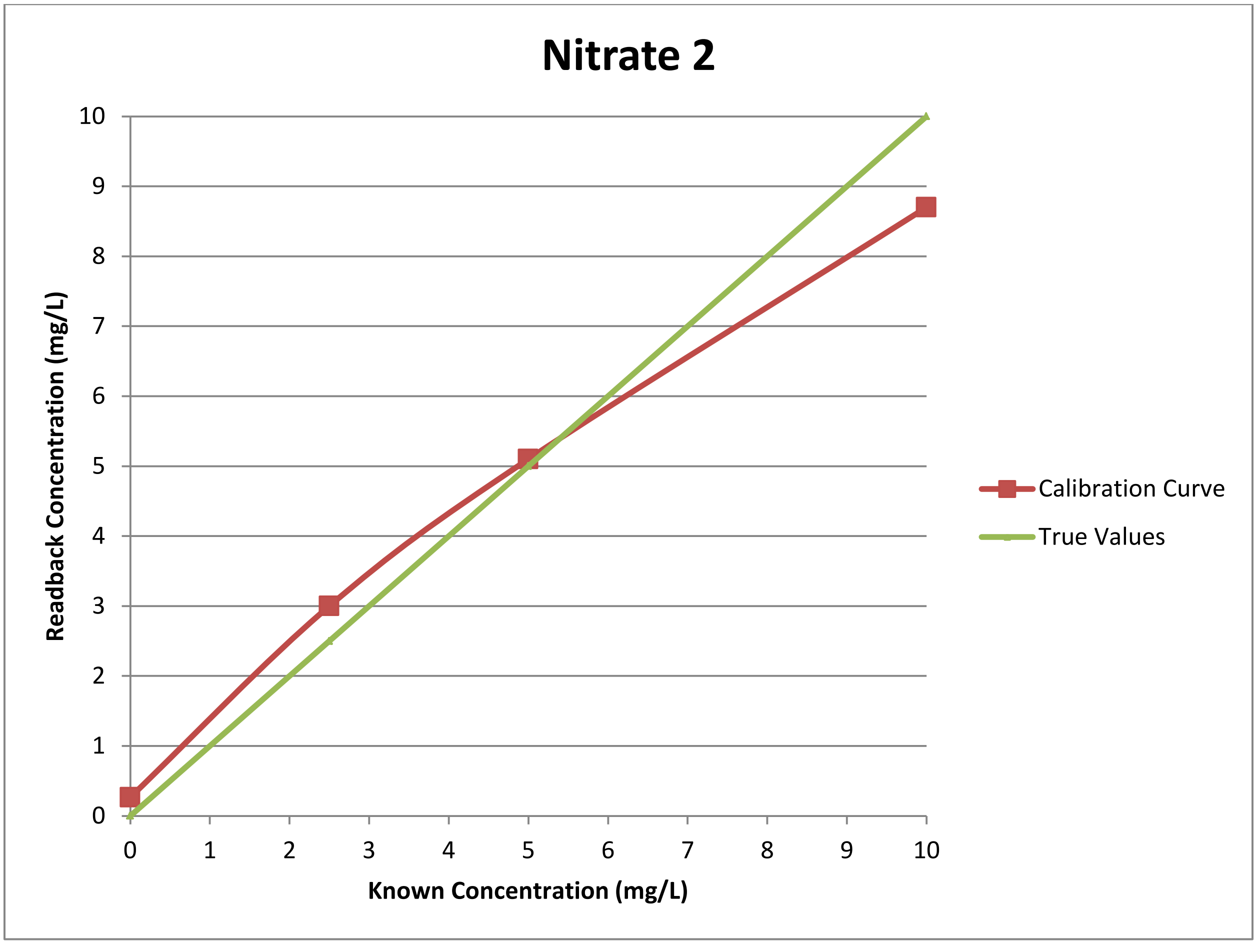
Phosphate 1			
Sample Name	Reading 1	Reading 2	Reading 3
RO w/ reagent	0.3	0	0
1 mg/L standard	1.06	1.05	1.06
0.5 mg/L standard	0.61	0.61	0.6
0.35 mg/L standard	0.44	0.41	0.44
Waltz-2-NAW	0.22	0.18	0.19
Waltz-2-NAW (1ml spike)	0.25	0.24	0.24
	96.60%	94.00%	95.50%
Waltz-2-NAW (2 ml spike)	0.31	0.31	0.31
	99.50%	99.00%	99.50%
Waltz-2-NAW (3 ml spike)	0.38	0.38	0.38
	102.60%	101.90%	101.90%

The remaining samples were run at the University of New Hampshire in the Gregg Hall laboratory.

