Reducing Nitrogen Loading in Truro, MA

A Worcester Polytechnic Institute Major Qualifying Project

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Abstract

Truro, MA is developing an integrated water resource management plan to assess and protect the town's water resources. Previous studies assessing drinking water quality found nitrate above the EPA limit of 10 mg/L in two samples. The goal of this project was to analyze waters in the Route 6 area of Truro for nitrogen and recommend management strategies. Samples were collected from wells and surface waters in June and July. Well water nitrate levels ranged from non-detectable to 5.6 mg/L, so no threat to public health is expected. However, concentrations of nitrate and phosphate in surface waters often exceeded 0.10 mg/L, which could lead to eutrophication. Recommendations for future water management include upgrading septic systems or implementing stormwater best management practices.

Executive Summary

While nitrogen is a vital nutrient that is naturally present in aquatic ecosystems, excess nitrogen leads to nutrient pollution. Water intended for human consumption is tested for the concentration of nitrogen in various forms. The EPA has set a maximum contaminant level (MCL) of 10 mg/ L for nitrate for potable water. Nitrate levels exceeding 10 mg/L in drinking water can cause serious illness in infants less than six months old, including shortness of breath and blueness of the skin. In surface waters, the main concern associated with nitrate and nitrite is eutrophication, the rapid growth of algae that depletes the oxygen supply in water bodies when the algae die and are biodegraded. To prevent eutrophication in Truro, MA, nitrate and phosphate concentrations in surface waters should be below 0.10 mg/L.

This goal of this project was to assess nitrogen concentrations in Truro and make recommendations for future water quality management. Samples were collected from twelve wells on July 16 and 22, 2015, and sixteen surface water locations on June 24 and July 22, 2015. Wells were installed in four transects approximately ¼ of a mile apart in the Route 6 area of Truro. Surface water samples were collected at specific GPS coordinates in East Harbor and Pamet River. Water samples were analyzed for nitrate, nitrite, and ammonia nitrogen, as well as phosphate, salinity, and conductivity. The July sampling dates coincided with high tourism times.

Nitrate + nitrite concentrations averaged 1.68 mg/L in the wells, compared to a drinking water standard of 10.0 mg/L. Surface waters averaged 1.63 mg/L, above the recommended value of 0.10 mg/L to prevent eutrophication. Phosphate concentrations averaged 0.22 mg/L in well water, and 0.078 mg/L in surface water. There was not sufficient data to determine the pollutant sources in Truro. The data were intended to determine pollutant concentrations, not to identify exact input sources. Therefore, it is uncertain which method of remediation would be most effective. Since there is no current threat to public health in drinking waters, the overall recommendation is to monitor and reassess pollutant concentrations in the future. Three potential courses of action for Truro are as follows:

1. Do Nothing
2. Monitor and Reassess
3. Remediate Waters

Immediate remediation of surface waters is not recommended because the largest contributor of nitrogen has not been identified. Further studies should first be conducted to verify the sources of pollutants in Truro. If stormwater runoff is the largest source of nitrogen, stormwater best management practices can be installed. If septic system discharge is the largest source of nitrogen, then upgrading to innovative/alternative septic systems can be recommended to homeowners. Best management practices and septic system upgrades can reduce nutrient loading by limiting nutrients input into the environment. Therefore, it is recommended that Truro continue to monitor and reassess water quality and take remedial action if nitrate levels consistently exceed 10.0 mg/L or frequent algal blooms occur in the future.

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Capstone Design

A capstone design experience is required by the Accreditation Board for Engineering and Technology (ABET). This major qualifying project (MQP) at Worcester Polytechnic Institute meets the capstone design requirements. In completing the capstone design experience, students should gain the ability to “design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” (ABET, 2014). The goal of this project was to determine nitrogen concentrations in Truro, Massachusetts and to design a plan for innovative/alternative septic system installation in the town. Truro is located on Cape Cod where many towns are developing integrated water resource management plans (IWRMP). This MQP is a step in creating an IWRMP for Truro. The purpose of this MQP was to determine the current conditions of Truro’s water resources and to develop recommendations for future monitoring and remediation. This was done by testing groundwater and surface waters in the Route A area of Truro.

This MQP incorporated environmental, health and safety, and economic considerations. The environmental constraint was the most prominent component of this project. The overarching goal of this MQP was to assess the environmental quality in Truro and to recommend ways to protect it in the future. Health and safety constraints were also encountered when determining water quality regulations set by the EPA for drinking water and environmental quality. The economic constraint was encountered when exploring the cost-effectiveness of innovative/alternative (I/A) septic systems. Septic system manufacturers were contacted to determine the price, availability, and suitability for use in Truro.

An I/A septic system configuration was designed that could be installed on residential lots in Truro to reduce the amount of nitrogen discharged to the groundwater. A schematic was developed that shows system components and the direction of water flow through the system. A design flow rate was determined that would be appropriate for a household of four people, since this configuration would be effective for most properties in Truro. The media filter component of the system was chosen to maximize nitrogen reduction in the wastewater. A step to recycle the water to the primary tank before discharge was added to allow for further denitrification.

Professional Licensure

Licensure of professional engineers ensures competency to protect public health, safety, and welfare. Professional engineer (PE) licensure is the highest standard for engineers and represents achievement and assurance of quality. In order to use the PE seal, engineers must earn a four-year degree in engineering from an accredited engineering program, pass the Fundamentals of Engineering (FE) exam, complete four years of engineering experience under a PE, and pass the Principles and Practice of Engineering (PE) exam. A professional engineer has a great deal of responsibility, since their work will affect the lives of those they serve. Therefore, professional engineers must uphold the highest ethical standards to ensure the safety of those who are affected by their work. Licensed professional engineers gain the ability to prepare, sign, seal, and submit engineering plans and designs to public and private clients. Licensure is becoming increasingly important, especially in government positions, where positions require the highest level of responsibility. For consulting engineers, licensure is a legal requirement for those who are in responsible charge of work (National Society of Professional Engineers, 2015).

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Chapter 1: Introduction

An effort to determine levels of nitrogen and other pollutants in local ground and surface waters has been ongoing in Truro, Massachusetts. Pollutant levels should be monitored in both drinking water and non-potable waters to protect public health and environmental quality. The pollutants of concern are nitrogen and phosphorous. Nitrate in drinking water should not exceed 10 mg/L, when adverse health effects can be expected and concentrations of nitrate and phosphate should each be less than 0.10 mg/L in surface waters to prevent eutrophication.

Previous water quality studies in Truro were conducted by the Water Resources Oversight Committee (WROC) in collaboration with engineers from Weston and Sampson. These studies collected drinking water samples from households in Truro. Results of these studies showed that nitrate exceeded 10.0 mg/L in some samples, which raised concern about the quality of the water resources in Truro. East Harbor in Truro was chosen as a focal point for this project since it has had frequent algal blooms in the past. Pamet River was also monitored in this project since it connects East Harbor and Cape Cod Bay.

The goal of this project was to determine levels of nitrogen and other pollutants in Truro groundwater and surface waters in the Route 6 area of Truro. Collaboration with Weston and Sampson and the WROC of Truro enabled access to equipment and information pertaining to previous water quality analyses and septic system data. The objective of this project was to expand on previous studies to identify trends, improve on sampling techniques, and assess potential sources of nitrogen. The data were then used to identify appropriate methods for remediation of Truro water resources if conditions worsen in the future.

The first step of this project was to conduct background research on nitrogen and review the data from previous Truro water quality studies. Then, monitoring wells were installed along Route 6 and Route 6A in Truro for the groundwater study. Next, a sampling schedule and sampling protocols for well and surface water sampling were developed. Water samples were tested for levels of nitrate + nitrite, phosphate, ammonia nitrogen, salinity, and conductivity. These data were compared to EPA guidelines and levels associated with healthy water ecosystems to determine overall water quality. Based on these results, it was decided whether immediate action in Truro is needed to remediate water resources. Recommendations were provided for the most appropriate course of action for Truro. While immediate action was not recommended, a design for an innovative/alternative (I/A) septic system was provided that could be installed on residential lots in Truro to reduce the amount of nitrogen entering the groundwater. Other nitrogen control options including various I/A septic systems and stormwater best-management practices (BMP's) were compared and analyzed.

Chapter 2: Background

The focus of this project was nitrogen concentrations in Truro, MA. Nitrogen exists naturally in several different forms and can enter water supplies through various means including stormwater runoff and wastewater discharge. The effects of the different forms of nitrogen on ecosystems and the mechanics of nitrogen travel were studied. The health effects of nitrogen and previous drinking water data from Truro were also investigated.

2.1 Nitrogen in Water and Wastewater

Nitrogen is the most abundant element in the air and is a critical input for agricultural systems in the production of food. While nitrogen is a vital nutrient that is naturally present in aquatic ecosystems, excess nitrogen leads to nutrient pollution. Nutrient loading in water has become a prominent environmental issue (U. S. Environmental Protection Agency, 2015). Since nitrogen pollution remediation is challenging and costly, it is important to develop environmental management plans to limit the amount of nutrients entering bodies of water.

2.1.1 Sources of Nitrogen

Nitrogen can enter waters via point or nonpoint sources. A point source is categorized as a single source that can be easily identified (University of Florida, 2011). An example of a point source is a pipe from which pollutants are discharged. Point sources discharges often originate from wastewater treatment plants and industrial waste. Under the National Pollutant Discharge Elimination System (NPDES), all facilities that discharge wastewater from a point source must be issued an NPDES permit (U. S. Environmental Protection Agency, 2015). A nonpoint source differs in that it cannot be identified from a specific source (University of Florida, 2011). Nonpoint sources are often large areas from which pollutants flow such as lawns, agricultural land, parking lots, and roads. Stormwater carries pollutants from these sources into nearby waters (University of Florida, 2011).

Many sources contribute to nitrogen pollution in the environment. Agriculture is a predominant source of nitrogen. Growing crops requires nitrogen fertilizer use, and animal operations produce manure which contains nitrogen. Another key contributor of nitrogen is stormwater. Precipitation from storm events creates runoff from impermeable surfaces including roads, roofs, and parking lots. Nitrogen can be present on these surfaces as a result of runoff from fertilized lawns and animal droppings. Stormwater runoff carries excess nitrogen from these surfaces into nearby water bodies (U. S. Environmental Protection Agency, 2015).

Wastewater effluent also contains nitrogen. Sewers and septic systems treat human waste, but may or may not be designed to remove specific nutrients to low levels, leading to excess nitrogen in the discharge. New innovative and alternative septic systems are available with nitrogen removing technology. Nitrogen from septic system effluent may seep into the groundwater, contaminating drinking water supplies. Nitrogen also originates from residential yards. Runoff from lawns containing fertilizer and pet manure contributes to nitrogen in local surface water bodies (U. S. Environmental Protection Agency, 2015). It is important to minimize the nitrogen loading from these sources in order to prevent nitrogen pollution.

2.1.2 Forms of Nitrogen in the Environment

Nitrogen may be naturally present in several different forms. Elemental nitrogen (N_2) comprises 78% of the atmosphere and does not impact the environment (Follett and Hatfield, 2001). Nitrogen in the N_2 form is not readily available for plant consumption. Elemental nitrogen must be "fixed" or converted to a form of reactive nitrogen. Reactive nitrogen can exist as nitrates (NO_3^-) or nitrites (NO_2^-) which are nitrogen-oxygen compounds that can combine with various other organic and inorganic compounds (U. S. Environmental Protection Agency, 2014). Nitrates are common nutrient constituents of fertilizers. Reactive nitrogen can also be present as ammonia (NH_3), ammonium (NH_4^+), nitric oxide (NO), and nitrogen dioxide (NO_2). Organic nitrogen, ammonium, and ammonia comprise Kjeldahl nitrogen. These forms of reactive nitrogen occur in the environment as a result of the fixation of elemental nitrogen by biological fixation, the combustion of fossil fuels, and the production of synthetic fertilizer (Follett and Hatfield, 2001). The total nitrogen is the summation of Kjeldahl nitrogen, nitrate, and nitrite present. The environmental impact of nitrogen depends on which form it is in. The cycle of nitrogen in the environment is shown in Figure 1.

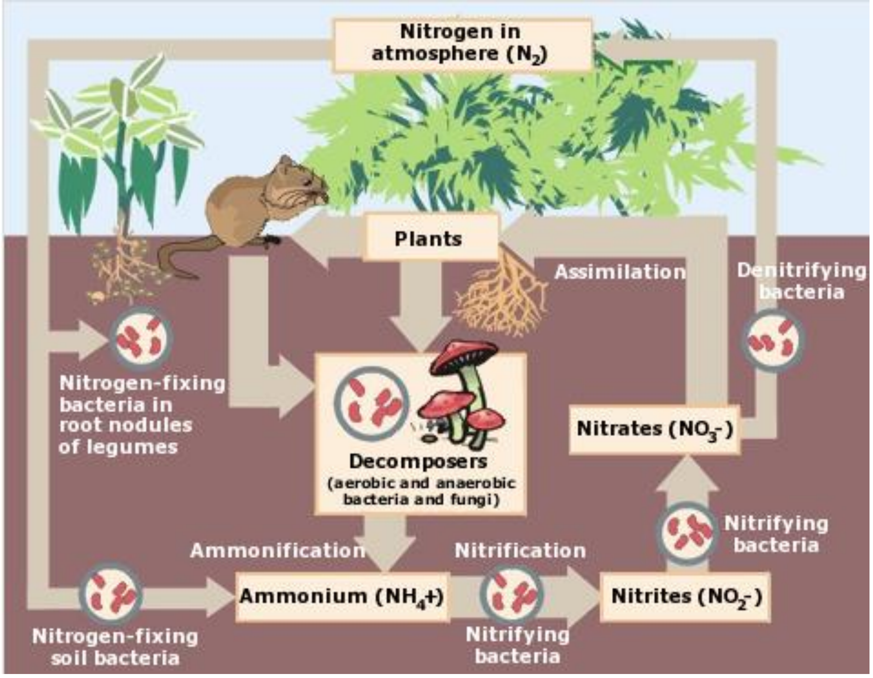


Figure 1: Nitrogen Cycle (U. S. Environmental Protection Agency, 2015)

2.1.3 Nitrogen Movement

Tracking nitrogen movement can be useful for identifying areas of health concern and deciding where remediation should be focused. Nitrogen as nitrate is highly soluble and has weak soil retention, thus is extremely mobile in soil. Nitrates move through soil at approximately the same rate as water and have high potential to enter groundwater supplies (U. S. Environmental Protection Agency, 2015). Since nitrate and nitrite do not volatilize, they usually remain in water until being consumed by organisms. It is challenging to model nitrogen movement since it depends on various factors including hydrologic processes, climate patterns, and land use (Follett and Hatfield, 2001).

2.2 Significance of Excess Nitrogen in Water

It is important to quantify nitrogen in waters. Depending on the intended use of the water, different levels of nitrogen are acceptable. This is because there are different concerns associated with nitrogen present in waters. For example, drinking water is monitored due to the potential impact on human health. Surface waters are also monitored for potential ecosystem impacts.

2.2.1 Nitrogen in Drinking Waters

Water intended for human consumption is tested for the concentration of nitrogen in various forms. Nitrate is one form of nitrogen that is regulated by the U. S. Environmental Protection Agency in drinking water. The EPA has set a maximum contaminant level (MCL) of 10 mg/ L for nitrate for potable water. The maximum contaminant level goal (MCLG) is also set at 10 mg/ L (U. S. Environmental Protection Agency, 2014). The MCL and MCLG are equivalent because nitrate levels above 10 mg/L are known to be hazardous to human health. Nitrate levels exceeding 10 mg/L in drinking water can cause serious illness in infants less than six months old, including shortness of breath and blueness of the skin (U. S. Environmental Protection Agency, 2014). If left untreated, this nitrate intake can be fatal. The cause of illness from nitrate is the conversion of nitrate to nitrite after ingestion. In the body, nitrite transforms hemoglobin to methemoglobin which cannot carry oxygen, resulting in suffocation. Infants are more susceptible to illness due to nitrate because they convert 10 percent of ingested nitrate to nitrite, compared to the 5 percent conversion in older people (New Hampshire Environmental Services, 2006). Nitrate is not known to be linked to any carcinogenic or teratogenic effects due to chronic exposure.

Since nitrite is the harmful agent in nitrate consumption, it has a lower MCL than nitrate. The EPA has set both the MCL and MCLG for nitrite at 1 mg/L (U. S. Environmental Protection Agency, 2012). Studies conducted by the National Research Council show that nitrite could be linked to cancer. Once in the body, nitrite can react with amine containing substances found in food to form nitrosamines, which are known carcinogens (New Hampshire Environmental Services, 2006). However, there is not significant evidence that nitrite can cause cancer in the absence of amines. This classifies nitrite as a Group D substance because there is inadequate evidence to determine carcinogenicity (New Hampshire Environmental Services, 2006).

2.2.2 Nitrogen in Ecosystems

In surface waters, the main concern associated with nitrate and nitrite is eutrophication. Eutrophication is the rapid growth of algae that depletes the oxygen supply in water bodies when the algae die and are biodegraded (National Ocean Service, 2008). The cause of eutrophication is excess pollutant loading in water bodies. Nitrogen and phosphorus are key contributors to eutrophication as they are vital nutrients that aid plant growth. Algal blooms, such as red and brown tides may be triggered by eutrophication and can be harmful to aquatic life and humans who come into contact with the water (National Ocean Service, 2008). Eutrophication is problematic for several other reasons. One consequence is that the penetration of light is reduced which decreases the productivity of plants at the bottom of the water body. Another issue is the depletion of oxygen which is due to increased oxygen demand from decomposers. Low oxygen levels cause death in fish that require high dissolved oxygen levels such as trout and salmon (Oregon State University, 2008). Anthropogenic eutrophication is a leading environmental concern since human inputs of nutrients continue to increase.

Nitrogen regulations in waters are based on the potential ecosystem impacts. There are no known health effects due to ammonia nitrogen in humans, but it is known to be toxic to aquatic life (Water Quality Association, 2006). Thus, ammonia nitrogen is not regulated in drinking water, but is regulated in surface water. The acute limit for ammonia nitrogen in surface water is 17 mg/L at pH 7 and 20^{o} C for one hour duration (U. S. Environmental Protection Agency, 2013). The acute limit cannot be exceeded more than once every three years. The chronic limit is 1.9 mg/L at pH 7 and 20^{o} C over a thirty day average. The chronic limit cannot be exceeded more than once every three years, and the highest four day average within a thirty day duration should not exceed 2.5 times the chronic limit (U. S. Environmental Protection Agency, 2013). These regulations are based on the toxicity of ammonia to sensitive species such as unionid mussels and gill-breathing snails (U. S. Environmental Protection Agency, 2013). Ammonia nitrogen exists in a more toxic form at high pH as un-ionized ammonia (NH_3) and is in a less toxic form at low pH as ionized ammonia (NH_4^+) (University of Kentucky, 2015). In aquatic systems, ammonia nitrogen from animal excrement and decomposition of organic material is a leading cause of fish mortality. In Chatham, MA, a town on Cape Cod, the total maximum daily load (TMDL) for total nitrogen ranges from 1 to 18 kg/day in various embayments (Commonwealth of Massachusetts, 2015). Since Chatham is geographically close to Truro, these TMDL values may or may not be appropriate for Truro embayments. The total maximum daily load is the maximum amount of a pollutant that can be present in a water body. It is used as a planning tool and a standard that helps to guide restoration projects (U. S. Environmental Protection Agency, 2015).

