Sources of Arsenic and Lead in Drinking Water of Eastport, Perry, and Pleasant Point, Maine

by

Abby Harvey

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Signature redacted

Author . . . .
Department of Civil and Environmental Engineering
May 18, 2018

Signature redacted

Certified by . . . .
. . . .
Harold Hemond
William E Leonhard Professor of Civil and Environmental Engineering
Thesis Supervisor

Signature redacted

Certified by . . . .
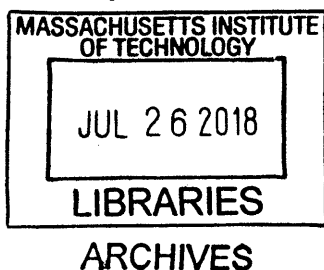Kathleen Vandiver
Director, Community Outreach Education & Engagement
Center for Environmental Health Sciences
Thesis Supervisor

Signature redacted

Accepted by . . . .
. . . .
Jesse Kroll
Professor of Civil and Environmental Engineering
Chair, Graduate Program Committee

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Abstract

Lead and arsenic in drinking water are a health risk to communities throughout the world; lead can be a problem in houses with old piping systems with either lead piping or 50/50 lead solder, and groundwater in Maine contains high arsenic concentrations. This study sought to determine the prevalence and sources of arsenic and lead in the drinking water of Eastport, Perry, and Pleasant Point, Maine. Citizens of these towns submitted water samples from their homes, and arsenic and lead were measured in these samples. Each citizen submitted two samples: one where water stood in the pipes for a minimum of six hours, and another where the tap was flushed for 2+ minutes before sample collection. The primary water sources in the region were municipal water, from the Passamaquoddy Water District (PWD), and well water from private wells. Water samples were also collected from the source waters of the municipal water system, the Passamaquoddy Water District, and immediately following water treatment to determine sources of lead in the municipal system. Lead concentrations were found to be below the Environment Protection Agency (EPA) action level of 15ppb throughout the municipal system, and less than 1% of PWD samples exceeded the action level for lead in the standing samples. Overall, including houses with wells, 2% of houses exceeded the EPA action level in standing samples, and these houses are inferred to contain high lead levels in their piping. Arsenic levels in well water samples were found to exceed the EPA Guideline of 10μg/L in 15% of samples, and did not depend on bedrock type, pH, or well depth, suggesting that bedrock heterogeneity and fracture geometry plays a large role in arsenic concentrations in this region.

Thesis Supervisor: Harold Hemond
Title: William E Leonhard Professor of Civil and Environmental Engineering

Thesis Supervisor: Kathleen Vandiver
Title: Director, Community Outreach Education & Engagement
Center for Environmental Health Sciences

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Chapter 1

Background

Drinking water is a key concern globally. Thousands of harmful substances have been identified in water sources, and millions of people are at risk of serious health effects due to water pollutants. As such, understanding drinking water quality of water sources is necessary for determining which water sources provide the least risk, and how to best treat these to improve water quality.

Approximately 560,000 people in Maine, USA rely on private wells for drinking water [Ayotte et al., 2017]. In New England, 30% of wells exceed the EPA health guideline for arsenic [Yang et al., 2012], and 1-3% exceed $50\mu g/L$ [Ayotte et al., 2003]. While anthropogenic sources may contribute to groundwater arsenic, the main arsenic source in Maine is bedrock minerals and thus arsenic levels cannot be reduced by control of anthropogenic pollution or by remediation [Ayotte et al., 2003, Ayotte et al., 2006, Yang et al., 2012]. However, despite the high arsenic prevalence in Maine, less than 50% of Maine residents with wells have tested their water for arsenic, meaning a significant number of people are at risk of high arsenic consumption [Maine BRFSS, 2017]

Maine residents without domestic wells largely rely on municipal water treatment and distribution. Public water utilities must comply with various drinking water guidelines set by the Environmental Protection Agency (EPA) and the State of Maine. Water utilities must also comply with extensive monthly, quarterly, and yearly testing of a range of pollutants, the extent of which depends on the utility size and history of compliance [Environmental Protection Agency, 2009]. Water system users must be notified of any EPA regulation exceedances. Lead is a water quality parameter that must be monitored in utilities. In the 1980s, the Lead and Copper rule was published by the EPA that restricted the use of 50/50 lead and tin solder in water systems. Any water systems installed or replaced since this rule are therefore unlikely to contain lead solder. However, older houses (pre-1980s) may still contain lead solder or even lead piping, and residents are at risk of lead exposure.