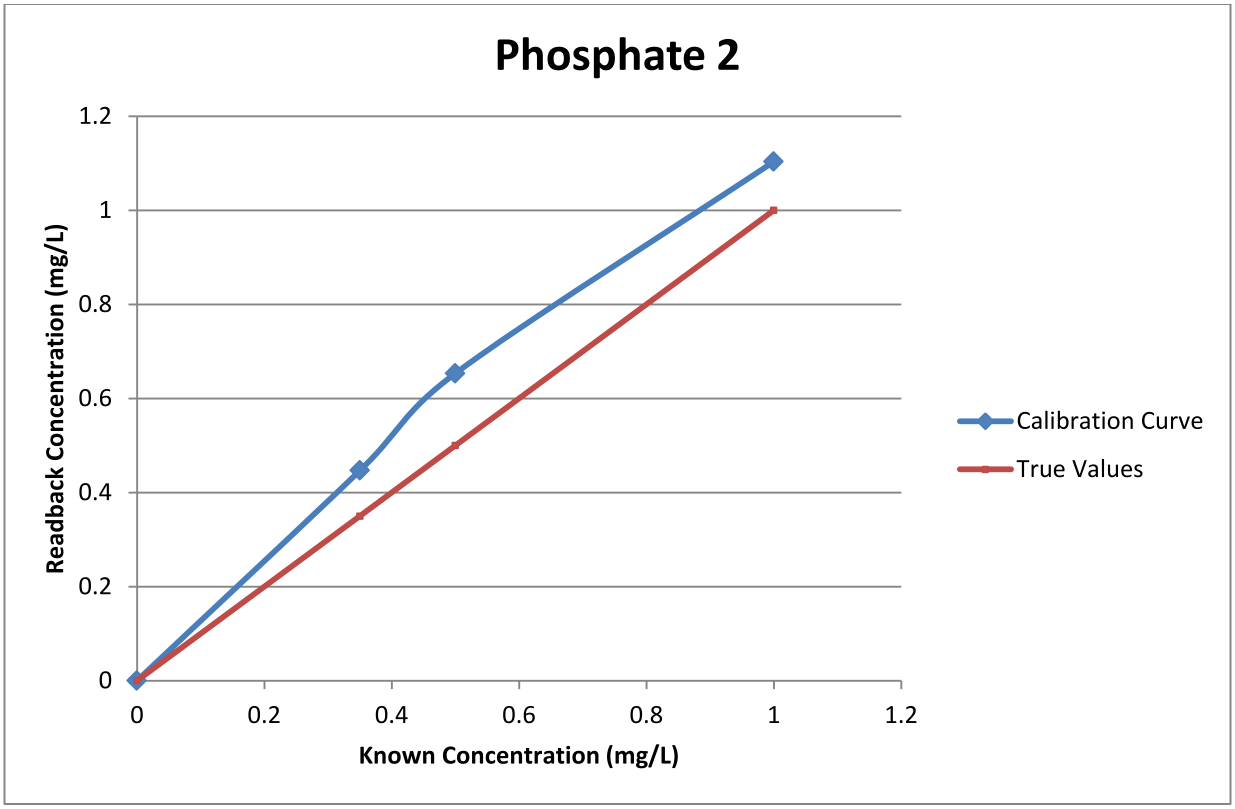


Sulfate 1			
Sample Name	Reading 1	Reading 2	Reading 3
RO Blank	0	0	0
10 mg/L standard (1.428ml)	9	9	9
20 mg/L standard (2.857ml)	22	23	22
30 mg/L standard (4.2847ml)	34	33	33
40 mg/L standard (5.714ml)	47	47	47
50 mg/L standard (7.14ml)	56	56	56
60 mg/L standard (8.57ml)	66	67	66
70 mg/L standard (10ml)	77	76	76
Buchtpunkt-1-NAW	4	4	5
Buchtpunkt (1ml spike)	11	11	N/A
	102.0%	103.8%	N/A
Buchtpunkt (2ml spike)	20	20	N/A
	132.5%	132.7%	N/A
Buchtpunkt (3ml spike)	25	N/A	N/A
	129.1%	N/A	N/A