2.3 Nitrogen Loading in Truro, MA

Nitrogen loading in Truro’s groundwater and surface water resources has been of concern in recent years. The land use patterns on Cape Cod have caused nutrient loading to emerge as the most critical environmental priority for the region (Association to Preserve Cape Cod, 2015). The largest contributors of nitrogen in Truro, MA are associated with human activity and waste. In order to combat this environmental challenge and become better prepared for the future, many communities on Cape Cod have been developing integrated water management plans (IWRMP). Truro is in the process of creating an IWRMP after nitrate concentrations exceeding 10 mg/L were detected in the town’s drinking water supplies in 2008 and 2009 studies. This is cause for alarm since there is a demonstrated health risk at 10 mg/L (U. S. Environmental Protection Agency, 2015). The Water Resources Oversight Committee (WROC) of Truro and Weston and Sampson have been collaborating since 2008 to assess nitrogen levels in Truro.

2.3.1 Effects of Population and Geography

Municipalities on Cape Cod face unique environmental challenges. This is in large part due to the population increase from tourists in the summer months. In the 2010 census, the Truro population was found to be 2,003 residents. This number has been estimated to increase to 15,000 – 20,000 residents and tourists during the summer (Town of Truro Massachusetts, 2015). This near tenfold increase in population puts tremendous stress on the stormwater and wastewater infrastructure. This summer population surge is experienced throughout all of Cape Cod. Water cannot be confined by town lines and the narrowness of Cape Cod is speculated to allow for one town’s water quality issues to spread rapidly to its neighbors. It is crucial that water quality is monitored on Cape Cod because of the close proximity of human development and the estuary ecosystems. Excess nitrogen in Truro has resulted in a reduction in the eel grass density in local embayments (Weston and Sampson, 2014).

The specific hydrogeology of Cape Cod also plays a role in the water system interactions and shapes the environmental challenges. Glacial deposits left a variety of sediments including low permeability clay, coarse sand, and gravel (Weston and Sampson, 2014). The groundwater flow system of these glacial sediments includes recharge in freshwater lenses, recharge and discharge in surface water bodies, and discharge to shoreline areas. Groundwater flows toward coastlines and bisecting rivers and ponds such as the Pamet River and East Harbor which can result in eutrophication. Three freshwater lenses including the Pilgrim, Pamet, and North Chequesset lenses are Truro's aquifers (Weston and Sampson, 2014). These freshwater lenses are underlain by salt water and are recharged by precipitation and surface water bodies (Masterson, 1998).

2.3.2 Previous Drinking Water Studies

The WROC has been conducting drinking water studies periodically since 2007. The primary purpose of these analyses was to determine the concentration of nitrate in the drinking water supplies from different parcels of land in Truro. Truro residents were asked to collect a water sample from the tap in their homes. Participation in these studies was optional, but a large number of samples was attained due to heightened public interest. The 2007 study, for example, garnered 436 water samples from 436 unique households during tourist season. The studies recorded the address of the parcel of land, the parcel number, and the nitrate concentration. Nitrate concentrations ranged from non-detectable levels to greater than 10 mg/L which may pose a threat to public health. In 2009 and 2010, 1,181 samples were collected with a 51% return rate of sample bottles distributed. The average concentration of these samples was 1.1 mg/L, but 45 samples (3.81%) were found to have nitrate concentrations between 5 mg/L and 10 mg/L. Two samples (0.169%) yielded readings of nitrate greater than 10 mg/L. Weston and Sampson and the WROC of Truro (2014) have developed a chart outlining the level of alarm associated with various nitrate concentrations, shown in Figure 2.

According to Figure 2, the data collected means that remediation is necessary in the form of improved water resource management or treatment. It is unclear from these data whether overall nitrate levels are increasing or decreasing from year to year since the readings were sporadic, ranging from 0 mg/L to 10 mg/L from parcel to parcel, and not all residencies participated in the studies. However, it is clear from these data that continued monitoring should be conducted since the MCL of 10 mg/L set by the EPA was exceeded in some cases.

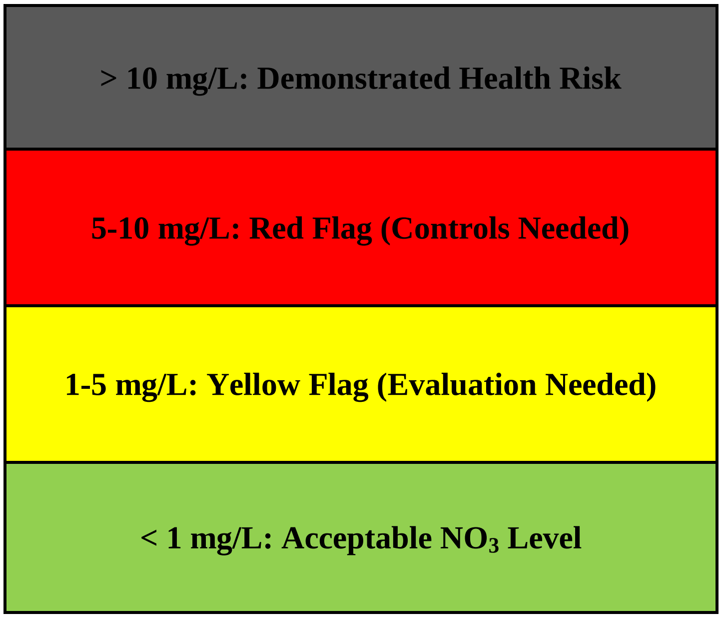


Figure 2: Nitrate Concern Levels (Weston and Sampson, 2014)

2.3.4 Preliminary GIS Mapping and Estimating Nutrient Loads

Other work that has been done on the Truro IWRMP includes GIS mapping of land use patterns in Truro. Using an iPad with GIS software, land was surveyed and land uses and types were assigned to all areas. These were categorized as permeable open spaces, vegetated cover, fertilized lawn, and impervious areas. These GIS data were then used to estimate overall nutrient loads in Truro. Nitrogen loading rates varied depending on the type of land. Impervious surfaces were assumed to have a nitrogen loading rate of 6.76 pounds/acre/year, vegetated cover was assumed to have a rate of 0.45 pounds/acre/year, and open area was assumed to have a rate of 9.73 pounds/acre/year (Weston and Sampson, 2014). Using these nitrogen loading rates, nitrogen loading was calculated for the various recharge zones in Truro, and a total was found by calculating the summation of these values. The total amount of nitrogen loading for the town of Truro was estimated to be 35,831 pounds/year, or 44.6 kg/day. This loading rate exceeds the TMDL values for nitrogen in Chatham of 1 – 18 kg/day. This could indicate that the nitrogen loading rate in Truro is problematic. Critical nitrate loading areas were then identified from these data. East Harbor and Pamet River were flagged as critical areas (Weston and Sampson, 2014). Nitrogen loading in East Harbor is evident from its historically frequent algal blooms. Pamet River receives stormwater discharge from Route 6 leading to excess nitrogen levels. Weston and Sampson (2014) outlined the critical areas in red in Figure 3.

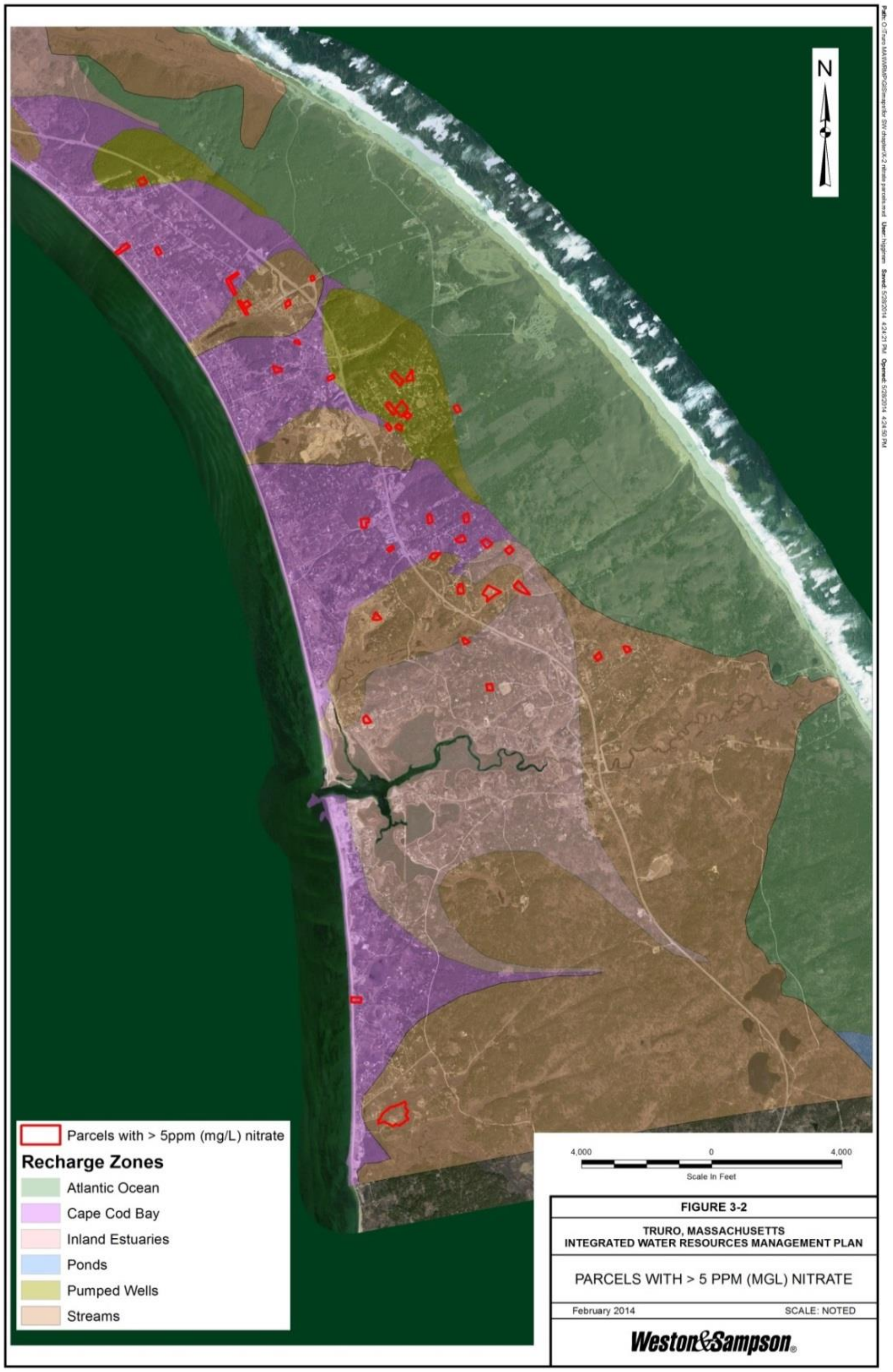


Figure 3: Critical Nitrate Parcels (Weston and Sampson, 2014)

2.4 Project Goals

The objectives for this project were two-fold. The immediate goal was to test Truro waters to determine existing nitrogen concentrations and conduct parcel surveys to determine potential nitrogen sources in the town. The long-term goal of the project was to develop recommendations for the most appropriate course of action for Truro to take in the future in order to minimize further nitrogen loading, if necessary.

2.4.1 Immediate Goal

The goal of this project was to further assess nitrogen concentrations in Truro. Through collaboration with the Water Resources Oversight Committee of Truro, this project involved sampling and analyzing groundwater and surface water from areas that have been flagged in the past as containing critical nitrate levels of greater than 5 mg/L. Twelve wells were drilled along Route 6 and Route 6A in Truro as collection points for groundwater samples. This analysis provided the town of Truro with information on short-term changes in nitrogen concentrations and where remediation should be focused.

The second immediate goal was to identify potential nitrogen sources in Truro. Several properties that were previously identified as likely nitrogen loading hotspots were investigated. The objective of this visual survey was to collect parcel-by-parcel data on lawn care practices, percentage of landscaped area, house occupancy, and well usage. The goal of surveying individual properties was to pinpoint potential factors that are contributing to nitrogen loading in Truro. It was currently not known what the main source of nitrogen loading is, whether stormwater plays a major role in nitrogen loading, or which direction nitrogen flows in groundwater. This study helped to identify where nitrogen is potentially coming from and what course of action may yield the largest reduction in nitrogen loading.

2.4.2 Long-Term Goals

This project is part of a larger initiative to develop an integrated water resource management plan for the town of Truro. The town of Truro wishes prepare for the future by eventually introducing nitrogen reducing technology. Another goal of this project was to research available options for stormwater best management practices and innovative and alternative septic systems. By presenting these technologies to local officials and educating them on options to reduce Truro’s environmental impact, a dialogue can be opened on the present threat to the town’s water resources. The long-term goal of this project was to recommend strategies to reduce nitrogen loading through the implementation of various technologies. This work was meant to raise awareness of the present issues in Truro and to offer and compare options for remediation. This component of the integrated water resource management plan will be crucial to the future health of Truro’s water.

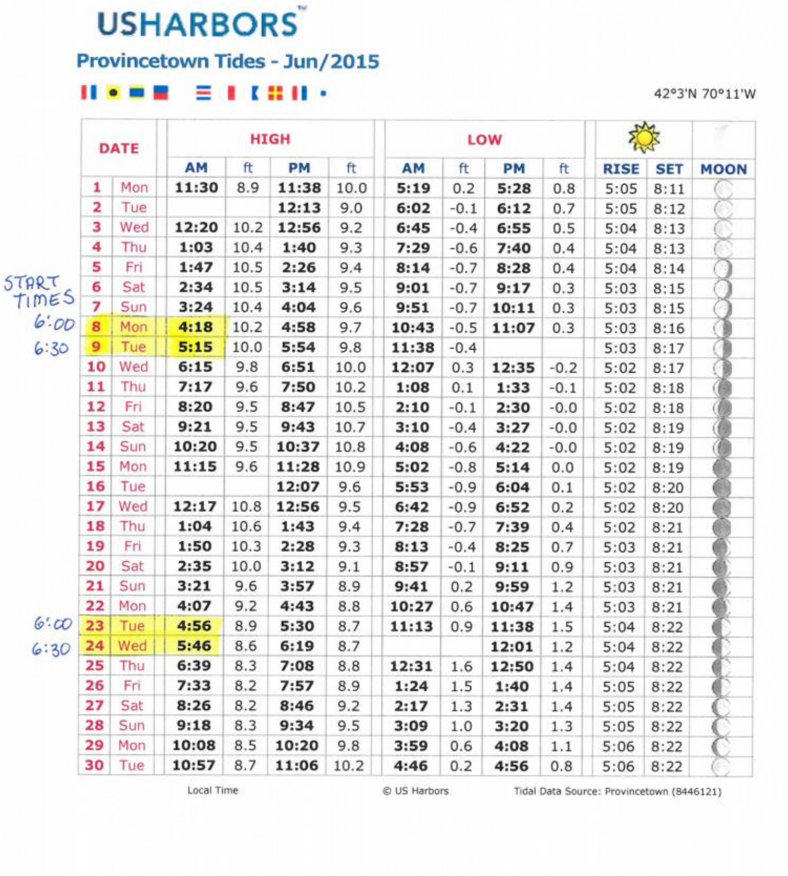
Chapter 3: Methodology

This goal of this project was to assess nitrogen concentrations in Truro and make recommendations for future water quality management. To achieve this goal, samples were collected from Truro and analyzed for water quality. First, optimal times based on previous studies and tides were determined. Then, the number and frequency of sampling events were chosen to gauge the effects of tourism on nitrogen concentrations in Truro waters.

The water samples were analyzed in the WPI environmental laboratory for nitrate, nitrite, and ammonia nitrogen, as well as phosphate, salinity, and conductivity. A field survey was also conducted to estimate the percent of landscaped area on forty-one parcels. The results were used to determine if there is a nutrient problem in Truro.

3.1 Truro Water Sampling

A sampling plan was developed for sampling groundwater and surface waters in Truro. The intent was to quantify nutrient concentrations in the town. Sampling events were conducted in early summer and in mid-summer, during the busiest time in terms of tourism. Tide charts were consulted to ensure that key sampling events aligned with high tide conditions, as was done in previous studies conducted by the WROC of Truro. The tide chart that was used to determine the sampling dates and times is shown in Figure 4.



USHARBORS™

Provincetown Tides - Jun/2015

42°3'N 70°11'W

START TIMES

	DATE		HIGH				LOW						
			AM	ft	PM	ft	AM	ft	PM	ft	RISE	SET	MOON
	1	Mon	11:30	8.9	11:38	10.0	5:19	0.2	5:28	0.8	5:05	8:11	
	2	Tue			12:13	9.0	6:02	-0.1	6:12	0.7	5:05	8:12	
	3	Wed	12:20	10.2	12:56	9.2	6:45	-0.4	6:55	0.5	5:04	8:13	
	4	Thu	1:03	10.4	1:40	9.3	7:29	-0.6	7:40	0.4	5:04	8:13	
	5	Fri	1:47	10.5	2:26	9.4	8:14	-0.7	8:28	0.4	5:04	8:14	
	6	Sat	2:34	10.5	3:14	9.5	9:01	-0.7	9:17	0.3	5:03	8:15	
	7	Sun	3:24	10.4	4:04	9.6	9:51	-0.7	10:11	0.3	5:03	8:15	
6:00	8	Mon	4:18	10.2	4:58	9.7	10:43	-0.5	11:07	0.3	5:03	8:16	
6:30	9	Tue	5:15	10.0	5:54	9.8	11:38	-0.4			5:03	8:17	
	10	Wed	6:15	9.8	6:51	10.0	12:07	0.3	12:35	-0.2	5:02	8:17	
	11	Thu	7:17	9.6	7:50	10.2	1:08	0.1	1:33	-0.1	5:02	8:18	
	12	Fri	8:20	9.5	8:47	10.5	2:10	-0.1	2:30	-0.0	5:02	8:18	
	13	Sat	9:21	9.5	9:43	10.7	3:10	-0.4	3:27	-0.0	5:02	8:19	
	14	Sun	10:20	9.5	10:37	10.8	4:08	-0.6	4:22	-0.0	5:02	8:19	
	15	Mon	11:15	9.6	11:28	10.9	5:02	-0.8	5:14	0.0	5:02	8:19	
	16	Tue			12:07	9.6	5:53	-0.9	6:04	0.1	5:02	8:20	
	17	Wed	12:17	10.8	12:56	9.5	6:42	-0.9	6:52	0.2	5:02	8:20	
	18	Thu	1:04	10.6	1:43	9.4	7:28	-0.7	7:39	0.4	5:02	8:21	
	19	Fri	1:50	10.3	2:28	9.3	8:13	-0.4	8:25	0.7	5:03	8:21	
	20	Sat	2:35	10.0	3:12	9.1	8:57	-0.1	9:11	0.9	5:03	8:21	
	21	Sun	3:21	9.6	3:57	8.9	9:41	0.2	9:59	1.2	5:03	8:21	
	22	Mon	4:07	9.2	4:43	8.8	10:27	0.6	10:47	1.4	5:03	8:21	
6:00	23	Tue	4:56	8.9	5:30	8.7	11:13	0.9	11:38	1.5	5:04	8:22	
6:30	24	Wed	5:46	8.6	6:19	8.7			12:01	1.2	5:04	8:22	
	25	Thu	6:39	8.3	7:08	8.8	12:31	1.6	12:50	1.4	5:04	8:22	
	26	Fri	7:33	8.2	7:57	8.9	1:24	1.5	1:40	1.4	5:05	8:22	
	27	Sat	8:26	8.2	8:46	9.2	2:17	1.3	2:31	1.4	5:05	8:22	
	28	Sun	9:18	8.3	9:34	9.5	3:09	1.0	3:20	1.3	5:05	8:22	
	29	Mon	10:08	8.5	10:20	9.8	3:59	0.6	4:08	1.1	5:06	8:22	
	30	Tue	10:57	8.7	11:06	10.2	4:46	0.2	4:56	0.8	5:06	8:22	

Local Time

© US Harbors

Tidal Data Source: Provincetown (8446121)

Figure 4: Provincetown Tide Chart - June 2015 (U. S. Harbors, 2015)

The sampling events are listed in Table 1. First, a set of samples was collected on June 12 to run laboratory validation tests in the WPI laboratory. Then, samples were collected on three dates: June 24, July 16, and July 22. The June 24 samples provided early summer data, and were analyzed at Envirotech Laboratories in Sandwich, MA. The July samples were during the high tourism season, and were analyzed in the WPI laboratory.