Because of the negative health impacts caused by lead and arsenic, the prevalence of arsenic in Maine, and the possibility of lead in older homes, study of arsenic and lead in drinking water in Maine provides useful health information. This study measured lead and arsenic concentrations in drinking water (i.e., both municipal water and well water) in three towns in Coastal Maine: Eastport, Perry, and Pleasant Point. Other metals were also studied to provide supporting information: aluminum, chromium, manganese, iron, cobalt, nickel, copper, zinc, selenium and cadmium. This study identifies possible sources of arsenic and lead in water, and offers recommendations to reduce exposure.

1.1 Community Background

Because of the small populations and relatively isolated location of Eastport, Perry, and Pleasant Point, Maine, the drinking water in this region has been subject to limited testing. The region contains a population of approximately 3000, 36% of whom use domestic wells for drinking water [Nielsen et al., 2010]. A 2010 United States Geological Survey (USGS) study of arsenic concentrations in domestic wells measured few (<20%) wells per town and found that the maximum arsenic concentrations exceeded the EPA guideline [Nielsen et al., 2010], suggesting that arsenic levels may be elevated in this region.

All three towns share a municipal water system, the Passamaquoddy Water District (PWD). While lead has not been measured above the EPA action level in the water system, the PWD has been in violation of its monitoring requirements for several quarters in previous years [Enforcement and Online,]. The PWD has also exceeded EPA health guidelines for trihalomethanes, a chlorine disinfection by-product, in several quarters [Enforcement and Online, , AE Hodsdon Engineers, 2010]. Town population and water usage statistics are displayed in Table 1.1, and house age distributions for each town are displayed in Table 1.2.

Pleasant Point, the smallest community included in this study, is unique due to its status as a Native American reservation for the Passamaquoddy tribe. Thus, exposures in Pleasant Point are of concern due to frequent environmental justice issues relating to Native American communities in the US. Pleasant Point has the largest percentage of PWD users, and nearly all houses on the reservation receive water from PWD (>95%) [Nielsen et al.,
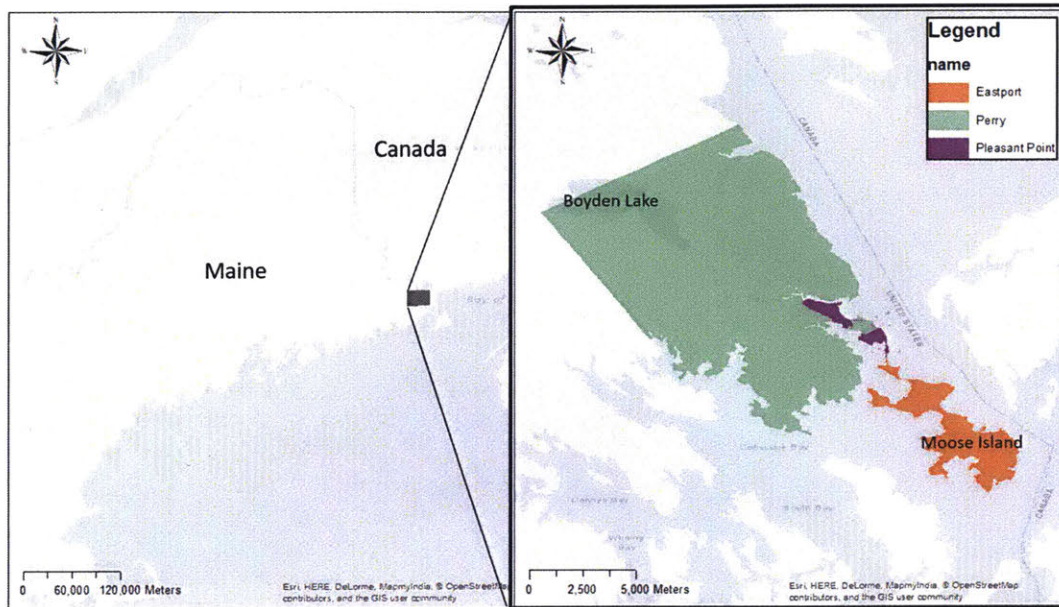
Figure 1-1: Schematic of study area