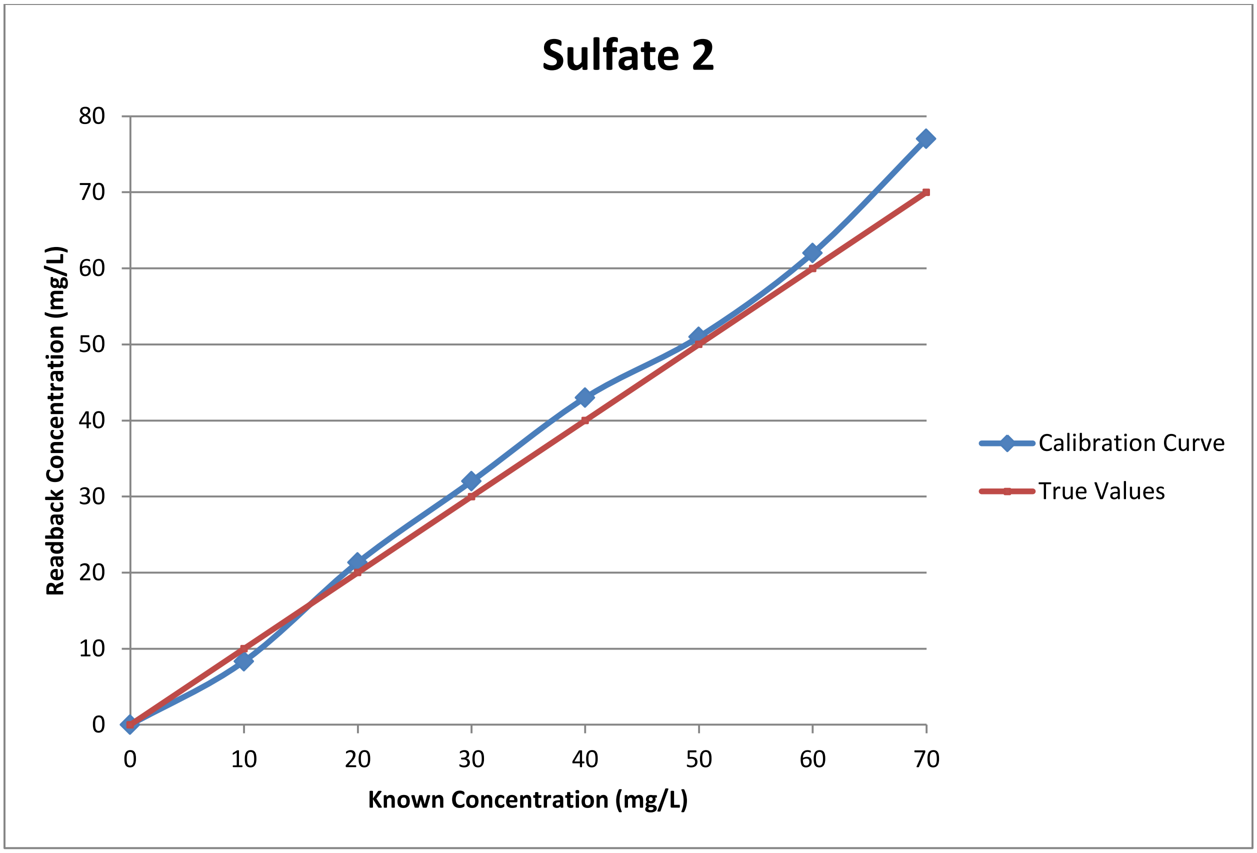
The second set of samples required an additional set of calibration curves.