Table 1: Sampling Details

Date	Samples Collected	Lab	Purpose	Sample Collector
6/12/2015	12 groundwater	WPI	Lab Method Validation	Douglas Geist
6/24/2015	16 surface water	Envirotech	Early summer samples	Douglas Geist and volunteers
7/16/2015	12 groundwater	WPI	High tourism samples	Douglas Geist
7/22/2015	12 groundwater and 16 surface water	WPI	High tourism samples	Douglas Geist and volunteers

3.1.1 Well Locations

Wells sites were staked on May 29 along Rt. 6 and Rt. 6A in Truro. The well sites were selected along thin strips of road between East Harbor and Cape Cod Bay. East Harbor was a focus area for surface water sampling since it has had algal blooms due to nutrient loading in the past (Kevin Kuechler, personal interview, 2015). Four transects with three wells each were placed along Rt.6 and 6A. The layout of the wells can be seen in Figure 5.

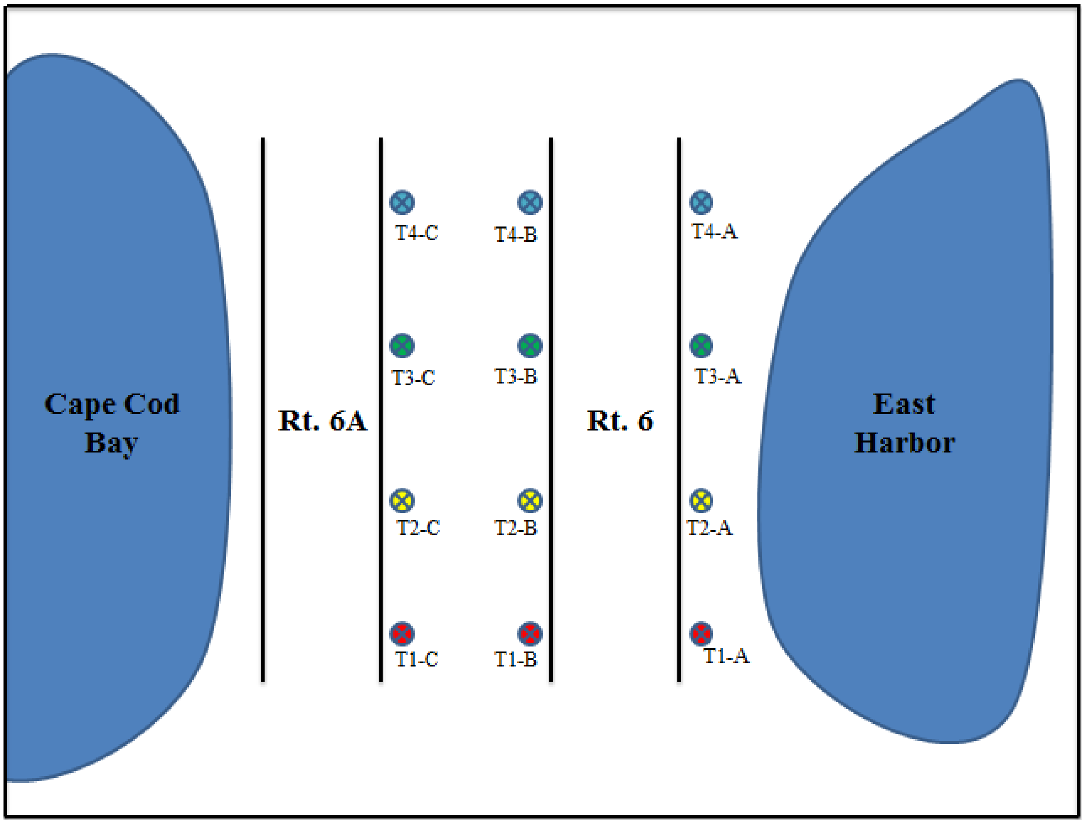


Figure 5: Well Locations

The wells were installed in four transects to determine the nutrient concentration at various locations. Placing three wells in a straight line showed whether the nitrogen concentration was higher toward Cape Cod Bay or near East Harbor. The transects were installed approximately ¼ of a mile apart.

3.1.2 Well Specifications

The wells were installed for the sole purpose of environmental quality monitoring. The wells were all shallow, at depths between 15 – 25 feet deep. The depth for each well was determined based on the depth to water and the difference in elevation due to tidal changes. The water level at the well sites was determined using a water level indicator. The appropriate depth for the well was calculated using Equation 1.

$$Well\ Depth = Water\ Level\ (ft) + 8ft\ (tidal\ variation) + 3ft\ (safety) \qquad \text{(Equation 1)}$$

In Equation 1, "Water Level" refers to the depth to water from the top of the well casing. The result from Equation 1 was then rounded up to the nearest 5 feet. For example, if the water level observed at a well site was 6 feet, the calculated well depth would be 17 feet, which would be rounded up to a total well depth of 20 feet. The specifications for each well are shown in Table 2.

Table 2: Monitoring Well Detailed Measurements

Well #	Well Location	Well Depth (ft)	Well Screen (ft)	Well Casing (ft)	Water Level (ft)	Time of Water Level Measurement	Top of Casing to Top of Box (in)
T1-A	Shoulder of Rt. 6 eastbound 38 ft from curb	15	10	5	3.10	5/20 - 3:30 PM	2.25
T2-A	Shoulder of Rt. 6 eastbound 4 ft from curb	20	10	10	9.65	5/20 - 3:45 PM	3.75
T3-A	Shoulder of Rt. 6 eastbound 11 ft from curb	20	10	10	9.30	5/20 - 3:55 PM	4.75
T4-A	Shoulder of Rt. 6 eastbound 7.7 ft from curb	20	10	10	7.50	5/20 - 4:20 PM	5.00
T1-B	Shoulder of Rt. 6 westbound ~10.5 ft from curb	20	10	10	7.80	5/21 - 2:50 PM	2.50
T2-B	Shoulder of Rt. 6 westbound ~10.5 ft from curb	20	10	10	9.20	5/21 - 2:35 PM	1.50
T3-B	Shoulder of Rt. 6 westbound ~10.5 ft from curb	20	10	10	8.60	5/20 - 4:50 PM	6.50
T4-B	Shoulder of Rt. 6 westbound ~10.5 ft from curb	20	10	10	6.80	5/20 - 4:40 PM	7.25
T1-C	Shoulder of Rt. 6A eastbound 4.5 ft from curb	25	15	10	13.80	5/21 - 3:00 PM	3.75
T2-C	Shoulder of Rt. 6A eastbound ~8.5 ft from curb	25	15	10	10.70	5/21 - 3:10 PM	3.50
T3-C	Shoulder of Rt. 6A eastbound ~7 ft from curb	25	15	10	11.10	5/21 - 3:15 PM	2.50
T4-C	Shoulder of Rt. 6A eastbound 11 ft from curb	25	15	10	7.00	5/21 - 3:20 PM	3.50

The wells were all 1-inch in diameter to minimize the space they occupied on the roadside in Truro. The length of the screening was chosen such that the water level would never be below the screening. This measure ensured that water was always accessible from the wells. The data collected from wells was compared to data from drinking water wells in residential areas of Truro.

3.1.3 Surface Water Sampling

Two surface water locations were studied in this project: East Harbor and Pamet River. The Pamet River connects with East Harbor at a clapper valve that permits fresh water to exit the harbor at low tides, and extends to Cape Cod Bay. Samples were taken at these two locations due to the frequent occurrence of algal blooms in East Harbor. Sampling form these bodies of water provided data on where nutrients flow, and how the clapper valve affects nutrient loading. These surface waters were sampled by traveling to GPS coordinates on the water by way of canoe.

3.1.4 Sampling Protocol

A specific protocol was followed for both surface water and well water sampling to ensure consistency. Volunteers from the Water Resources Oversight Committee were recruited to assist with surface water sampling. A surface water sampling training session was conducted on June 22 to ensure that volunteers knew how to utilize all tools involved, where they needed to report, how to collect samples, and how to record data accurately.

The surface water sampling protocol was as follows. The night before sampling, volunteers were asked to fill out the available information on the Data Sheet including station ID, sample date, embayment, volunteer names, and time of nearest low tide. The data log sheet can be seen in Appendix B. The morning of sampling, volunteers were instructed to check their equipment case for all necessary equipment, acquire a sampling pole, and arrive at the assigned sampling station as close to the designated start time as possible. Specialized sampling poles were designed and built using piping, twine, hose clamps, and rubber stoppers. These sampling poles allowed sample bottles to be attached and using the rubber stoppers, samples could be taken at any depth. At the sampling station, the following procedure was followed:

1) Fill in the data sheet with the following: Weather Conditions, 24-hour Precipitation, Wind Direction, and Observations.
2) Use the bottles labeled for the station.
3) Drop the Secchi Disk into the water until it disappears from view and read and record the depth at the water line; raise the disk until it reappears and read and record the depth at the water line. Then take the average of the two depths and record that.
4) Drop the Secchi Disk again, slowly, to the bottom and record the total sample depth at the water line. Be careful not to stir up sediments.
5) Rinse the sample bottle. Using surface water – dunk the bottles down into the water opening first and invert to let some water in, rinse and discard.
6) Place the sample bottle securely in the sampling pole holder.
7) Place the rubber stopper in the sample bottle on the sampling pole.
8) Lower the sampling pole (straight down) to the proper depth – for example, for a mid-point sample with an overall depth of 1 meter, lower the pole so that at the water line, it is down 0.5 meters. Once the pole is at the proper level, pull the stopper to fill up the bottle.

9) Pull the bottle up (straight up) and carefully remove it from the sampling pole (cap it or put the plug back in to avoid spilling). Once the bottle is removed, place the thermometer in to take the water temperature.
10) Record the temperature of the water on the data sheet, along with the time of the collection and the collection depth.
11) Cap the bottle and place it in the cooler.
12) Complete steps 5 – 11 for a surface sample and for a sample measured 0.5 meters up from the bottom.

The sample bottles and coolers were then brought back to the Weston and Sampson vehicle.

The groundwater sampling protocol was as follows. Bottles were labeled with the names of each well. At each station, the well was first pumped until one well volume worth of water had been bailed from the well. This was done to ensure that no "stale" water was collected. The well water was pumped using a Wattera ball-valve bailer. This was a manual pump that operated by inserting long tubing into the well and pumping the tubing up and down rapidly. The sample bottle was rinsed out with well water before the actual sample was taken. The bottle was then filled, capped and placed into a cooler filled with ice for preservation. This procedure was repeated for each well in the following order: T1-A, T2-A, T3-A, T4-A, T4-B, T3-B, T2-B, T1-B, T1-C, T2-C, T3-C, T4-C.

3.2 Laboratory Analysis

The sample bottles from the June 12, July 16, and July 22 sampling dates were transported to the WPI laboratory the day after collection to be analyzed. In the WPI laboratory, nitrate, nitrite, ammonia nitrogen, phosphate, salinity, and conductivity were measured in all water samples. The methods used to analyze the samples are described in the following sections. The samples from the June 24 sampling date were transported to Envirotech Laboratories in Sandwich, MA immediately after sampling and were analyzed for nitrate + nitrite, phosphate, ammonia nitrogen, chloride, sulfate, fluoride, and bromide.

3.2.1 Anions by Ion Chromatography

The initial plan was to use ion chromatography to determine the concentration of various anions present in the water samples including nitrate, nitrite, phosphate, chlorate, fluoride, bromide, and sulfate. However, complications were encountered during the June 12 trial run. Water samples from the wells were injected into the ion chromatograph, but the results were not accurate. This was because the water was unexpectedly brackish. Ion chromatography is meant for the analysis of fresh water. The well water had a high chloride concentration due to the high salt content which overshadowed the results of other anions. As a result, ion chromatography was not able to be used.

3.2.2 Nitrate and Nitrite

Hach method 8171 (Hach Company, Loveland, CO) was used to determine the nitrate + nitrite concentration. In this method, cadmium metal reduces nitrate in the sample to nitrite. The nitrite ion then reacts with sulfanilic acid to form diazonium salt. An amber color develops when the salt reacts with gentisic acid which is proportional to the amount of nitrate present (Hach, 2014).

To conduct this method, the 353 N, Nitrate MR PP program was started on the Hach DR 3900 or Hach DR 6000 spectrophotometer (Hach Company, Loveland, CO). Then, 10 mL of sample water was measured into a spectrophotometer vial. The contents of a NitraVer 5 Nitrate powder pillow was added to the sample cell and the stopper was placed on the vial. A one minute reaction time was allowed with vigorous shaking. Then, five minutes were allowed for the reaction to take place. A blank was then prepared by adding 10 mL of sample water to another spectrophotometer vial. The outside of the blank vial was cleaned using a kimwipe and it was inserted into the spectrophotometer cell holder. The ZERO button on the instrument was then pressed. Within two minutes, the outside of the vial containing the water sample was cleaned and it was inserted into the spectrophotometer cell holder. The READ button was pressed and the result was shown in mg/L nitrate + nitrite. The entire QA/QC report for nitrate + nitrite can be seen in Appendix A.

The Hach spectrophotometers have pre-programmed calibration curves stored in the instrument. The absorbance of the sample is compared to the absorbance in the standard curves to determine a mg/L value for nitrate + nitrite. The pre-programmed calibration curves are based on a chloride concentration of 0 mg/L. Since chloride concentrations greater than 100 mg/L can cause artificially low results due to interference, calibration curves were made with standards that had elevated chloride concentrations similar to the samples. These curves are shown in Figure 6.

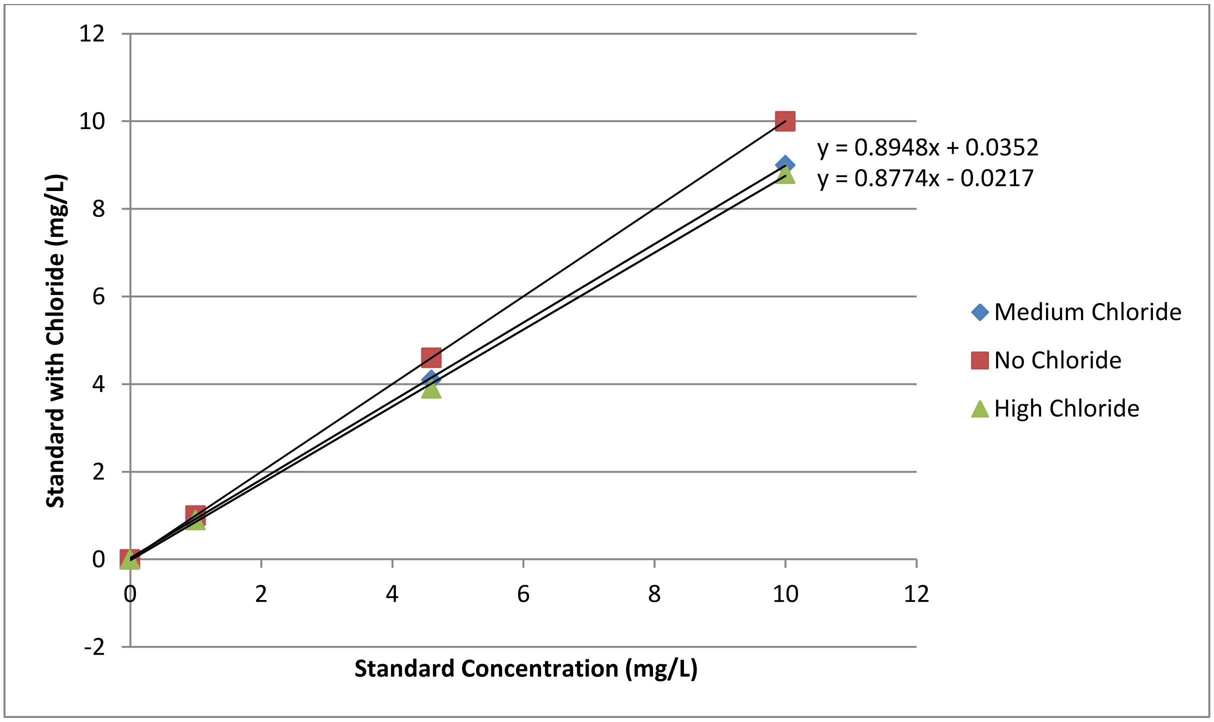


Figure 6: Nitrate Calibration Curves

Nitrate standards with chloride added were analyzed using the same experimental procedures as the samples. The standards were created with no chloride as a quality control check, low chloride (7 ppt), and high chloride (16 ppt). These data were graphed and the resulting equations for the curves were used to adjust the concentrations of samples. For example, if a sample contained chloride concentration greater than 12 ppt, the nitrate + nitrite concentration for that sample would be adjusted by substituting the nitrate + nitrite concentration for *y* in the equation, and solving for *x*.

3.2.3 Phosphate

Hach method 8048 (Hach Company, Loveland, CO) was used to determine the phosphate concentration in water samples. In this method, phosphate reacts with molybdate in an acid to form a phosphate/molybdate complex. A blue color develops when ascorbic acid reduces the complex, proportional to the amount of phosphate in the sample (Hach, 2014).

To conduct the phosphate analysis, first the 490 P, React. PP program was started on the Hach DR 3900 or Hach DR 6000 spectrophotometer (Hach Company, Loveland, CO). Then, 10 mL of sample water was measured into a spectrophotometer vial. The contents of a PhosVer 3 powder pillow were added to the sample vial and the stopper was placed on the vial. The vial was then shaken vigorously for 20 – 30 seconds. Two minutes were allowed for the reaction to take place. The blank was then prepared by adding 10 mL of sample water to another spectrophotometer vial. The outside of the vial containing the blank was cleaned and it was inserted into the spectrophotometer cell holder. The ZERO button was pressed. The outside of the vial containing the water sample was then cleaned and it was inserted into the spectrophotometer cell holder and the READ button was pressed. The result was displayed in mg/L phosphate. The entire QA/QC report for phosphate can be seen in Appendix A.

3.2.4 Ammonia Nitrogen

The Nessler Method, Hach method 8038 (Hach Company, Loveland, CO), was used to determine the ammonia nitrogen concentration in water samples. In this method, the mineral stabilizer complexes hardness in the sample and the polyvinyl alcohol dispersing agent contributes to the color development in the reaction of Nessler Reagent with ammonia. A yellow color forms that is proportional to the ammonia concentration.

To measure ammonia, first the 380 N, Ammonia, Ness program was started on the Hach DR 3900 or Hach DR 6000 spectrophotometer (Hach Company, Loveland, CO). Then, 25 mL of sample water was added to a spectrophotometer vial. Next, 25 mL of reagent grade water was measured into another spectrophotometer vial to be used as a blank. Three drops of mineral stabilizer were then added to each vial. The stoppers were placed on the vials and they were inverted several times. Three drops of polyvinyl alcohol dispersing agent were then added to each vial. The stoppers were replaced on the vials and they were inverted several times to mix. One minute was allowed for the reaction to take place. The outside of the vial containing the blank was cleaned and the vial was inserted into the spectrophotometer. The ZERO button was pressed and the display showed 0.00 mg/L NH_3-N. The outside of the vial containing the sample water was then cleaned and it was inserted into the spectrophotometer cell holder. The READ button was pressed and the result was shown in mg/L NH_3-N. The entire QA/QC report for this method can be seen in Appendix A.

3.2.5 Salinity and Conductivity

Salinity and conductivity were measured using a YSI Model 85 salinity probe (YSI Incorporation, Yellow Springs, OH). A sample of water was poured into a small vial and the probe was placed into the water. The results for salinity were displayed on the screen in parts per thousand (ppt). The mode was then changed and the result for conductivity was displayed in microsiemens.

3.3 Parcel Survey

Visual surveys were conducted at forty-one parcels in Truro. The surveys involved estimating the percentage of landscaped lawn area, the land use of the parcel, and residency data. The number of residents and land uses were estimated by noting the number of visible vehicles present, the size of the house, and any landscaping company signs on the property. This study did not account for vehicles that were hidden from view in a garage or not currently on the property. Lawn areas and visible wells on the properties were added to a GIS map in the field. Lastly, the land surrounding the parcels was assessed for its suitability as a site for a stormwater best management practice (BMP).

Chapter 4: Findings and Analysis

Nitrogen concentrations in Truro, MA were quantified by collecting samples from wells and surface waters. Laboratory analyses included determination of phosphate, nitrate + nitrite, ammonia nitrogen, salinity, and conductivity in order to characterize the quality of the waters. The waters were sampled several times to determine concentrations during the summer when tourism peaks. The following sections detail nutrient concentrations in Truro based on the June 24, July 16, and July 22 sampling events (laboratory validation data from June 12 were previously discussed in Chapter 3).

4.1 Monitoring Well Water Results

The monitoring wells were sampled on July 16 and 22, 2015. These samples were delivered to the WPI laboratory on July 17 and July 23, 2015 respectively. The results of the laboratory analysis are shown in the following sections. These data were used to estimate which direction nutrients flow in the Route 6 area of Truro and whether remedial action should be taken in this area.

4.1.3 Well Water Quality – 7/16/15

The monitoring wells were installed in four transects along Route 6 and 6A, between East Harbor and Cape Cod Bay. This configuration made it possible to determine spatial differences in nutrient concentrations. The results of laboratory analysis from the July 16, 2015 sampling event are shown in Table 3.

Table 3: Monitoring Well Data - July 16, 2015 (Analysis at WPI)

Sample ID	Phosphate (mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen (mg/L)	Salinity (ppt)	Conductivity (mS/cm)	Distance Below Measuring Point (ft)
T1-A	0.71	5.6	2.26	15.8	20.41	2.9
T1-B	0.08	1.7	1.34	7.9	10.12	7.2
T1-C	0.03	5.8	0.04	2.2	3.188	12.1
T2-A	0.06	2.1	3.10	16.5	18.90	9.2
T2-B	0.03	1.4	3.03	17.5	20.72	8.3
T2-C	0.07	0.8	2.91	16.2	18.68	8.7
T3-A	0.89	1.5	2.02	13.8	16.62	8.7
T3-B	0.90	2.4	1.23	7.7	9.260	8.1
T3-C	0.05	4.1	0.14	2.0	2.774	9.9
T4-A	0.16	ND*	0.14	0.2	0.2706	7.0
T4-B	0.25	0.6	1.79	0.1	0.2338	6.2
T4-C	0.02	0.4	0.85	0.2	0.2883	6.6

* ND = non-detectable level

In Table 3, the distance below measuring point is the distance from the top of the well casing to the water surface. The salinity ranged from 0.1 to 17.5 ppt. The water from T1, T2, and T3 wells, 75% of all wells tested, was categorized as brackish water, which ranges from 0.5 to 35 ppt (National Oceanic and Atmospheric Administration, 2008). The salinity of water from T4 wells was characteristic of fresh water. The salinity data were used to adjust the nitrate + nitrite readings due to the interference of chloride as explained in Chapter 3. The pre-adjustment nitrate + nitrite data are shown in Appendix D. The conductivity of all well samples was characteristic of brackish water. The typical conductivity range of fresh water is 0.01 – 0.2 mS/cm (State of California, 2004). The salinity and conductivity levels were highest toward the first two transects. Transect 4 had the significantly lower levels of salinity and conductivity due to their distance from the flapper valve. The water on the easternmost side of East Harbor is closer to fresh water compared to the brackish water found on the western side of the harbor.

The monitoring well samples from this sampling event had nitrate + nitrite concentrations ranging from non-detectable to 5.8 mg/L. Thus, all samples had nitrate less than the 10 mg/L drinking water MCL set by the U.S. EPA. This means that there would be no expected adverse health effects associated with this water due to nitrate if it was used as a drinking water source (it is noted that these are not drinking water wells, and the salinity is high in many of the wells). According to these data, nitrate and nitrite are most highly concentrated in the Transect 1 wells. Transect 1 is the most westward transect of wells, closest in proximity to the flapper valve that allows tidal water to enter East Harbor. This suggests that East Harbor may be a source of nutrients via the flapper valve. However, the nitrate + nitrite concentration in well T1-B was low compared to T1-A and T1-C. The nitrate data are shown visually in Figure 7.

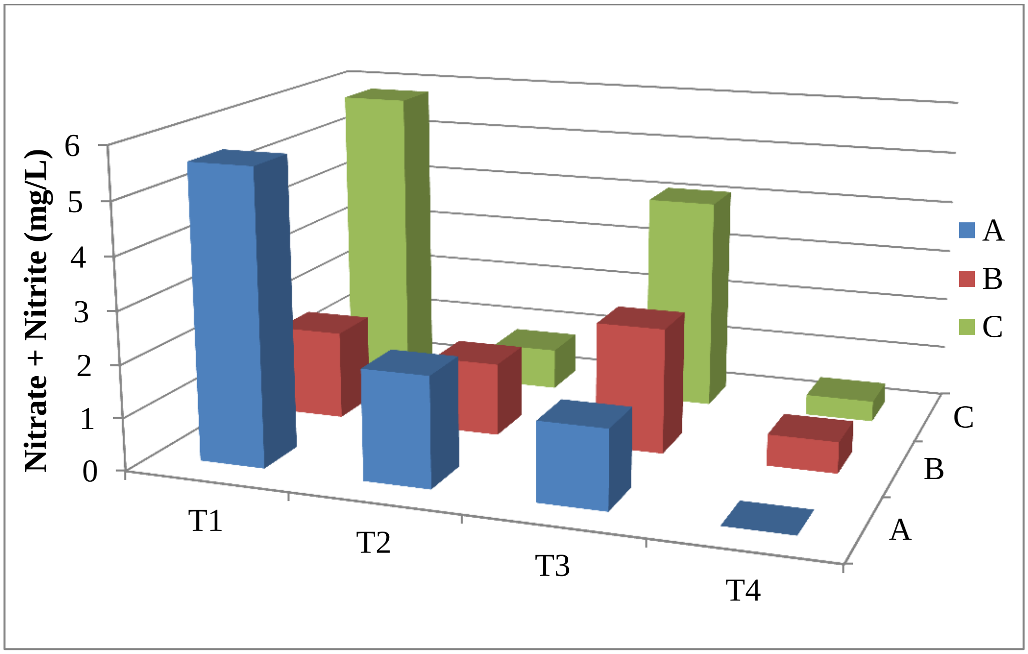


Figure 7: Nitrate + Nitrite Readings - July 16, 2015

For “A” wells, the nitrate concentration decreases steadily from transect 1 to transect 4. Trends are not apparent in the “B” or “C” wells. The average concentrations of nitrate + nitrite and phosphate from the wells are shown in Table 4.

Table 4: Monitoring Well Average Concentrations - July 16, 2015

Monitoring Well Average Concentrations		
	Nitrate + Nitrite (mg/L)	Phosphate (mg/L)
"A" Wells	2.30	0.455
"B" Wells	1.53	0.315
"C" Wells	2.78	0.043
T1 Wells	4.37	0.273
T2 Wells	1.43	0.053
T3 Wells	2.67	0.613
T4 Wells	0.333	0.143

The highest average concentrations of nitrate + nitrite were found in the “C” wells and in Transect 1 wells, while the highest concentrations of phosphate were found in the “A” wells and in Transect 3 wells.

The phosphate levels ranged from 0.02 to 0.90 mg/L. Phosphate concentrations of 0.08 to 0.10 mg/L may result in periodic algal blooms (North Carolina State University, 2015). Fifty percent of the wells had concentrations of 0.08 mg/L or higher. If there is a connection between the aquifer(s) supplying the wells and East Harbor, these phosphorus levels could indicate concern with algal blooms in the harbor. The ammonia nitrogen concentrations ranged from 0.04 mg/L in well T1-C to 3.10 mg/L in well T2-A. The average ammonia nitrogen concentration was 1.57 mg/L.

4.1.3 Well Water Quality – 7/22/15

The monitoring wells were sampled again six days later. This allowed for more data to be collected in order to determine whether the concentrations are relatively stable or variable over time. The data from this round of sampling are shown in Table 5.

Table 5: Monitoring Well Data - July 22, 2015 (Analysis at WPI)

Sample ID	Phosphate (mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen (mg/L)	Salinity (ppt)	Conductivity (mS/cm)	Distance Below Measuring Point (ft)
T1-A	0.24	4.1	0.74	15.8	19.46	2.9
T1-B	0.12	1.0	0.73	5.6	7.33	7.2
T1-C	0.15	2.6	0.00	3.0	3.784	12.7
T2-A	0.09	0.7	1.56	15.6	18.54	9.5
T2-B	0.05	1.5	2.61	16.6	19.22	9.0
T2-C	0.09	1.4	1.22	14.8	17.64	9.6
T3-A	1.09	0.1	1.84	10.7	13.15	8.7
T3-B	0.96	0.1	1.37	6.1	8.45	8.3
T3-C	0.16	1.2	0.13	1.2	1.604	10.3
T4-A	0.06	0.2	0.09	0.2	0.2246	7.1
T4-B	0.04	0.9	1.69	0.1	0.1447	6.2
T4-C	0.05	0.2	0.56	0.1	0.2159	7.8

The data from this sampling event were generally consistent with the data from July 16, 2015. The salinity and conductivity data classify the water as mostly brackish. The salinity of the T4 wells was characteristic of fresh water. The salinity data were used to adjust the nitrate + nitrite readings due to chloride interference as explained in Chapter 3. Salinity and conductivity concentrations were highest in Transect 1 wells and lowest in Transect 4 wells. The nitrate data are shown visually in Figure 8. Nitrate + nitrite concentrations ranged from 0.10 mg/L in wells T3-A and T3-B to 4.1 mg/L in well T1-A.

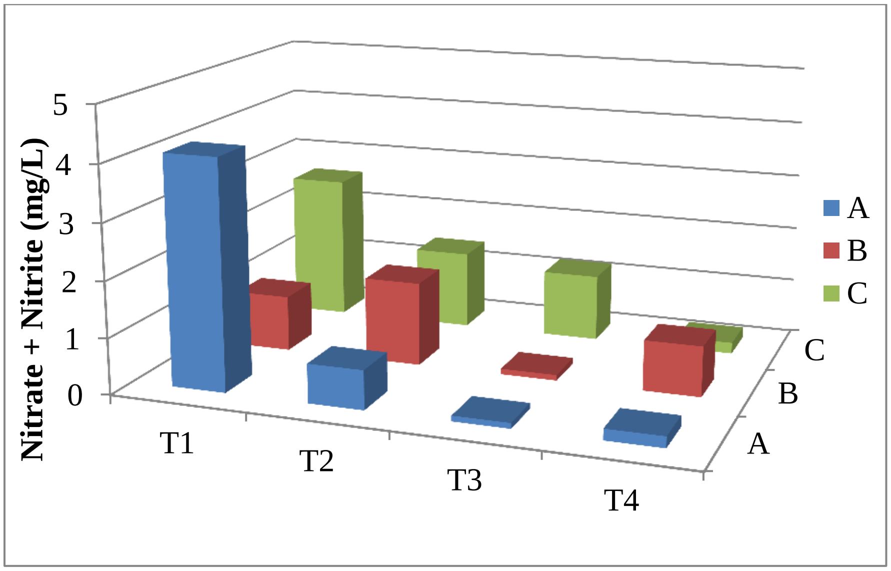


Figure 8: Nitrate + Nitrite Readings - July 22, 2015

The trends are consistent with the July 16 data. In general, nitrate concentrations decreased from transect 1 to transect 4 with the exception of the "B" wells. Average concentrations for wells by letter and by transect are show in Table 6.

Table 6: Monitoring Well Average Concentrations – July 22, 2015

Monitoring Well Average Concentrations		
	Nitrate + Nitrite (mg/L)	Phosphate (mg/L)
"A" Wells	1.28	0.370
"B" Wells	0.875	0.293
"C" Wells	1.35	0.113
T1 Wells	2.57	0.170
T2 Wells	1.20	0.077
T3 Wells	0.467	0.737
T4 Wells	0.433	0.150

The "C" wells had the highest average nitrate + nitrite concentration while the "A" wells had the highest average phosphate concentration. Transect 1 wells had the highest average nitrate + nitrite concentration while the Transect 3 wells had the highest average phosphate concentration. Phosphate concentrations ranged from 0.04 mg/L in well T4-B to 1.09 mg/L in well T3-A. Five out of the 12 wells (41.7%) had a phosphate concentration greater than the eutrophication problem level of 0.10 mg/L. As noted previously, this could be of concern if there is hydraulic connection between the wells and the harbor. The ammonia nitrogen concentrations ranged from 0.00 mg/L to 2.61 mg/L and the average concentration was 1.05 mg/L.

4.2 Surface Water Results

East Harbor and Pamet River were sampled on June 24 and July 22, 2015. The samples from June 24, 2015 were delivered to Envirotech Laboratory in Sandwich, MA after sampling was completed. The samples from July 22, 2015 were delivered to the WPI laboratory and analyzed on July 23, 2015. The surface water data were also compared with the monitoring well data in order to draw conclusions about the location and flow of nutrients.

4.2.1 Sampling Field Log Sheet Data

A sampling field log was used to collect data at each surface water sampling location. The field logs were used to record information on any human activities observed on the water and any wildlife seen on the water. For both surface water sampling events, there were no observations of human activity or animal sightings. Sampling was conducted between 6:00 am and 8:00 am on Wednesday, June 24 and Wednesday, July 22. This could suggest that human activity and animal droppings are not likely contributors to nutrient loading in East Harbor and Pamet River; however, it is possible that human activities may take place at other times. Twenty-four hour weather conditions were also recorded. There were no storm events on or the day before either day of sampling, so immediate effects of stormwater input could not be determined.

4.2.2 Surface Water Quality – 6/24/15

The surface water samples from June 24, 2015 were analyzed by Envirotech Laboratory in Sandwich, MA. The chloride concentrations in East Harbor and Pamet River categorize these waters as brackish. The concentration of chloride in freshwater ranges from 1 to 100 mg/L while the typical concentration in saltwater is 35,000 mg/L (University of Rhode Island, 2012). The average chloride concentration between both East Harbor and Pamet River is 14,691 mg/L which is common for estuarine systems. No fluoride was detected in the samples. Bromide concentrations were high, ranging from non-detectable at PH1-S to 64.4 mg/L at EH12-S. The bromide concentrations were high compared to the typical concentration of United States surface waters which ranges from 0.014 - 0.2 mg/L (U. S. Environmental Protection Agency, 2015). The typical bromide concentration in seawater ranges from 65 mg/L to 67.3 mg/L (Flury and Papritz, 1993). Therefore, the bromide concentrations from this study are characteristic of brackish waters and seawaters. Sulfate concentrations were also characteristic of brackish waters to seawaters. In freshwater, sulfate greater than 100 mg/L is toxic to organisms. The typical concentration of sulfate in seawater is 2,700 mg/L (Ministry of Environment, 2000).

The analysis by Envirotech Laboratory yielded significantly lower nitrate + nitrite and ammonia nitrogen concentrations in the surface water than the analysis by WPI of the well waters. For example, every sample resulted in a reading that was below the reportable limits for ammonia nitrogen in the June 24 surface water samples compared with the 0.04 – 3.10 mg/L ammonia nitrogen range observed in the well samples from July 16, 2015. In the June 24 surface water samples, the nitrate + nitrite concentrations ranged from below readable limits to 0.19 mg/L compared to the range of non-detectable to 5.6 mg/L in the July 16 well water samples. The average concentration of nitrate + nitrite was 0.024 mg/L in East Harbor and 0.068 mg/L in Pamet River, while the average concentration of phosphate was 0.019 mg/L for both water bodies. These data suggests that nutrient loading has not reached problematic levels in Truro. The data are shown in Table 7.

Table 7: Surface Water Data - June 24, 2015 (Analysis by Envirotech Laboratory)

Sample ID	Phosphate (mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Fluoride (mg/L)	Bromide (mg/L)
EH1-S	0.018	0.03	BRL**	11,700	1,600	ND*	34.9
EH1-D	0.021	BRL**	BRL**	11,500	1,500	ND*	42.7
EH6-S	0.015	BRL**	BRL**	14,700	2,000	ND*	51.8
EH6-D	0.018	0.02	BRL**	14,800	2,000	ND*	57.2
EH11-S	0.019	0.03	BRL**	15,400	2,200	ND*	53.5
EH11-D	0.015	0.06	BRL**	15,200	2,100	ND*	46.3
EH12-S	0.023	0.03	BRL**	18,700	2,600	ND*	64.4
EH12-D	0.023	0.02	BRL**	18,600	2,600	ND*	61.5
PH1-S	0.016	0.19	BRL**	1,250	150	ND*	ND
PH1-D	0.017	0.16	BRL**	10,600	1,500	ND*	28.5
PH2-S	0.023	0.08	BRL**	16,600	2,300	ND*	55.4
PH2-D	0.022	0.06	BRL**	17,600	2,400	ND*	51.9
PH3-S	0.020	0.02	BRL**	18,600	2,600	ND*	58.5
PH3-D	0.019	0.02	BRL**	18,400	2,600	ND*	57.0
PH6-S	0.019	BRL**	BRL**	18,600	2,600	ND*	60.0
PH6-D	0.018	0.01	BRL**	18,800	2,600	ND*	157

* ND = non-detectable level

** BRL = below readable limit

4.2.3 Surface Water Quality – 7/22/15

East Harbor and Pamet River were sampled again about a month later on July 22, 2015. This allowed data to be collected during the busiest time of the summer in Truro, when the population reaches 20,000. These data provided information on the impact of tourism on nutrient loading. The samples collected on this date were delivered to the WPI laboratory and analyzed on July 23, 2015.

These data for the surface water samples are fairly consistent with the monitoring well data, but conflict with the surface water data from Envirotech Laboratory on June 24. The results of the surface water sample analysis conducted at the WPI laboratory are shown in Table 8.