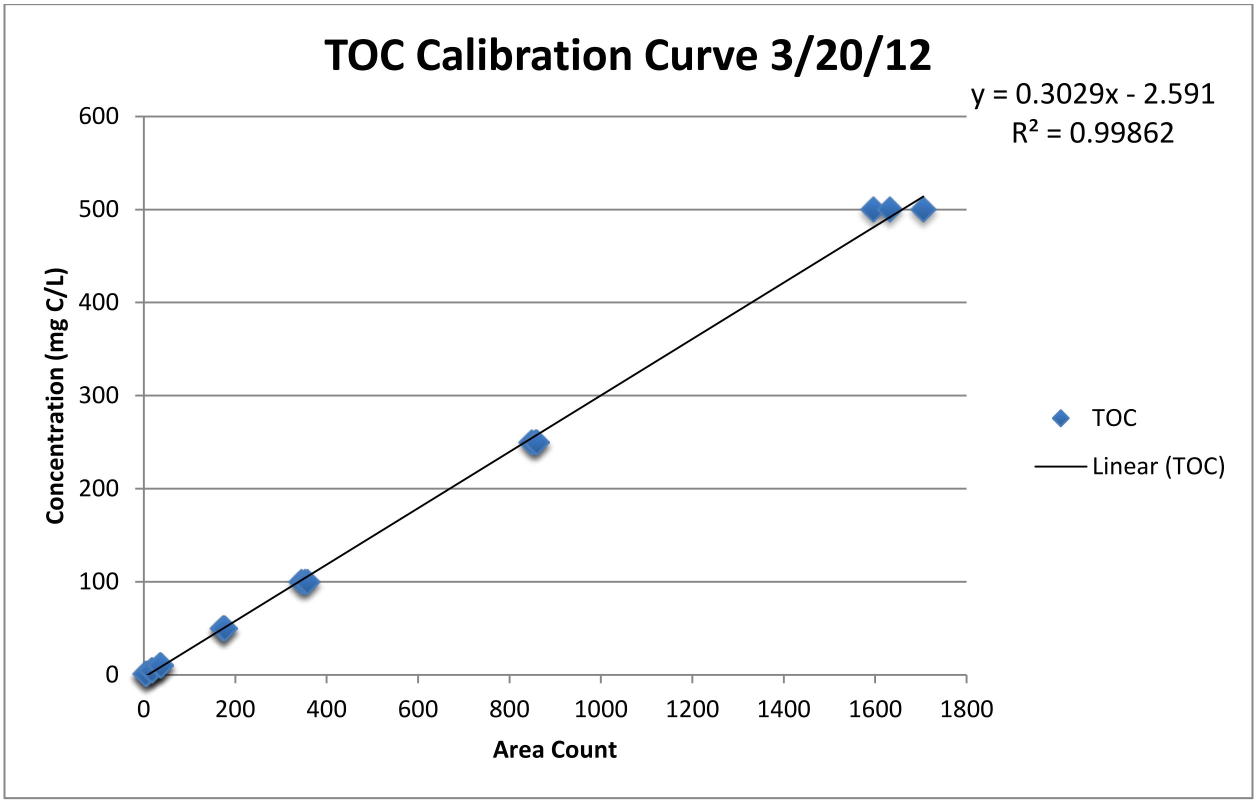
Nitrate 2			
Sample Name	Reading 1	Reading 2	Reading 3
10mg/L standard	8.6	8.7	8.8
5mg/L standard	5.1	5.1	5.1
2.5mg/L standard	3	3	3
RO w/reagent	0.2	0.3	0.3
Seis-Rep 7	0.2	0.3	0.2
Seis-Rep 7 (1ml spike)	0.6	0.6	0.6
	55.4%	54.8%	55.0%
Seis-Rep 7 (2ml spike)	1	1	1
	53.8%	54.1%	54.0%
Seis-Rep 7 (3ml spike)	1.6	1.6	1.6
	66.3%	65.4%	64.9%



Phosphate 2			
Sample Name	Reading 1	Reading 2	Reading 3
RO w/ reagent	Underrange	Underrange	Underrange
1mg/L standard	1.11	1.09	1.11
0.5 mg/L standard	0.64	0.66	0.66
0.35 mg/L standard	0.45	0.45	0.44
1mg/L standard (new)	1.06	1.08	1.06
Seis-Rep 1	0.24	0.26	0.23
Seis-Rep 1 (1ml spike)	0.35	0.33	N/A
	116.90%	110.80%	N/A
Seis-Rep 1 (2ml spike)	0.37	0.34	N/A
	103.10%	94.60%	N/A
Seis-Rep 1 (3ml spike)	0.45	0.41	N/A
	110.60%	101.40%	N/A



Sulfate 2			
Sample Name	Reading 1	Reading 2	Reading 3
10 mg/L standard	8	9	8
20 mg/L standard	22	21	21
30 mg/L standard	32	32	32
40 mg/L standard	43	43	43
50 mg/L standard	51	51	51
60 mg/L standard	62	62	62
70 mg/L standard	77	77	77
RO w/ reagent	0	0	0
Uno-Rep 6	0	0	0
Uno-Rep 7	0	0	0
Dos-Rep 6	16	16	16
Dos-Rep 6 (1ml spike)	29	29	29
	124.0%	124.6%	124.7%
Dos-Rep 6 (2ml spike)	32	32	32
	107.0%	107.1%	105.9%
Dos-Rep 6 (3ml spike)	46	46	46
	131.5%	131.5%	131.3%


TOC Calibration Curve 3/20/12
y = 0.3029x - 2.591
R² = 0.99862
600
500
400
300
200
100
0
Concentration (mg C/L)
0
200
400
600
800
1000
1200
1400
1600
1800
Area Count
TOC
Linear (TOC)

APPENDIX C

The following pages represent the full methods for chloride, nitrate, phosphate, sulfate, total coliform and *E. coli* as described by Hach.

APPENDIX D

Pump Test Calculations

To determine the yield of a well, pump tests were performed. This was done by pumping water via a faucet for 10 minutes and measuring the depth to water in the well for every minute of those 10 minutes and 3 minutes after the faucet was turned off. The water storage tanks were also monitored to determine when the pump would turn on to draw water from the well. Using the measurements taken in the minutes after the pump stopped withdrawing water, the yield was calculated based on how much water refilled into the well during that time. When the pump turned on multiple times during the 10 minute period, the minutes in between pumping were used to calculate the yield and averaged to get the average yield. All wells tested had a 6inch diameter, giving them all the same surface area of 0.758ft^2. This was used in calculating the volume of water along with the change in water depth.

Well #1

Diameter (ft)	0.5
GPM	--
Amt Casing	--
Date Installed	--
Water Depth (ft)	**Time (min)**
24.28	0
23.9	1
28.25	2
25.7	3
26.4	4
27.25	5
26.7	6
28.7	7
28	8
29.7	9
29.1	10
28.7	11
28.1	12
27.82	13

Well Pumping	Time
On	1:25
Off	1:45
On	3:53
Off	4:13
On	6:22
Off	6:42
On	8:52
Off	9:12

Recharge

Pump 1 time	1:25-1:45
elev after pumping (t=2min)	28.25
min 2-3, ft/min	2.55
Pump 2 time	3:53-4:13
elev after pumping (t=5min)	27.25
min 5-6, ft/min	0.55
Pump 3 time	6:22-6:42
elev after pumping (t=7min)	28.7
min 7-8, ft/min	0.7
Pump 4 time	8:52-9:12
elev after pumping (t=9min)	29.7
min 9-10, ft/min	0.6
min 10-11, ft/min	0.4
min 11-12, ft/min	0.6
min 12-13, ft/min	0.28
Avg	0.47

Overall Avg	1.0675
Recharge (ft^3/min)	0.837988
gal/min	6.268147

Well #7

Diameter (ft)	0.5
GPM	15
Amt Casing	21
Date Installed	Mar-02
Water Depth (ft)	**Time (min)**
79.5	0
82.7	1
84.25	2
82.5	3
81.9	4
81.55	5
81.35	6
83.55	7
83.35	8
82.35	9
82.9	10
82.6	11
81.4	12
81.35	13

Well Pumping	Time
On	0:56
Off	2:02
On	6:30
Off	7:35

Recharge

Pump 1 time	0:56-2:02
elev after pumping (t=2min)	84.25
min 2-3, ft/min	1.75
min 3-4, ft/min	0.6
min 4-5, ft/min	0.35
min 5-6, ft/min	0.2
Avg	0.725
Pump 2 time	6:30-7:35
elev after pumping (t=8min)	83.35
min 8-9, ft/min	1
min 9-10, ft/min	-0.55
min 10-11, ft/min	0.3
min 11-12, ft/min	1.2
Avg	0.4875

Overall Avg	0.60625
Recharge (ft^3/min)	0.475906
gal/min	3.559779

Well #10

Diameter (ft)	0.5
GPM	3
Amt Casing	--
Date Installed	--
Water Depth (ft)	**Time (min)**
30.25	0
31.7	1
31.2	2
32.2	3
31.75	4
32.55	5
33.6	6
32.9	7
33.85	8
33.2	9
33.9	10
33.35	11
33.1	12
32.9	13