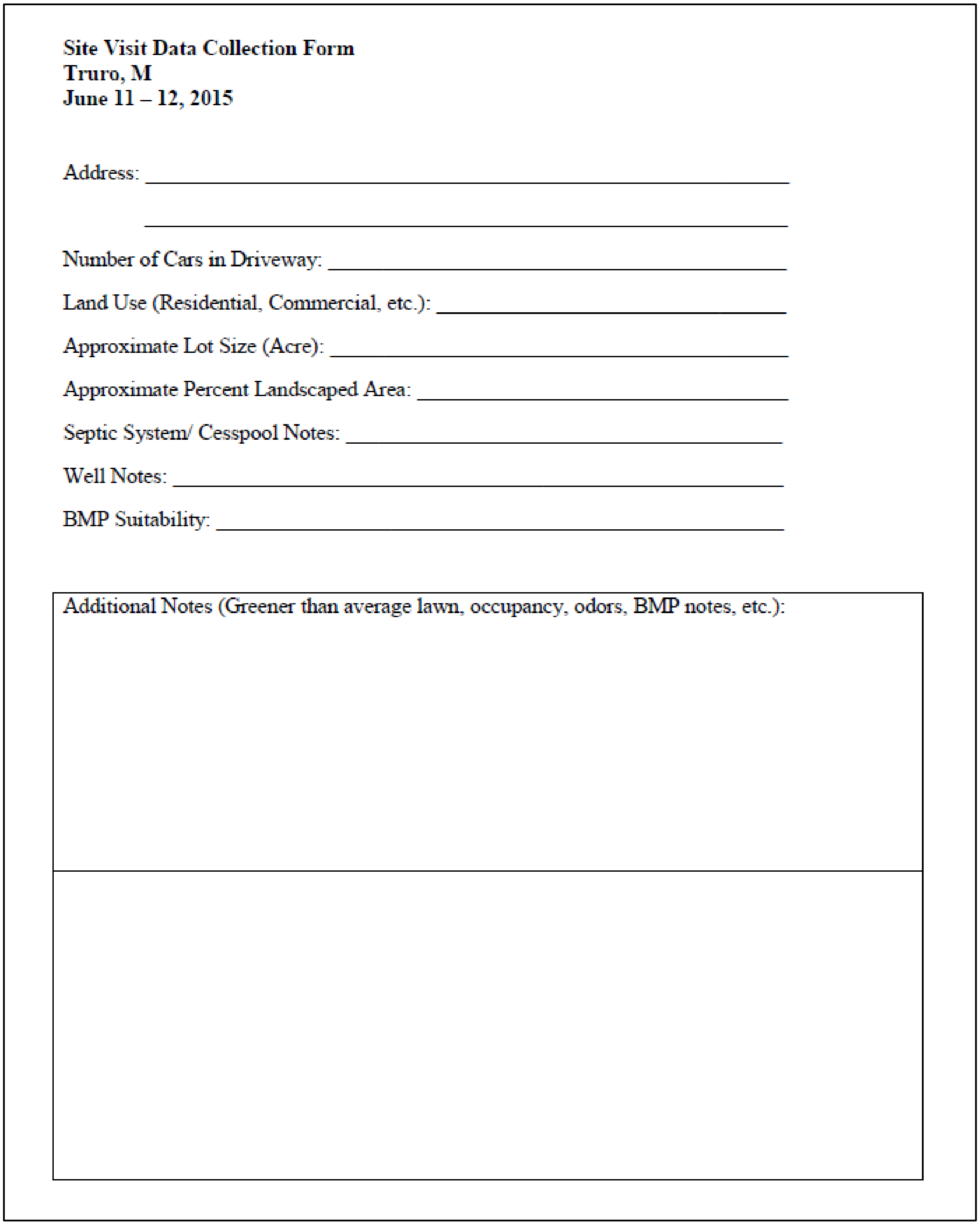
Table 8: Surface Water Data - July 22, 2015 (Analysis at WPI)

Sample ID	Phosphate (Mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen (mg/L)	Salinity (ppt)	Conductivity (mS/cm)	Distance Below Water Surface (ft)
EH1-S	0.12	4.1	3.23	18.4	24.32	0.0
EH1-D	0.26	1.2	2.60	9.5	12.26	1.3
EH6-S	0.06	2.4	3.65	23.2	28.16	0.0
EH6-D	0.14	2.2	3.75	13.5	17.01	2.6
EH11-S	0.13	1.7	3.80	22.8	27.36	0.0
EH11-D	0.11	1.3	3.60	22.9	26.97	0.7
EH12-S	0.20	2.6	4.34	12.2	15.38	0.0
EH12-D	0.12	3.1	4.31	12.3	15.36	8.9
PH1-S	0.14	0.7	0.50	1.8	2.521	0.0
PH1-D	0.12	2.2	0.38	14.9	18.01	1.6
PH2-S	0.15	3.1	4.15	11.0	13.96	0.0
PH2-D	0.23	2.8	4.16	26.8	31.21	1.3
PH3-S	0.08	2.4	4.56	18.5	21.18	0.0
PH3-D	0.08	2.9	4.32	10.7	13.52	2.0
PH6-S	0.06	2.6	4.62	20.2	22.36	0.0
PH6-D	0.20	3.1	4.23	12.0	14.31	3.6

In Table 8, the distance below water surface is the depth at which the water sample was collected. The salinity ranged from 1.8 to 26.8 ppt and the conductivity ranged from 2.521 to 31.21 mS/cm. The salinity data were used to adjust the nitrate + nitrite readings due to chloride interference as explained in Chapter 3. These salinity and conductivity data categorize East Harbor and Pamet River waters as brackish. The average concentration of nitrate + nitrite was 2.33 mg/L in East Harbor and 2.48 mg/L in Pamet River, while the average concentration of phosphate was 0.143 mg/L in East Harbor and 0.133 mg/L in Pamet River. The concentrations of these constituents in East Harbor were highest toward the western side of the harbor, where the flapper valve is located. The average nitrate + nitrite concentration in East Harbor from the Envirotech analysis was 0.0238 mg/L, two orders of magnitude lower than the average from the WPI analysis. The average phosphate concentration in East Harbor from the Envirotech analysis was 0.0190 mg/L, one order of magnitude lower than the WPI analysis. The ammonia nitrogen findings differed most. An average ammonia nitrogen concentration of 3.66 mg/L was found in East Harbor in the WPI analysis, while Envirotech reported that ammonia nitrogen was below the readable limit for every sample.

4.3 Results of Parcel Survey

A parcel survey was conducted at 41 addresses in Truro, MA on June 11 and 12, 2015. The objective of this study was to determine the land use for each parcel, occupancy, and the percentage of landscaped area. The form used to record data in the field is shown in Figure 9.



Site Visit Data Collection Form
Truro, M
June 11 – 12, 2015

Address:

Number of Cars in Driveway:

Land Use (Residential, Commercial, etc.):

Approximate Lot Size (Acre):

Approximate Percent Landscaped Area:

Septic System/ Cesspool Notes:

Well Notes:

BMP Suitability:

Additional Notes (Greener than average lawn, occupancy, odors, BMP notes, etc.):

Figure 9: Parcel Survey Data Log

Previous well water studies conducted by the WROC from 2007-2010 showed that these properties had nitrogen readings in excess of 5 mg/L. The data from the parcel survey were used to estimate if fertilizer use in Truro is a potential contributor of nitrogen to the environment.

Land use and occupancy data were used to estimate whether residential land use is possibly contributing to nitrogen loading in Truro.

4.3.1 Fertilized Lawn Area

The fertilized lawn area on each parcel was estimated since overuse of fertilizer use can lead to nitrogen in stormwater runoff. Of the 41 parcels visited, eight (20%) appeared to use fertilizer based on the appearance of the lawn. A fertilized lawn tends to stand out due to the contrast between the darker natural lawns and bright green, monoculture fertilized lawns (Kevin Kuechler, personal interview, 2015). The remaining 33 properties had natural lawns, which were less vibrant in color. Forested area and the absence of a lawn were also categorized as natural lawn area. Based on the parcel survey, it is not likely that fertilizer overuse is a problem in Truro.

4.3.2 Occupancy and Septic System Data

All of the parcels surveyed with the exception of 1 Tryworks Road and 12 Longnook Road appeared to be residential lots. It was found that 1 Tryworks Road was an undeveloped parcel of wooded land and 12 Longnook Road contained farmland which indicates commercial use. Occupancy data for homes was estimated based on the size of the house and the number and type of vehicles present on the property as recommended by Weston and Sampson. Most of the houses on the parcels visited appeared to be year-round residencies and were estimated to be four person homes. Ideally, the assessor's records for the town could be used to determine the number of bedrooms in homes; however, obtaining these data was beyond the scope of this study.

Of the 41 parcels involved in this study, five had cesspools in use as the primary septic system on the property (Town of Truro, 2015). Thirteen of the parcels had 1978 Title 5 septic systems in use. The remaining 23 parcels had 1995 Title 5 Septic systems in use.

4.4 Synthesis of Data

The results of water sampling in Truro must be interpreted in relation to both drinking water regulations and ecosystem quality standards.

The well water data, while not coming from public or private drinking water wells, can be compared to drinking water regulations to draw preliminary conclusions, as drinking water in Truro is obtained from wells. From the July 22, 2015 well water sampling, in the peak of tourist season in Truro, the average nitrate + nitrite concentration was 1.17 mg/L. This nitrate concentration is well below the drinking water MCL of 10 mg/L. This provides some evidence that there is no imminent hazard to public health from nutrient loading in Truro. Since studies conducted between 2007 and 2010 found two tap water samples with nitrate concentrations exceeding the 10 mg/L MCL, continual monitoring in a wider area should be conducted, and should focus on wells that are used as public or private drinking water sources. Year-round data is needed to draw conclusions on whether nitrate is a health hazard in Truro groundwater.

The surface water data are inconclusive with regard to threats to ecosystem quality in Truro surface waters. The average surface water concentration of nitrate was 0.046 mg/L on June 24 and 2.4 mg/L on July 22, compared to a recommended concentration below 0.10 mg/L to prevent eutrophication. For phosphate, the average concentration was 0.019 and 0.14 mg/L on June 24 and July 22, respectively, in comparison to the recommended ecosystem limit of 0.10 mg/L. Because the concentrations in the samples analyzed by Envirotech Laboratories and the samples analyzed at WPI are not consistent, additional testing is required to address quality control and quality assurance issues before definitive conclusions can be drawn. If the Envirotech data are accurate, then nitrogen concentrations have not reached problematic levels in the waters tested. If the WPI data are accurate, then these pollutant levels could result in periodic algal blooms in surface waters.

The groundwater and surface water analyses were limited to the East Harbor and Pamet River areas of Truro, and concentrations of nutrients could change in the future.

Chapter 5: Nitrogen Control Alternatives

Immediate action in Truro is not recommended based on the findings in the project. However, pollutant concentrations could change in the future. The options for Truro are as follows:

1. No action
2. Monitor and reassess
3. Remedial action

Since nitrogen levels in Truro indicated that further evaluation is needed, the town should continuously monitor and reassess the water resources. This chapter details the options that are available for Truro.

5.1 No Action

The first option for Truro is to take no action. The 2015 laboratory analysis did not indicate that there was a demonstrated public health risk in well waters. However, the wells that were tested were not drinking water sources, and the WPI laboratory is not a certified laboratory. Second, surface water concentrations of nitrate + nitrite and phosphate were acceptable in June (Envirotech data), but above recommended levels that could cause eutrophication in July (WPI data). Therefore some action is recommended to address inconsistencies in data and further assess if there are water quality issues that should be addressed.

5.2 Monitor and Reassess

The second option is to monitor and reassess the nitrogen levels in Truro. This option entails taking samples year-round at a wider range of locations to better evaluate the concentrations of pollutants in Truro waters. If nutrient concentrations are continuously monitored, time-trend data can be obtained to determine the effect of tourism on nutrient loading. This option could also involve taking samples from septic system discharge and studying the stormwater runoff to identify the largest source of nitrogen, which would enable more effective remedial action. Because nitrate + nitrite and phosphate concentrations in surface waters exceeded the level that could cause eutrophication in some samples, periodic monitoring and reassessment of both drinking water (from wells used as drinking water sources) and surface water concentrations of nitrate and phosphate is recommended.

5.3 Remedial Action

One option for Truro is to implement remediation strategies to reduce nitrogen loading. Installing nitrogen reducing technology could have an impact on the environmental quality in Truro and better prepare the town for future growth. Available nitrogen control alternatives include innovative/alternative (I/A) septic systems and stormwater best management practices. These are examples of technology that can be installed in a specific area to reduce the nitrogen loading locally. With the concentrations of nitrogen detected in this study, nitrogen control measures are not compulsory for the town of Truro, but this is subject to change in the future, and for areas of the town that were not tested. Therefore, remedial action is not recommended at this time. The following sections provide information on some remedial options for the town in the event that remedial action is recommended at a future time.

5.3.1 Title 5 Septic System Design

The Title 5 septic system is the required standard for residential wastewater treatment in Massachusetts. Typically made of concrete or fiberglass, Title 5 systems are prefabricated tanks that act as a combined settling and skimming tank and as an unheated, unmixed anaerobic digester (Metcalf and Eddy, 1991). An interior baffle wall is sometimes included to divide the tank. A schematic of a two-compartment Title 5 septic system is shown in Figure 10.

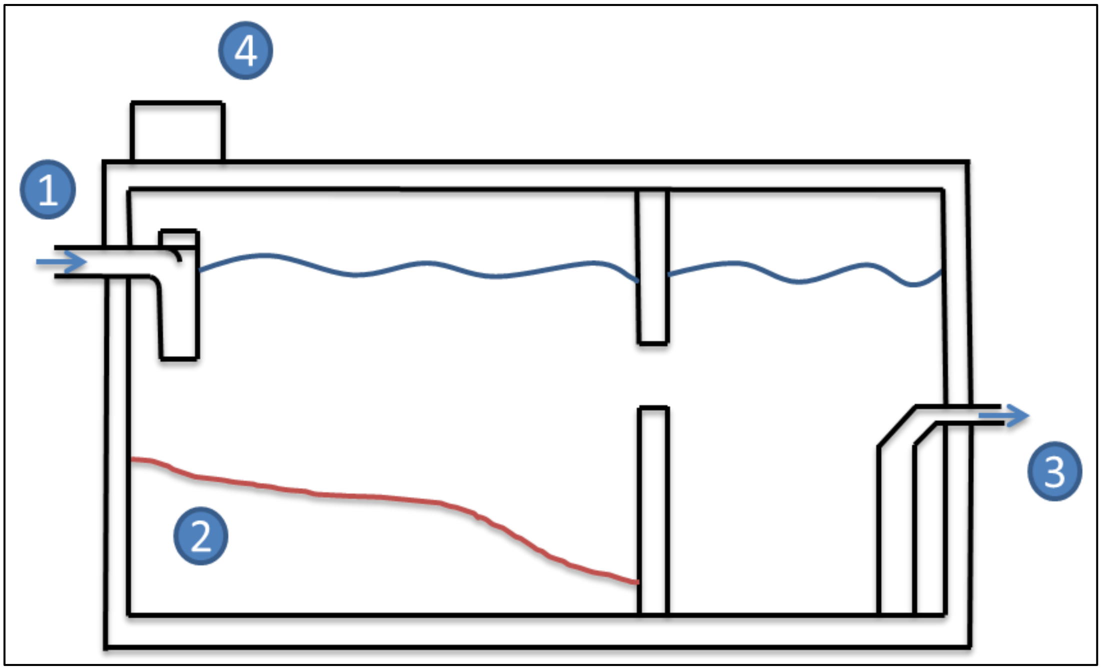


Figure 10: Title 5 Septic System Schematic

In Figure 10, the number 1 represents the influent wastewater. Number 2 represents solids settling in the primary compartment as water flows through the system. Water passes the baffle wall in the secondary compartment and is discharged as shown by Number 3 in the schematic. Number 4 represents the access port to the septic system which enables permit inspection and cleaning. Solids settle and form a layer of sludge at the bottom of the tank while greases float to the surface and create a scum layer (Metcalf and Eddy, 1991). Organic material at the bottom of the tank undergoes anaerobic decomposition and is converted to gases such as carbon dioxide, methane, and hydrogen sulfide. While the volume of solids in the tank is continually reduced by anaerobic decomposition, the contents of the tank must be pumped periodically. Settled and skimmed wastewater flows to the disposal field, or to another treatment unit, if one is used (Metcalf and Eddy, 1991). Additional treatment unis are used in innovative/alternative (I/A) septic systems, which are detailed in Sections 5.3.2 to 5.3.6.

5.3.2 Innovative/Alternative Septic Systems

If septic system effluent is identified as a significant contributor of nitrogen to the water resources in Truro, then upgrading to I/A septic systems could reduce the amount of nitrogen discharged. An I/A septic system is any septic system that does not conform to the design of the conventional Title 5 septic system design. I/A septic systems offer an additional treatment step before wastewater is discharged to the surrounding soil (Jantrania and Gross, 2006). In many I/A systems, this additional step uses bacterial growth to reduce the amount of nitrogen in the discharge. The added treatment step in I/A systems is usually installed in a septic system by either installing an additional compartment within a single processing tank or installing a separate component placed between the septic tank and the drain field (Jantrania and Gross, 2006). Two of the most commonly used types of I/A septic system are aerobic treatment units and media filters. Aerobic treatment systems inject air to create an aerated environment to enable bacteria growth while media filters utilize various types of media that are used to grow bacterial populations and facilitate biochemical and physical treatment. Many I/A systems also incorporate final dispersal technology. In some cases, alternative drain field options continue treatment of effluent as it is discharged to the surrounding soil. Drip dispersal, low pressure distribution, and media filter drain field options are available (Jantrania and Gross, 2006).

5.3.3 Innovative/Alternative Septic System Data

Various I/A septic systems have been approved for use in Massachusetts. Five I/A systems out of the thirty-four that have been approved by MassDEP for general use were compared to determine their suitability for implementation in Truro. These systems were selected because they specialized in nitrogen removal. The systems that were researched were the FAST system, the Ruck system, the AdvanTex system, the Bioclere system, the Waterloo Biofilter, and recirculating sand filters (Commonwealth of Massachusetts, 2015). The most important factors in determining the possibility for use in Truro were price, seasonal functionality, and nitrogen removal ability. Price was selected as a criterion because residents are responsible for funding a septic system upgrade on their property. The system must remain functional when used seasonally because many homes in Truro are only used during the summer months. Nitrogen removal ability of the septic systems was considered the paramount criterion because the purpose of upgrading to an I/A septic system is to reduce the amount of nitrogen entering the groundwater.

5.3.4 System Comparison and Specifications

Information pertaining to the I/A septic systems listed here was collected by emailing each manufacturer. Contact information is provided in Appendix C. Speaking with company representatives yielded current data and accurate price estimates for various system configurations.

Pricing was requested for a 600 GPD and 2000 GPD system configurations. A 600 GPD system is representative of a typical system for a single family 4-bedroom house while a 2000 GPD system is appropriate for larger developments such as condominiums. Most of the systems that were researched were media filters, with the FAST system as an exception which uses aeration for aerobic treatment. The price estimates varied significantly among the systems, ranging from $2,500 for a 600 GPD Bioclere system to $33,000 for a 600 GPD RUCK system. RUCK systems had the highest operational and maintenance cost, at an estimated $800 per year. The Bioclere system from Aquapoint offers the lowest costs in 600 GPD systems, 2000 GPD systems, and operational and maintenance costs. Manufacturer and pricing data are shown in Table 9.