Well Pumping	Time
On	0:48
Off	1:04
On	2:26
Off	2:42
On	4:15
Off	4:25
On	5:51
Off	6:06
On	7:35
Off	7:51
On	9:21
Off	9:36

Recharge

Pump 1 time	0:48-1:04
elev after pumping (t=1min)	31.7
min 1-2, ft/min	0.5
Pump 2 time	2:26-2:42
elev after pumping (t=3min)	32.2
1min later, ft/min	0.45
min 3-4, ft/min	4:15-4:25
elev after pumping (t=5min)	32.55
No Drawdown info, more pumping interfered	
Pump 4 time	5:51-6:06
elev after pumping (t=7min)	32.9
No Drawdown info, more pumping interfered	
Pump 5 time	7:35-7:51
elev after pumping (t=8min)	33.85
min 8-9, ft/min	0.65
Pump 6 time	9:21-9:36
elev after pumping (t=10min)	33.9
min 10-11, ft/min	0.55
min 11-12, ft/min	0.25
min 12-13, ft/min	0.2
Avg	0.333333

Overall Avg	0.483333
Recharge (ft^3/min)	0.379417
gal/min	2.838037

Well #14

Diameter (ft)	0.5
GPM	
Amt Casing	--
Date Installed	--
Water Depth (ft)	**Time (min)**
32.2	0
27.6	1
28	2
28.55	3
29	4
29.1	5
28.6	6
30	7
29.2	8
30.6	9
30.6	10
29.7	11
29.1	12
28.45	13

Recharge

Pump 1 time	1:56-2:12
elev after pumping (t=3min)	28.55
min 3-4, ft/min	-0.45
Pump 2 time	4:06-4:22
elev after pumping (t=5min)	29.1
min 5-6, ft/min	0.5
Pump 3 time	6:15-6:30
elev after pumping (t=7min)	30
min 7-8, ft/min	0.8
Pump 4 time	8:27-8:43
elev after pumping (t=9min)	30.6
min 9-10, ft/min	0
min 10-11, ft/min	0.9
min 11-12, ft/min	0.6
min 12-13, ft/min	0.65
Avg	0.5375

Overall Avg	0.59375
Recharge (ft^3/min)	0.466094
gal/min	3.486381

Well Pumping	Time
On	1:56
Off	2:12
On	4:06
Off	4:22
On	6:15
Off	6:30
On	8:27
Off	8:43

Well # 16

Diameter (ft)	0.5
GPM	4
Amt Casing	21
Date Installed	Jul-99

Water Depth (ft)	**Time (min)**
63.6	0
63.55	1
64.3	2
65.65	3
65.15	4
66.1	5
66.7	6
66.2	7
67.8	8
67.45	9
66.9	10
66.3	11
66.1	12
65.8	13

Recharge

Pump 1 time	1:54-2:38
elev after pumping (t=3min)	65.65
min 3-4, ft/min	0.5
Pump 2 time	4:42-5:27
elev after pumping (t=6min)	66.7
min 6-7, ft/min	0.5
Pump 3 time	7:32-8:18
elev after pumping (t=9min)	67.45
min 9-10, ft/min	0.55
min 10-11, ft/min	0.6
min 11-12, ft/min	0.2
min 12-13, ft/min	0.3
Avg	0.4125

Overall Avg	0.470833
Recharge (ft^3/min)	0.369604
gal/min	2.764639

Well Pumping	Time
On	1:54
Off	2:38
On	4:42
Off	5:27
On	7:32
Off	8:18

Well #19

Diameter (ft)	0.5
GPM	--
Amt Casing	--
Date Installed	--

Water Depth (ft)	**Time (min)**
40.63	0
40.6	1
40.6	2
40.6	3
43.25	4
43	5
42.8	6
42.61	7
42.4	8
42.3	9
42.15	10
42.1	11
41.9	12
41.8	13

Well Pumping

On	3:10
Off	3:35

Recharge

elev after pumping (t=4min)	43.25
min 4-5, ft/min	0.25
min 5-6, ft/min	0.2
min 6-7, ft/min	0.19
min 7-8, ft/min	0.21
min 8-9, ft/min	0.1
Avg	0.19

Recharge (ft^3/min)	0.14915
gal/min	1.115642

APPENDIX E

Raw data and anova table for student’s t-test from excel.

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