Table 9: I/A Manufacturers and Pricing

System	Manufacturer	System Unit Type	Operation and Maintenance Cost	600 GPD Price Estimate	2000 GPD Price Estimate
Fixed Activated Sludge Treatment	Bio-Microbics	Aerobic Treatment	$300/year	$6,850	$14,000-18,000
RUCK System	Innovative Ruck Systems	Media Filter	$800/year	29,000-$33,000	$44,000-$49,000
AdvanTex	Orenco Systems	Media Filter	$200/year	$8,000-$10,000	$20,000
Bioclere	Aquapoint	Media Filter	$200/year	$2,500	$13,000
Waterloo Biofilter	Waterloo Biofilter Systems	Media Filter	$150/year	$12,000	$30,000

The expected concentration of total nitrogen in the effluent was requested for 600 GPD and 2000 GPD configurations. The manufacturers were also asked about the maximum design flow rate their systems can process, the suitability for seasonal use, and the expected lifespan of the systems. Nitrogen reduction data and other logistics as provided by the manufacturers are shown in Table 10.

The maximum design flow rate for each system is sufficient for residential use in Truro. Additionally, all five of the systems are able to operate seasonally without suffering from operational complications. This is important since a large portion of Truro residents only occupy their homes in the summer months. The average lifespans of the system were fairly consistent with the exception of the FAST system which claims to have a lifespan of at least 30 years compared to the 20 year lifespans of the other systems.

Table 10: Nitrogen Reducing Capability and Logistics

System	Max Design Flow Rate (GPD)	Total Nitrogen Conc. in Effluent (mg/L) (600 GPD)	Total Nitrogen Conc. in Effluent (mg/L) (2000 GPD)	Okay for Seasonal Use?	Average Lifespan
Fixed Activated Sludge Treatment	2,000	19	19	Yes	> 30 years
RUCK System	2,000	10 - 17	10 - 17	Yes	> 20 years
AdvanTex	10,000	13	13	Yes	> 20 years
Bioclere	2,000	10 - 15	10 - 15	Yes	> 20 years
Waterloo Biofilter	10,000	19	25	Yes	> 20 years

MassDEP established an accepted regulatory limit of 19 mg/L of nitrate in septic system effluent, which indicates that the system is in compliance with the DEP Approval Letters. The DEP Approval Letters are a reporting system for performance samples from I/A septic systems (Barnstable County Department of Health and Environment, 2007). The RUCK, AdvanTex, and Bioclere systems remove the largest amount of nitrogen from influent wastewater. According to the manufacturers, the RUCK system achieves 10 – 17 mg/L total nitrogen in the effluent, the AdvanTex system achieves 13 mg/L total nitrogen in the effluent, and the Bioclere system achieves 13 mg/L total nitrogen in the effluent. These concentrations are below the accepted regulatory limit of 19 mg/L which indicates that a system is in compliance with the DEP Approval Letters (Barnstable County Department of Health and Environment, 2007). When combining the cost and nitrogen reduction data, the AdvanTex and Bioclere systems appear to be the best value and the most effective treatment systems. The design for the AdvanTex system is provided because multiple studies support the effectiveness of the system including the AdvanTex Performance Summary (Orenco Systems, 2006).

5.3.5 I/A System Schematic

The AdvanTex system adds additional treatment to the conventional septic tank with the AdvanTex filter which contains engineered textile material (Orenco Systems, 2014). In this system, wastewater enters the primary chamber of the septic system, where solids settle out. The wastewater then flows to a secondary chamber where it is recirculated through the AdvanTex filter and back to the primary chamber. This step allows for further denitrification of the wastewater, which converts nitrate to dinitrogen in stepwise reactions (University of Michigan, 2015). The wastewater flows back to the secondary chamber and is discharged from the system using a discharge pump. A schematic of the AdvanTex system is shown in Figure 11.

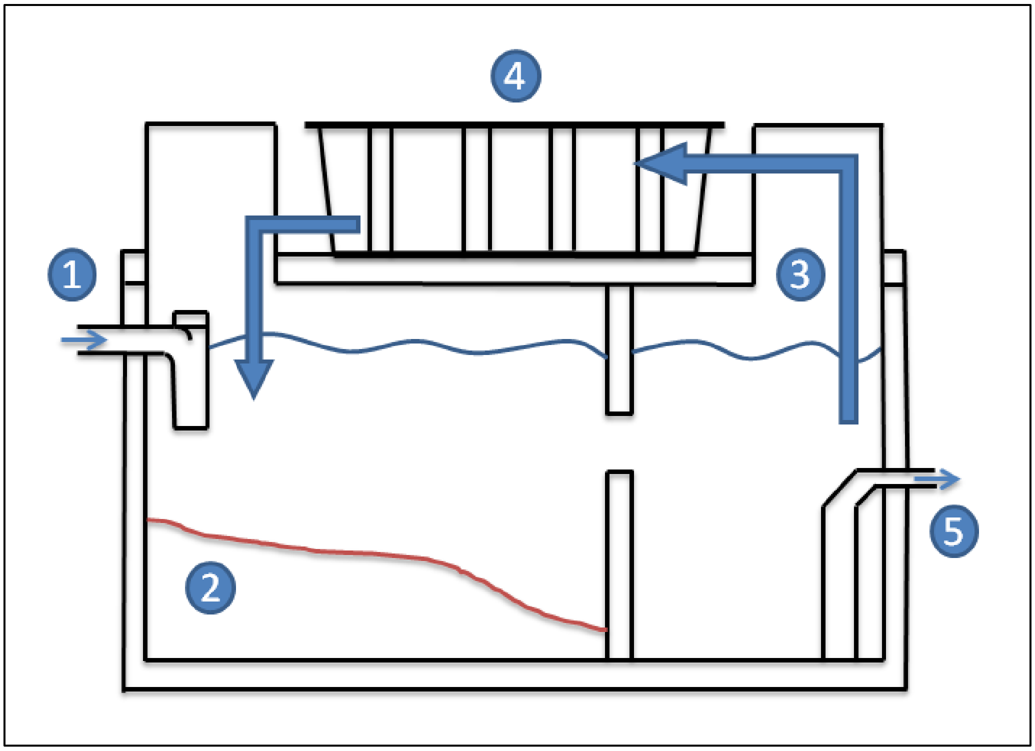


Figure 11: AdvanTex System Schematic

The septic system has various components and processes to treat wastewater and remove nutrients before discharge. Number 1 represents the point at which influent wastewater enters the system from a home. Number 2 shows solids settling at the bottom of the septic tank in the primary chamber. Baffle walls separate the primary and secondary chamber. Once water enters the secondary chamber, 75% of the water is recirculated to the primary chamber, shown by Number 3. In this step, the water is recirculated through the AdvanTex textile filter basin, represented by Number 4. The media are used to grow bacterial populations and to facilitate biochemical and physical treatment. Bacterial organisms break down organic matter and consume nutrients in the effluent. Recirculation to the primary chamber is included in this design because the conditions of the primary chamber allow for further denitrification. Number 5 represents the discharge section of the tank which includes a discharge pump and flow inducer (Orenco Systems, 2014).

5.3.6 Design Considerations

The AdvanTex system, manufactured by Orenco Systems, would be suitable for implementation in Truro based on the price, nitrogen reduction, and season use criteria. These advanced septic systems are ideal for residential use since they require little space. The septic tank volume required for various home sizes from 2 to 4 bedrooms is shown in Table 11. Most Truro homes are in this bedroom range, and thus would need tank sizes from 750 to 1,500 gallons. In comparison, the volume of the AdvanTex filter unit is an additional 420 gallons.

Table 11: Septic Tank Volume Requirements (Adapted from Metcalf and Eddy, 1991)

Design Parameter	Range (gal)	Typical (gal)
2 bedrooms	750 - 1,000	750
3 bedrooms	1,000 - 1,500	1,200
4 bedrooms	1,000 - 2,000	1,500

In addition to the small space requirement, AdvanTex systems can be configured to process a wide range of design flow rates. The design flow rate for septic systems is based on the number of bedrooms, as shown in Equation 2.

$$Number\ of\ Bedrooms\ \times 110\ GPD \qquad \text{(Equation 2)}$$

In Massachusetts, the MassDEP also specifies the minimum allowable design flow rate for a single family dwelling septic system is 330 GPD (Commonwealth of Massachusetts, 2015). Applying Equation 2 and the MassDEP requirements, the design flow rate was calculated for 2, 3, and 4 bedroom configurations. The design flow rates are shown in Table 12.

Table 12: Design Flow Rates

Design Parameter	Design Flow Rate (GPD)
2 bedrooms	330
3 bedrooms	330
4 bedrooms	440

These AdvanTex systems excel at nitrogen reduction. As part of Maryland's "Best Available Technology" program, AdvanTex systems were found to produce effluent with a mean total nitrogen concentration of 13 mg/L. The manufacturer claims that the system removes 60% of the influent total kjeldahl nitrogen (TKN) (Orenco Systems, 2006). The typical influent concentration of total nitrogen in residential wastewater is 26 – 75 mg/L (U. S. Environmental Protection Agency, 2002). The expected effluent total nitrogen is calculated using Equation 3.

$$Effluent\ TN = Influent\ TN\ (\frac{mg}{L}) - (0.60\ \times Influent\ TN\ \left(\frac{mg}{L}\right))$$

(Equation 3)

In Equation 3, TN stands for total nitrogen. For example, if the influent total nitrogen concentration is 26 mg/L, then the effluent total nitrogen concentration will be 10.4 mg/L.

The hydraulic detention time (HDT) is a key design parameter for septic systems. The HDT is calculated using Equation 4.

$$HDT\ = \frac{Volume\ of\ tank}{Design\ flow\ rate} \qquad \text{(Equation 4)}$$

Example calculations (not considering recycle) were completed for 2, 3, and 4 bedroom, single family dwellings, and the results are shown in Table 13. Hydraulic detention times ranged from 2.27 to 3.41 days. Because a percentage of the wastewater is recycled, the actual retention time in the septic tank will be longer.

Table 13: Hydraulic Detention Times

Number of Bedrooms	Tank Volume (gal)	Flow Rate (GPD)	HDT (days)
2	750	330	2.27
3	1200	330	3.64
4	1500	440	3.41

It is recommended that 75% of the wastewater is recycled through the AdvanTex filter. For the filter, the loading rate in GPD/ft^2 is a key design component. The loading rate is calculated using Equation 5.

$$Loading\ Rate\ (\frac{GPD}{feet^2}) = \frac{Flow\ Rate\ (GDP)}{Cross\ sectional\ area\ (feet^2)} \qquad \text{(Equation 5)}$$

Example calculations were completed for 2, 3, and 4 bedroom, single family dwellings, and the results are shown in Table 14.

Table 14: AdvanTex Filter Loading Rates

Number of Bedrooms	Flow Rate GPD	Filter Unit Cross-sectional Area (ft^2)	Loading Rate (GPD/ft^2)
2	330	22.5	11.0
3	330	22.5	11.0
4	440	22.5	14.7

The trench sidewall capacity and required disposal field trench length were also calculated for a 330 GPD design flow rate. The trench sidewall capacity was calculated using Equation 6.

$$Trench\ sidewall\ capacity = 2(trench\ \ depth\ (ft) \times HLR(\frac{gal}{ft^2 \cdot day}) \qquad \text{(Equation 6)}$$

In Equation 6, HLR represents the hydraulic loading rate. For this calculation, the trench depth was assumed to be 4 feet, since this is a typical value for trench depth. The HLR for a septic tank is 0.2 gallons per foot squared per day (Metcalf and Eddy, 1991). The trench sidewall capacity was calculated to be 1.6 gallons per foot per day of trench. The trench length was then calculated using Equation 7.

$$Trench\ Length = \frac{Design\ flow\ rate}{Trench\ sidewall\ capacity} \qquad \text{(Equation 7)}$$

Using Equation 7, the required trench length was calculated to be 206 feet. Installation of AdvanTex systems in the aforementioned configurations is feasible for residential lots in Truro. Upgrading from Title 5 septic systems and cesspools could reduce the amount of nitrogen entering Truro waters.

5.3.7 Stormwater Best Management Practices

Another option to reduce nitrogen loading in Truro is to implement stormwater best management practices. Stormwater best management practices (BMP's) are methods and technologies used to control stormwater discharges. Various methods to control stormwater runoff are considered BMP's including public education, public involvement, illicit discharge detection and elimination, construction, post-construction, and pollution prevention (U. S. Environmental Protection Agency, 2015). The aim of each stormwater BMP is to either prevent runoff or collect runoff and treat it before discharging it to the surrounding environment. For example, proactive public involvement and education are considered stormwater BMP's since the public can actively reduce the pollutants in the runoff from their property by using less fertilizer. Post-construction stormwater BMP's would be most effective in Truro since there is not a great deal of new development occurring. An example of a post-construction BMP is bio-retention via rain gardens. Rain gardens provide onsite stormwater treatment by directing runoff into landscaped depressions. These depressions are designed to contain the pollutant removal mechanisms that exist naturally in a forest ecosystem (U. S. Environmental Protection Agency, 2015). Rain gardens are usually situated in parking lots or on residential parcels of land. These could be applicable in Truro on parcels of land where high fertilizer use is suspected. Rain garden installations in Truro assist in nitrogen removal and could be used as a specialized spot-treatment method for problem areas.

There are structural and non-structural stormwater BMPs. Non-structural BMPs reduce the amount of pollutants that enter a stormwater system by changing human behavior. Changes to human behavior are encouraged by institutional and educational practices (Urbonas, 1994). Non-structural BMP's also include controlling pollutant spills, identifying point sources, and enforcing violations for the deposition of pollutants into the environment. Structural BMPs are built water treatment systems that are implemented to collect stormwater and treat it before it enters the natural environment (Scholes *et al.*, 2008). Some example structural and non-structural stormwater BMPs are listed in Table 15.

Truro could benefit from a combination of non-structural and structural BMPs. Non-structural BMPs including public education, reduction in use of nitrogen fertilizers, and elimination of illicit wastewater discharges are effective practices that are a strong framework for stormwater management. If stormwater is identified as a significant source of nitrogen in Truro, then structural BMPs like constructed wetlands and porous asphalt could be implemented in problem areas of the town to reduce nitrogen loading.

Table 15: BMP Options

System Type	BMP System	Description
Structural	Filter drains	Gravel trench system that filters stormwater and collects effluent in a pipe
	Porous asphalt	Open graded powdered/crushed stone with a high void ratio
	Porous paving	Continuous surface with high void area, porous blocks, or solid blocks with infiltration spaces
	Sedimentation tank	Concrete structure that allows for settling of suspended solids
	Filter strip	Vegetated strip of land in the path of stormwater flow
	Swales	Vegetated channels for transporting stormwater
	Soakaways	Underground chamber into which stormwater enters through the base and sides
	Infiltration trench	A long, thin soakaway
	Infiltration basin	Detains stormwater above ground and drains into vegetated or rock base
	Retention ponds	Retains incoming stormwater; sometimes includes vegetated margins
	Detention basins	Grassed surface that stores rainwater during storm events
	Constructed wetlands	Vegetated system with extended retention time
Non-structural	Public education	Distributing informational materials or conducting educational presentations
	Reduction in use of pollutant product	Reducing use of fertilizers, pesticides, and other pollutant-containing substances
	Adoption of site development codes	Changing town policies regarding new developments
	Adoption of erosion control programs	Developing a plan to reduce erosion
	Street sweeping and leaf pickup	Removing organic matter from stormwater pathways
	Elimination of illicit wastewater discharges	Identifying and eliminating point sources of pollutants

Chapter 6: Conclusions and Recommendations

Nitrogen levels in monitoring wells in this study were low relative to drinking water standards. Surface water sampling was inconclusive with regard to ecosystem quality due to inconsistent results, but indicated the need for additional testing. Nitrate + nitrite concentrations averaged 1.68 mg/L in the wells, compared to a drinking water standard of 10.0 mg/L. In surface waters, the nitrate + nitrite concentrations averaged 0.046 mg/L on June 24 and 2.4 mg/L on July 22. The average phosphate concentration in surface waters was 0.019 mg/L on June 24 and 0.14 mg/L on July 22. The June 24 data were low relative to the ecosystem standards, while the July 22 data were above the recommended value of 0.10 mg/L for nitrate and phosphate to prevent eutrophication. Based on these findings, the recommendations are as follows:

1. Conduct additional monitoring.
2. Identify the largest source of nitrogen in Truro and analyze seasonal trends.
3. If levels exceed the 10 mg/L drinking water MCL in the future, or frequent algal blooming in surface waters occurs, then consider remediation.

Recommendations are explained for both drinking water and surface water in this section.

6.1 Drinking Water

Since nitrate concentrations were low in the monitoring wells relative to EPA drinking water standards, remedial action for drinking water is not needed. However, continued monitoring should be conducted since a limited number of tap water samples had elevated nitrate concentrations in a 2008 study, and nitrate concentrations could increase in the future. Also, the wells sampled in this study were not used as public or private drinking water sources. If nitrate concentrations exceed the EPA MCL in the future, then the water should be treated to remove nitrate before consumption. Design of treatment systems for drinking water is beyond the scope of this project.

6.2 Surface Water

Immediate remediation of surface waters is not recommended. Further studies should first be conducted to address quality assurance issues with the nutrient data, and then, if necessary, to identify the sources of pollutants in Truro. Potential sources of pollutants in Truro are septic system discharge and stormwater runoff. If a problematic input of nitrogen is identified, nitrogen control alternatives can be considered. Seasonal data should also be obtained to identify trends over time and samples should be collected from a wider range of locations in Truro. If stormwater runoff is a significant source of nitrogen, then stormwater BMP’s can be installed. If septic system discharge is problematic with regard to nitrogen, then upgrading to I/A septic systems can be recommended to homeowners. These methods both reduce nutrient loading by limiting nutrient inputs into the environment.

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Appendix A: Quality Assurance/Quality Control Reports

Hach Method 8171 – QA/QC Report

Hach Method 8171

Determination of Nitrate by Semi-Automated Colorimetry

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1.0 SCOPE AND APPLICATION

1.1 This method covers the quantification of nitrate in a water sample.

1.2 A range of 0.1 – 10.0 mg/L nitrate can be tested by this method. Higher concentrations can be determined by diluting the sample.

2.0 SUMMARY OF METHOD

2.1 A Hach DR 3900 or Hach DR 6000 spectrophotometer is used to analyze the nitrate concentration of water samples. A 10 mL sample and a 10 mL blank consisting of sample water are added to spectrophotometer vials. A NitraVer Nitrate 5 Reagent powder pillow packet is added to the sample vial. The blank is used to calibrate the zero value for nitrate concentration. After a 1 minute reaction time with vigorous shaking, another five minutes is allowed for the reaction to take place. The vial containing the water sample is then inserted into the spectrophotometer and the nitrate concentration is displayed in mg/L.

3.0 DEFINITIONS

3.1 **Calibration Standard (CAL):** A solution prepared from the stock standard solution. This solution is used to calibrate the instrument response with respect to analyte concentration.

3.2 **Laboratory Fortified Blank (LFB):** A volume of reagent grade water to which known quantities of analyte under investigation is added. The LFB is analyzed exactly like a sample. This is used to ensure the instrument reading is accurate and precise.

3.3 **Laboratory Fortified Sample Matrix (LFM):** A volume of the water sample under investigation to which a known quantity of the method analyte is added. This serves to determine if the sample matrix contributes bias to the results.

3.4 **Laboratory Reagent Blank (LRB):** A volume of reagent grade water that is treated as a sample in order to identify any interferences.

3.5 **Linear Calibration Range (LCR):** The concentration range that will yield a linear response from the instrument.

3.6 **Stock Standard Solution (SSS):** A concentrate solution containing the method analyte prepared in the laboratory or purchased from a commercial source.

4.0 INTERFERENCES

4.1 Chloride concentrations above 100 mg/L cause low results. This can be corrected by using a calibration curve that is made with standards that have the same chloride concentration as the sample.
4.2 Ferric iron interferes at all levels.
4.3 Iron, which causes turbidity with Nessler Reagent.
4.4 Nitrite, which can be compensated for by adding 30 g/L Bromine Water dropwise to the sample until a yellow color develops, then adding 1 drop of Phenol Solution to remove the color. Results are then reported as total nitrate and nitrite.
4.5 Highly buffered samples or extreme sample pH, which can be corrected by pre-treatment.
4.6 Strong oxidizing and reducing substances interfere at all levels.

5.0 SAFETY

5.1 This method requires the use of hazardous chemicals. These chemicals must be discarded as hazardous waste.
5.2 Gloves and protective eyewear should be worn when using this method.

6.0 EQUIPMENT AND SUPPLIES

6.1 Pipet, serological, 1 mL
6.2 Graduated Cylinder, 25 mL
6.3 Spectrophotometer Cells

7.0 REAGENTS AND STANDARDS

7.1 Hach Item no. 2106169: NitraVer 5 Nitrate Reagent Powder Pillow, 10 mL
7.2 Hach Item no. 194749: Nitrate Nitrogen Standard Solution, 100 mg/L NH_3-N
7.3 Hach Item no. 221120: Bromine Water, 30 g/L
7.4 Hach Item no. 211220: Phenol Solution, 30 g/L

8.0 QUALITY ASSURANCE

8.1 Samples should be collected in plastic or glass bottles. All bottles must be rinsed with reagent grade water. The volume of samples collected must be large enough to be representative and allow for duplicate analysis.
8.2 The pH should be reduced to less than 2 using concentrated sulfuric acid and cooled to 6^oC after collection. No acid addition is necessary if samples are tested immediately.

8.3 Samples should be treated with Bromine Water and Phenol Solution to prevent nitrite interference.
8.4 Samples are transferred to the laboratory on ice the day of collection and analyzed within 24 hours of collection.
8.5 If the pH was dropped using acid, the pH must be increased to approximately 7 using 5 N sodium hydroxide solution prior to testing.

9.0 Quality Control

9.1 Initial Demonstration of Performance

9.1.1 The initial demonstration of performance should be completed if a laboratory has not conducted the test before, or if there has been some change in the measurement system, the analyte, or the instrument used.
9.1.2 One LRB and four LFB's of standard solutions between 0.2 and 1.25 mg/L should be analyzed. Each replicate must be carried through the complete experimental procedures.
9.1.3 The accuracy and precision of the five samples should then be calculated and compared with the acceptable ranges of bias. Accuracy can be measured by calculating the percent recovery using the following formula:

$$\%\ Recovery = \frac{found\ value}{true\ value} \times 100\%$$

The acceptable range for percent recovery is between 80 – 120%. Precision can be measured by calculating the relative percent difference using the following equation:

$$RPD = \frac{(sample\ result - duplicate\ result)}{(sample\ result + duplicate\ result)} \times 100\%$$

The values for precision must be within ±10% of the known concentration. If the accuracy and/or the precision are not within the acceptable ranges, the initial demonstration of performance must be repeated.

9.2 Laboratory Fortified Blank (LFB)

9.2.1 An LFB containing a mid-range concentration of nitrate should be analyzed with each batch or ten samples in order to ensure that the test method is in control.

9.2.2 The LFB must be carried through all of the experimental procedures and must fall within a ±10% of the known concentration.

9.2.3 If the result is not within the acceptable range, then the experiment must be halted until the problem is diagnosed and corrected. Then, the batch should either be reanalyzed or it must be indicated that they did not meet performance criteria.

9.3 Laboratory Fortified Matrix (LFM)

9.3.1 In order to check for interferences, one sample in each batch should be spiked with a known concentration of nitrate and carried through the experimental procedures.

9.3.2 It is important that the sum of the background and spike concentrations of nitrate does not exceed the concentration of the high calibration standard. The spike must yield a concentration in the spiked sample that is two to five times the analyte concentration, or 10 to 50 times the detection limit of the test method, whichever is greater.

9.3.3 The percent recovery of the LFM is calculated using the following formula:

$$\%\ Recovery = \frac{(LFM\ sample\ result - sample\ result)}{known\ LFM\ added\ concentration}$$

Percent recovery of the LFM should fall within the acceptable limit of ±10%.

9.4 Duplicate

9.4.1 A sample should be analyzed in duplicate in each batch in order to check the precision of the results.

9.4.2 The standard deviation of the duplicate should be calculated. The acceptable range for standard deviation is within ±10%.

10.0 CALIBRATION AND STANDARDIZATION

10.1 The calibration curve is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers.

10.2 To perform an accuracy check, use the test procedure to measure the concentration of the sample, and then keep the un-spiked sample in the spectrophotometer. Next, open the instrument menu, select the Standard

Additions option, and select values for the standard concentration, sample volume, and spike volumes. Then, prepare three spiked samples by adding 0.1 mL, 02 mL, and 0.3 mL of the standard 50 mg/L nitrate solution respectively, to three 25 mL portions of sample water and mix. Use the test procedure to measure the concentration of each of the three spiked samples, staring with the smallest spike. Select graph to compare the expected result to the actual results.

11.0 PROCEDURE

11.1 Start program **353 N, Nitrate MR PP** on the Hach DR 3900 or Hach DR 6000.
11.2 Measure 10 mL of sample water into a spectrophotometer vial.
11.3 Add the contents of a NitraVer 5 Nitrate powder pillow to the sample cell. Place the stopper on the vial.
11.4 Start a one minute reaction time and shake the vial vigorously until the timer expires.
11.5 Wait five minute to allow the reaction to take place.
11.6 Prepare the blank by adding 10 mL of sample water to another spectrophotometer vial.
11.7 Clean the outside of the vial containing the blank and insert it in the spectrophotometer cell holder.
11.8 Press ZERO. The display should show 0.00 mg/L nitrate.
11.9 Within two minutes, clean the outside of the vial containing the water sample and insert it into the spectrophotometer cell holder.
11.10 Press READ. The result will be shown in mg/L nitrate.

12.0 DATA ANALYISIS AND CALCULATIONS

12.1 A calibration curve of instrument response against standard concentration is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers. The sample concentration is calculated by comparing sample response with the standard curve and provided in mg/L nitrate by the instrument. Multiply the answer by the appropriate dilution factor.
12.2 Only values that fall in the range of the method should be reported. Samples that exceed the highest calibration standard should be diluted and reanalyzed.

13.0 METHOD PERFORMANCE

13.1 Hach reports that a standard containing 5.00 mg/L nitrate was measured with 95% confidence limits of 4.8 to 5.2 mg/L nitrate. The sensitivity is a 0.04 mg/L concentration change per 0.010 Abs. change.

14.0 POLLUTION PREVENTION

14.1 Pollution prevention is any process that reduces or eliminates that quantity of waste at the point of origin. Laboratory personnel should use pollution prevention to minimize their waste production. If the waste cannot be reduced at the source, then recycling should be considered where applicable.

14.2 The quantity of chemicals purchased should be limited to the expected demand for usage.

15.0 WASTE MANAGEMENT

15.1 Excess reagents, samples, and other wastes must be disposed of in an acceptable manner. Hazardous wastes must be deposited in the designated hazardous waste container.

References

Hach Company. Nitrate, MR, Cadmium Reduction Method. Loveland, CO. 2014.

Hach Method 8048 – QA/QC Report

Hach Method 8048

Determination of Orthophosphate by Semi-Automated Colorimetry

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June, 2015

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16.0 SCOPE AND APPLICATION

16.1 This method covers the quantification of orthophosphate in a water sample.

16.2 A range of 0.02 – 2.50 mg/L orthophosphate can be tested by this method. Higher concentrations can be determined by diluting the sample.

17.0 SUMMARY OF METHOD

17.1 A Hach DR 3900 or Hach DR 6000 spectrophotometer is used to analyze the phosphate concentration of water samples. A 10 mL sample and a 10 mL blank consisting of sample water are added to spectrophotometer vials. A PhosVer 3 Phosphate Reagent powder pillow is added to the sample vial, and the vial is shaken for 20-30 seconds. The blank is used to calibrate the zero value for phosphate concentration. A 2 minute reaction time is allowed for the reaction to take place. The vial containing the water sample is then inserted into the spectrophotometer and the phosphate concentration is displayed in mg/L.

18.0 DEFINITIONS

18.1 **Calibration Standard (CAL):** A solution prepared from the stock standard solution. This solution is used to calibrate the instrument response with respect to analyte concentration.

18.2 **Laboratory Fortified Blank (LFB):** A volume of reagent grade water to which known quantities of analyte under investigation is added. The LFB is analyzed exactly like a sample. This is used to ensure the instrument reading is accurate and precise.

18.3 **Laboratory Fortified Sample Matrix (LFM):** A volume of the water sample under investigation to which a known quantity of the method analyte is added. This serves to determine if the sample matrix contributes bias to the results.

18.4 **Laboratory Reagent Blank (LRB):** A volume of reagent grade water that is treated as a sample in order to identify any interferences.

18.5 **Linear Calibration Range (LCR):** The concentration range that will yield a linear response from the instrument.

18.6 **Stock Standard Solution (SSS):** A concentrate solution containing the method analyte prepared in the laboratory or purchased from a commercial source.

19.0 INTERFERENCES

19.1 Aluminum at concentrations greater than 200 mg/L.

19.2 Arsenate interferes at all levels.
19.3 Chromium at concentrations greater than 100 mg/L.
19.4 Copper at concentrations greater than 10 mg/L.
19.5 Hydrogen sulfide interferes at all levels.
19.6 Iron at concentrations greater than 100 mg/L.
19.7 Nickel at concentrations greater than 300 mg/L.
19.8 Highly buffered samples or extreme sample pH which can be corrected through pre-treatment.
19.9 Silica at concentrations greater than 50 mg/L.
19.10 Silicate at concentrations greater than 10 mg/L.
19.11 Turbidity or color can give inconsistent results.
19.12 Zinc at concentrations greater than 80 mg/L.

20.0 SAFETY

20.1 Gloves and protective eyewear should be worn when using this method.

21.0 EQUIPMENT AND SUPPLIES

21.1 Pipet, serological, 1 mL
21.2 Graduated Cylinder, 25 mL
21.3 Spectrophotometer Cells

22.0 REAGENTS AND STANDARDS

22.1 Hach Item no. 2106069: PhosVer 3 Phosphate Reagent Powder Pillow, 10 mL
22.2 Hach Item no. 1436832: Phosphate Standard Solution, 100 mg/L PO_4

23.0 QUALITY ASSURANCE

23.1 Samples should be collected in plastic or glass bottles. All bottles must be rinsed with reagent grade water. The volume of samples collected must be large enough to be representative and allow for duplicate analysis.
23.2 The pH should be reduced to less than 2 using concentrated sulfuric acid and cooled to 6^oC after collection. No acid addition is necessary if samples are tested immediately.
23.3 Samples are transferred to the laboratory on ice the day of collection and analyzed within 24 hours of collection.
23.4 If the pH was dropped using acid, the pH must be increased to approximately 7 using 5 N sodium hydroxide solution prior to testing.

24.0 <u>Quality Control</u>

24.1 Initial Demonstration of Performance

24.1.1 The initial demonstration of performance should be completed if a laboratory has not conducted the test before, or if there has been some change in the measurement system, the analyte, or the instrument used.

24.1.2 One LRB and four LFB's of standard solutions between 0.2 and 1.25 mg/L should be analyzed. Each replicate must be carried through the complete experimental procedures.

24.1.3 The accuracy and precision of the five samples should then be calculated and compared with the acceptable ranges of bias. Accuracy can be measured by calculating the percent recovery using the following formula:

$$\%\ Recovery = \frac{found\ value}{true\ value} \times 100\%$$

The acceptable range for percent recovery is between 80 – 120%. Precision can be measured by calculating the relative percent difference using the following equation:

$$RPD = \frac{(sample\ result - duplicate\ result)}{(sample\ result + duplicate\ result)} \times 100\%$$

The values for precision must be within ±10% of the known concentration. If the accuracy and/or the precision are not within the acceptable ranges, the initial demonstration of performance must be repeated.

24.2 Laboratory Fortified Blank (LFB)

24.2.1 An LFB containing a mid-range concentration of phosphate should be analyzed with each batch or ten samples in order to ensure that the test method is in control.

24.2.2 The LFB must be carried through all of the experimental procedures and must fall within a ±10% of the known concentration.

24.2.3 If the result is not within the acceptable range, then the experiment must be halted until the problem is diagnosed and corrected. Then, the batch should either be reanalyzed or it must be indicated that they did not meet performance criteria.

24.3 Laboratory Fortified Matrix (LFM)

24.3.1 In order to check for interferences, one sample in each batch should be spiked with a known concentration of phosphate and carried through the experimental procedures.

24.3.2 It is important that the sum of the background and spike concentrations of phosphate does not exceed the concentration of the high calibration standard. The spike must yield a concentration in the spiked sample that is two to five times the analyte concentration, or 10 to 50 times the detection limit of the test method, whichever is greater.

24.3.3 The percent recovery of the LFM is calculated using the following formula:

$$\% \, Recovery = \frac{(LFM \ sample \ result - sample \ result)}{known \ LFM \ added \ concentration}$$

Percent recovery of the LFM should fall within the acceptable limit of ±10%.

24.4 Duplicate

24.4.1 A sample should be analyzed in duplicate in each batch in order to check the precision of the results.

24.4.2 The standard deviation of the duplicate should be calculated. The acceptable range for standard deviation is within ±10%.

25.0 CALIBRATION AND STANDARDIZATION

25.1 The calibration curve is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers.

25.2 To perform an accuracy check, use the test procedure to measure the concentration of the sample, and then keep the un-spiked sample in the spectrophotometer. Next, open the instrument menu, select the Standard Additions option, and select values for the standard concentration, sample volume, and spike volumes. Then, prepare three spiked samples by adding 0.1 mL, 02 mL, and 0.3 mL of the standard 50 mg/L phosphate solution respectively, to three 25 mL portions of sample water and mix. Use the test procedure to measure the concentration of each of the three spiked samples, staring with the smallest spike. Select graph to compare the expected result to the actual results.

26.0 PROCEDURE

26.1 Start program **490 P, React. PP** on the Hach DR 3900 or Hach DR 6000.
26.2 Measure 10 mL of sample water into a spectrophotometer vial.
26.3 Add the contents of a PhosVer 3 powder pillow to the sample cell. Place the stopper on the vial.
26.4 Shake the vial vigorously for 20-30 seconds.
26.5 Wait two minute to allow the reaction to take place.
26.6 Prepare the blank by adding 10 mL of sample water to another spectrophotometer vial.
26.7 Clean the outside of the vial containing the blank and insert it in the spectrophotometer cell holder.
26.8 Press ZERO. The display should show 0.00 mg/L phosphate.
26.9 Clean the outside of the vial containing the water sample and insert it into the spectrophotometer cell holder.
26.10 Press READ. The result will be shown in mg/L phosphate.

27.0 DATA ANALYISIS AND CALCULATIONS

27.1 A calibration curve of instrument response against standard concentration is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers. The sample concentration is calculated by comparing sample response with the standard curve and provided in mg/L phosphate by the instrument. Multiply the answer by the appropriate dilution factor.
27.2 Only values that fall in the range of the method should be reported. Samples that exceed the highest calibration standard should be diluted and reanalyzed.

28.0 METHOD PERFORMANCE

28.1 Hach reports that a standard containing 2.00 mg/L phosphate was measured with 95% confidence limits of 1.98 to 2.02 mg/L phosphate. The sensitivity is a 0.02 mg/L concentration change per 0.010 Abs. change.

29.0 POLLUTION PREVENTION

29.1 Pollution prevention is any process that reduces or eliminates that quantity of waste at the point of origin. Laboratory personnel should use pollution prevention to minimize their waste production. If the waste cannot be reduced at the source, then recycling should be considered where applicable.

29.2 The quantity of chemicals purchased should be limited to the expected demand for usage.

30.0 WASTE MANAGEMENT

30.1 Excess reagents, samples, and other wastes must be disposed of in an acceptable manner. Hazardous wastes must be deposited in the designated hazardous waste container.

References

Hach Company. Phosphorus, Reactive (Orthophosphate), USEPA PhosVer 3 (Absorbic Acid) Method. Loveland, CO. 2014.

Nessler Method – QA/QC Report

Nessler Method

Determination of Ammonia Nitrogen by Semi-Automated Colorimetry

Douglas Geist

Environmental Engineering

April, 2015

Environmental Engineering Laboratory

Worcester Polytechnic Institute

Worcester, MA 01609

31.0 SCOPE AND APPLICATION

31.1 This method covers the quantification of ammonia nitrogen in a water sample.

31.2 A range of 0.02 – 2.50 mg/L NH_3 as N can be tested by this method. Higher concentrations can be determined by diluting the sample.

32.0 SUMMARY OF METHOD

32.1 A Hach DR 3900 or Hach DR 6000 spectrophotometer is used to analyze the ammonia nitrogen concentration of water samples. A 25 mL sample and a 25 mL blank consisting of reagent grade water are added to spectrophotometer vials. To each vial, 3 drops of mineral stabilizer, 3 drops of polyvinyl alcohol dispersing agent, and 1.0 mL of Nessler reagent are added. The blank is used to calibrate the zero value for ammonia nitrogen concentration. After a 1 minute reaction time, the vial containing the water sample is inserted into the spectrophotometer and the ammonia nitrogen concentration is displayed in mg/L.

33.0 DEFINITIONS

33.1 **Calibration Standard (CAL):** A solution prepared from the stock standard solution. This solution is used to calibrate the instrument response with respect to analyte concentration.

33.2 **Laboratory Fortified Blank (LFB):** A volume of reagent grade water to which known quantities of analyte under investigation is added. The LFB is analyzed exactly like a sample. This is used to ensure the instrument reading is accurate and precise.

33.3 **Laboratory Fortified Sample Matrix (LFM):** A volume of the water sample under investigation to which a known quantity of the method analyte is added. This serves to determine if the sample matrix contributes bias to the results.

33.4 **Laboratory Reagent Blank (LRB):** A volume of reagent grade water that is treated as a sample in order to identify any interferences.

33.5 **Linear Calibration Range (LCR):** The concentration range that will yield a linear response from the instrument.

33.6 **Stock Standard Solution (SSS):** A concentrate solution containing the method analyte prepared in the laboratory or purchased from a commercial source.

34.0 INTERFERENCES

34.1 Chlorine, which can be removed by adding one drop of 0.1 N sodium thiosulfate for each mg/L of chlorine, in a 250 mL sample.

34.2 Hardness, if the solution contains more than a mixture of 500 mg/L as $CaCO_3$ and 500 mg/L Mg as $CaCO_3$. Excess hardness can be removed by adding extra mineral stabilizer.
34.3 Iron, which causes turbidity with Nessler Reagent.
34.4 Seawater, due to magnesium, which can be removed by the addition of mineral stabilizer.
34.5 Sulfide, which causes turbidity with Nessler Reagent.
34.6 Glycine, which may cause discoloration or turbidity.

35.0 SAFETY

35.1 This method requires the use of hazardous chemicals. These chemicals must be discarded as hazardous waste.
35.2 Gloves and protective eyewear should be worn when using this method.

36.0 EQUIPMENT AND SUPPLIES

36.1 Pipet, serological, 1 mL
36.2 Graduated Cylinder, 25 mL
36.3 Spectrophotometer Cells

37.0 REAGENTS AND STANDARDS

37.1 Hach Item no. 27256: Reagent Grade Water
37.2 Hach Item no. 2119449: Nessler Reagent
37.3 Hach Item no. 2376626: Mineral Stabilizer
37.4 Hach Item no. 2376526: Polyvinyl Alcohol Dispersing Agent
37.5 Hach Item no. 189149: Nitrogen Ammonia Standard Solution, 1.0 mg/L NH_3-N
37.6 Hach Item no. 1479110: Nitrogen Ammonia Standard Solution, 10 mL Voluette Ampule, 50 mg/L NH_3-N

38.0 QUALITY ASSURANCE

38.1 Samples should be collected in plastic or glass bottles. All bottles must be rinsed with reagent grade water. The volume of samples collected must be large enough to be representative and allow for duplicate analysis.
38.2 The pH should be reduced to less than 2 using concentrated sulfuric acid and cooled to $6^{o}C$ after collection. No acid addition is necessary if samples are tested immediately.

38.3 Samples containing chlorine should be treated with one drop of 0.1 N sodium thiosulfate for each 0.3 mg/L of chlorine in 1 L of sample.
38.4 Samples are transferred to the laboratory on ice the day of collection and analyzed within 24 hours of collection.
38.5 If the pH was dropped using acid, the pH must be increased to approximately 7 using 5 N sodium hydroxide solution prior to testing.

39.0 Quality Control

39.1 Initial Demonstration of Performance

39.1.1 The initial demonstration of performance should be completed if a laboratory has not conducted the test before, or if there has been some change in the measurement system, the analyte, or the instrument used.
39.1.2 One LRB and four LFB's of standard solutions between 0.2 and 1.25 mg/L should be analyzed. Each replicate must be carried through the complete experimental procedures.
39.1.3 The accuracy and precision of the five samples should then be calculated and compared with the acceptable ranges of bias. Accuracy can be measured by calculating the percent recovery using the following formula:

$$\%\ Recovery = \frac{found\ value}{true\ value} \times 100\%$$

The acceptable range for percent recovery is between 80 – 120%. Precision can be measured by calculating the relative percent difference using the following equation:

$$RPD = \frac{(sample\ result - duplicate\ result)}{(sample\ result + duplicate\ result)} \times 100\%$$

The values for precision must be within ±10% of the known concentration. If the accuracy and/or the precision are not within the acceptable ranges, the initial demonstration of performance must be repeated.

39.2 Laboratory Fortified Blank (LFB)

39.2.1 An LFB containing a mid-range concentration of ammonia nitrogen should be analyzed with each batch or ten samples in order to ensure that the test method is in control.

39.2.2 The LFB must be carried through all of the experimental procedures and must fall within a ±10% of the known concentration.

39.2.3 If the result is not within the acceptable range, then the experiment must be halted until the problem is diagnosed and corrected. Then, the batch should either be reanalyzed or it must be indicated that they did not meet performance criteria.

39.3 Laboratory Fortified Matrix (LFM)

39.3.1 In order to check for interferences, one sample in each batch should be spiked with a known concentration of ammonia nitrogen and carried through the experimental procedures.

39.3.2 It is important that the sum of the background and spike concentrations of ammonia nitrogen does not exceed the concentration of the high calibration standard. The spike must yield a concentration in the spiked sample that is two to five times the analyte concentration, or 10 to 50 times the detection limit of the test method, whichever is greater.

39.3.3 The percent recovery of the LFM is calculated using the following formula:

$$\%\,Recovery = \frac{(LFM\ sample\ result - sample\ result)}{known\ LFM\ added\ concentration}$$

Percent recovery of the LFM should fall within the acceptable limit of ±10%.

39.4 Duplicate

39.4.1 A sample should be analyzed in duplicate in each batch in order to check the precision of the results.

39.4.2 The standard deviation of the duplicate should be calculated. The acceptable range for standard deviation is within ±10%.

40.0 CALIBRATION AND STANDARDIZATION

40.1 The calibration curve is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers.

40.2 To perform an accuracy check, use the test procedure to measure the concentration of the sample, and then keep the un-spiked sample in the spectrophotometer. Next, open the instrument menu, select the Standard Additions option, and select values for the standard concentration, sample volume, and spike volumes. Then, prepare three spiked samples by adding 0.1 mL, 02 mL, and 0.3 mL of the standard 50 mg/L ammonia nitrogen solution respectively, to three 25 mL portions of sample water and mix. Use the test procedure to measure the concentration of each of the three spiked samples, staring with the smallest spike. Select graph to compare the expected result to the actual results.

41.0 PROCEDURE

41.1 Start program **380 N, Ammonia, Ness** on the Hach DR 3900 or Hach DR 6000.
41.2 Measure 25 mL of sample water into a spectrophotometer vial.
41.3 Measure 25 mL of reagent grade water into another spectrophotometer vial to be used as a blank.
41.4 Add 3 drops of mineral stabilizer to each vial. Place the stoppers on both vials and invert each several times to mix.
41.5 Add 3 drops of polyvinyl alcohol dispersing agent to each vial. Replace the stoppers on both vials and invert each several times to mix.
41.6 Pipet 1.0 mL of Nessler reagent to each vial. Replace the stoppers on both vials and invert each several times to mix.
41.7 Wait one minute to allow the reaction to take place.
41.8 Clean the outside of the vial containing the blank and insert it in the spectrophotometer cell holder.
41.9 Press ZERO. The display should show 0.00 mg/L NH_3-N.
41.10 Clean the outside of the vial containing the water sample and insert it into the spectrophotometer cell holder.
41.11 Press READ. The result will be shown in mg/L NH_3-N.

42.0 DATA ANALYISIS AND CALCULATIONS

42.1 A calibration curve of instrument response against standard concentration is pre-programmed in the Hach DR 3900 and Hach DR 6000 spectrophotometers. The sample concentration is calculated by comparing sample response with the standard curve and provided in mg/L NH_3-N by the instrument. Multiply the answer by the appropriate dilution factor.
42.2 Only values that fall in the range of the method should be reported. Samples that exceed the highest calibration standard should be diluted and reanalyzed.

43.0 METHOD PERFORMANCE

43.1 Hach reports that a standard containing 1.00 mg/L NH_3-N was measured with 95% confidence limits of 0.99 to 1.01 mg/L NH_3-N. The sensitivity is a 0.02 mg/L concentration change per 0.010 Abs. change.

44.0 POLLUTION PREVENTION

44.1 Pollution prevention is any process that reduces or eliminates that quantity of waste at the point of origin. Laboratory personnel should use pollution prevention to minimize their waste production. If the waste cannot be reduced at the source, then recycling should be considered where applicable.

44.2 The quantity of chemicals purchased should be limited to the expected demand for usage.

45.0 WASTE MANAGEMENT

45.1 Excess reagents, samples, and other wastes must be disposed of in an acceptable manner. Hazardous wastes must be deposited in the designated hazardous waste container.

References

ASTM International. *Standard Test Methods for Ammonia Nitrogen in Water*. http://compass.astm.org/EDIT/html_annot.cgi?D1426+08#_ga=1.204212883.2061926146.1429129495 (accessed April13, 2015).

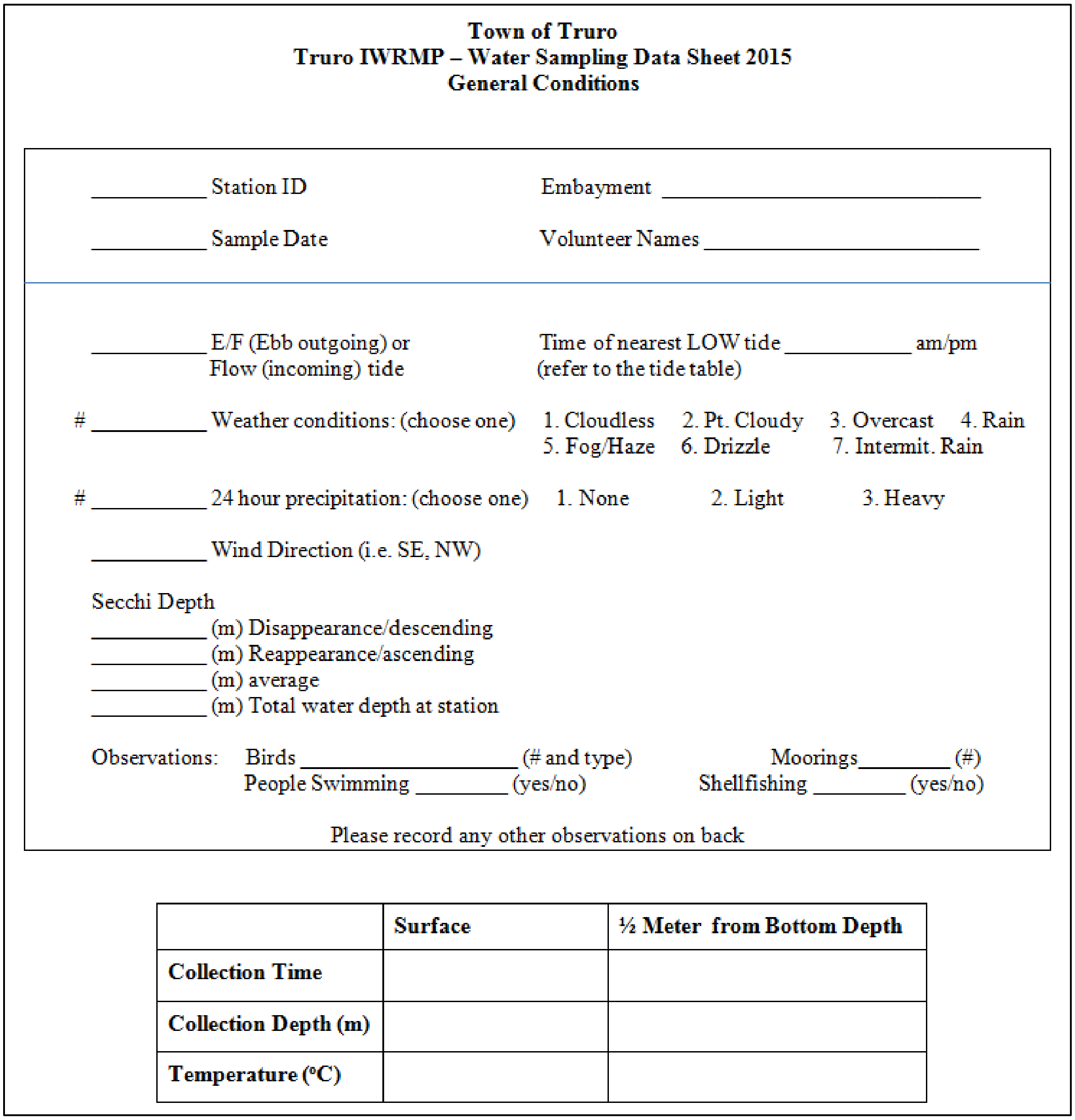
Hach Company. Nitrogen-Ammonia, Nessler Method. Loveland, CO. 2014.

Rice, E. W.; Baird, R. B.; Eaton, A. D.; Clesceri, L. S. 1020 Quality Assurance. *Standard Methods for the Examination of Water and Wastewater*, 22nd Edition; American Public Health Association, American Water Works Association, Water Environment Federation: Washington, D. C., 2012; 56-65.

U. S. Environmental Protection Agency. Determination of Ammonia Nitrogen by Semi-Automated Colorimetry. http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_350_1.pdf (accessed April 13, 2015).

Appendix B: Field Data Log Sheets

Surface Water Sampling Field Data Sheet



Town of Truro
Truro IWRMP – Water Sampling Data Sheet 2015
General Conditions

__________ Station ID

Embayment ____________________________

__________ Sample Date

Volunteer Names ________________________

__________ E/F (Ebb outgoing) or Flow (incoming) tide

Time of nearest LOW tide __________ am/pm (refer to the tide table)

__________ Weather conditions: (choose one) 1. Cloudless 2. Pt. Cloudy 3. Overcast 4. Rain 5. Fog/Haze 6. Drizzle 7. Intermit. Rain

__________ 24 hour precipitation: (choose one) 1. None 2. Light 3. Heavy

__________ Wind Direction (i.e. SE, NW)

Secchi Depth
__________ (m) Disappearance/descending
__________ (m) Reappearance/ascending
__________ (m) average
__________ (m) Total water depth at station

Observations: Birds ___________________ (# and type) Moorings________ (#)
People Swimming ________ (yes/no) Shellfishing ________ (yes/no)

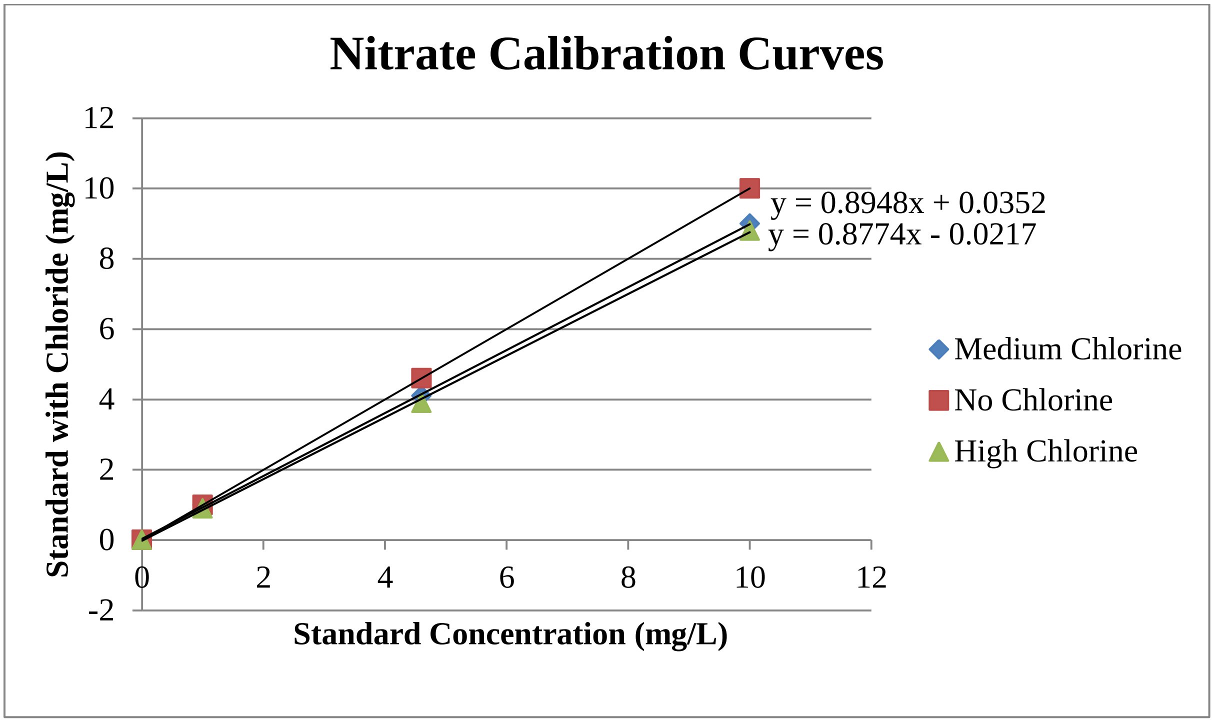
Please record any other observations on back

	Surface	**½ Meter from Bottom Depth**
Collection Time		
Collection Depth (m)		
Temperature (°C)		

Appendix C: Manufacturer Contact Information

Manufacturer	Contact Name	Contact Email Address
Bio-Microbics	Lauren Usilton	laurenu@jrsalesinc.com
Innovative Ruck Systems	Michael McGrath	mmcgrath@holmesandmcgrath.com
Orenco Systems	Blake Johnston	bjohnston@orenco.com
Aquapoint	Mark Lubbers	mlubbers@aquapoint.com
Waterloo Biofilter Systems	Mark Cottrell	mcottrell@clearwaterindustries.com

Appendix D: Raw Data and Nitrate + Nitrite Adjustment Curves



Note: The "Medium Chloride" equation was used for salinity between 4 and 9 ppt.
The "High Chloride" equation was used for salinity greater than 9 ppt.
Samples with salinity less than 4 mg/L were not adjusted.

July 22 Samples

Sample ID	Salinity (ppt)	Unadjusted Nitrate + Nitrite (mg/L)	Adjusted Nitrate + Nitrite (mg/L)	Calibration Curve
T1-A	15.8	3.6	4.1	y = 0.8774x - 0.0217
T1-B	5.6	0.9	1	y = 0.8948x + 0.0352
T1-C	3.0	2.3	2.6	N/A
T2-A	15.6	0.6	0.7	y = 0.8774x - 0.0217
T2-B	16.6	1.3	1.5	y = 0.8774x - 0.0217
T2-C	14.8	1.2	1.4	y = 0.8774x - 0.0217
T3-A	10.7	0.1	0.1	y = 0.8774x - 0.0217
T3-B	6.1	0.1	0.1	y = 0.8948x + 0.0352
T3-C	1.2	1.2	1.2	N/A
T4-A	0.2	0.2	0.2	N/A
T4-B	0.1	0.9	0.9	N/A
T4-C	0.1	0.2	0.2	N/A
EH1-S	18.4	3.6	4.1	y = 0.8774x - 0.0217
EH1-D	9.5	1	1.2	y = 0.8774x - 0.0217
EH6-S	23.2	2.1	2.4	y = 0.8774x - 0.0217
EH6-D	13.5	1.9	2.2	y = 0.8774x - 0.0217
EH11-S	22.8	1.5	1.7	y = 0.8774x - 0.0217
EH11-D	22.9	1.1	1.3	y = 0.8774x - 0.0217
EH12-S	12.2	2.3	2.6	y = 0.8774x - 0.0217
EH12-D	12.3	2.7	3.1	y = 0.8774x - 0.0217
PH1-S	1.8	0.7	0.7	N/A
PH1-D	14.9	1.9	2.2	y = 0.8774x - 0.0217
PH2-S	11.0	2.7	3.1	y = 0.8774x - 0.0217
PH2-D	26.8	2.4	2.8	y = 0.8774x - 0.0217
PH3-S	18.5	2.1	2.4	y = 0.8774x - 0.0217
PH3-D	10.7	2.5	2.9	y = 0.8774x - 0.0217
PH6-S	20.2	2.3	2.6	y = 0.8774x - 0.0217
PH6-D	12.0	2.7	3.1	y = 0.8774x - 0.0217

July 16 Well Water Samples				
Sample ID	Salinity (ppt)	Unadjusted Nitrate + Nitrite (mg/L)	Adjusted Nitrate + Nitrite (mg/L)	Calibration Curve
T1-A	15.8	4.9	5.6	y = 0.8774x - 0.0217
T1-B	7.9	1.6	1.7	y = 0.8948x + 0.0352
T1-C	2.2	5.8	5.8	N/A
T2-A	16.5	1.8	2.1	y = 0.8774x - 0.0217
T2-B	17.5	1.2	1.4	y = 0.8774x - 0.0217
T2-C	16.2	0.7	0.8	y = 0.8774x - 0.0217
T3-A	13.8	1.3	1.5	y = 0.8774x - 0.0217
T3-B	7.7	2.2	2.4	N/A
T3-C	2.0	4.1	4.1	N/A
T4-A	0.2	ND	ND	N/A
T4-B	0.1	0.6	0.6	N/A
T4-C	0.2	0.4	0.4	N/A