2010]. Pleasant Point also has the largest proportion of homes built after 1990, after the EPA Lead and Copper Rule went into effect, as 46% of Pleasant Point houses were built after 1990. The remaining 54% were built before 1990.

Perry encompasses the largest area of the study region, and has the lowest population density of the region. Only about 3% of Perry residents receive PWD water, and the remaining 97% of residents have private wells. Thirty-nine percent of Perry houses were built after the Lead and Coper Rule in 1990.

Eastport has the largest population of all three towns, and is located on Moose Island. 11% of Eastport residents have private wells, and the remaining 89% receive PWD water. Only 16% of Eastport houses were built after the Lead and Copper Rule, and a large portion of Eastport houses were built before 1939.

1.2 Passamaquoddy Water District System

1.2.1 Overview

The Passamaquoddy Water District is a non-profit municipal corporation governed by five trustees. Three trustees are members of the Passamaquoddy Tribe, one member is from

Table 1.1: Town Populations & Water Usage

Town	Population[a]	Percent PWD Users[a]	Percent Domestic Wells[a]
Eastport	1536	89%	11%
Perry	922	2.8%	97.2%
Pleasant Point	594	95.8%	4.2%

[a]Source: [Nielsen et al., 2010]

Table 1.2: Housing Age by Town

	Eastport[a]	Perry[a]	Pleasant Point[a]
Total housing units	1099±35	570±42	323±33
Built 2014 or later	0±2%	2±2%	0±7%
Built 2010 to 2013	0±2%	3±2%	3±3%
Built 2000 to 2009	6±2%	18±4%	14±5%
Built 1990 to 1999	10±3%	16±5%	29±6%
Built 1980 to 1989	5±2%	8±3%	21±7%
Built 1970 to 1979	6±3%	17±4%	29±6%
Built 1960 to 1969	3±1%	5±3%	1±1%
Built 1950 to 1959	4±2%	7±3%	0±7%
Built 1940 to 1949	3±1%	3±2%	1±1%
Built 1939 or earlier	64±5%	22±6%	3±3%

[a]Source: [U.S. Census Bureau,]

Eastport, and one member is from Perry [Harper, 1991]. PWD began operation of a new water treatment facility in 1989 to comply with the EPA Safe Drinking Water Act, and water quality is generally believed to have improved following operation [Harper, 1991, AE Hodsdon Engineers, 2010]. However, PWD has violated the disinfection by-product rule for three quarters in 2004-2005 and for 11 quarters from 2005-2007 [AE Hodsdon Engineers, 2010]. Because of this violation, PWD entered into an Administrative Consent Order with the EPA in April, 2009. The engineering consulting company AE Hodsdon was employed by PWD to provide recommendations for improvements, and Hodsdon executed a preliminary study of the treatment facilities in 2008 and a complete study in 2010 [AE Hodsdon Engineers, 2010].

The PWD receives water from the Boyden Stream Impoundment. Water is treated by a 14-step process at the PWD facility and then delivered via a piping system to two reservoirs: the Pleasant Point Reservoir and Eastport Reservoir. From the reservoirs, water

is distributed to homes [AE Hodsdon Engineers, 2010]. Figure 1-2 shows a schematic of water flow and piping system.
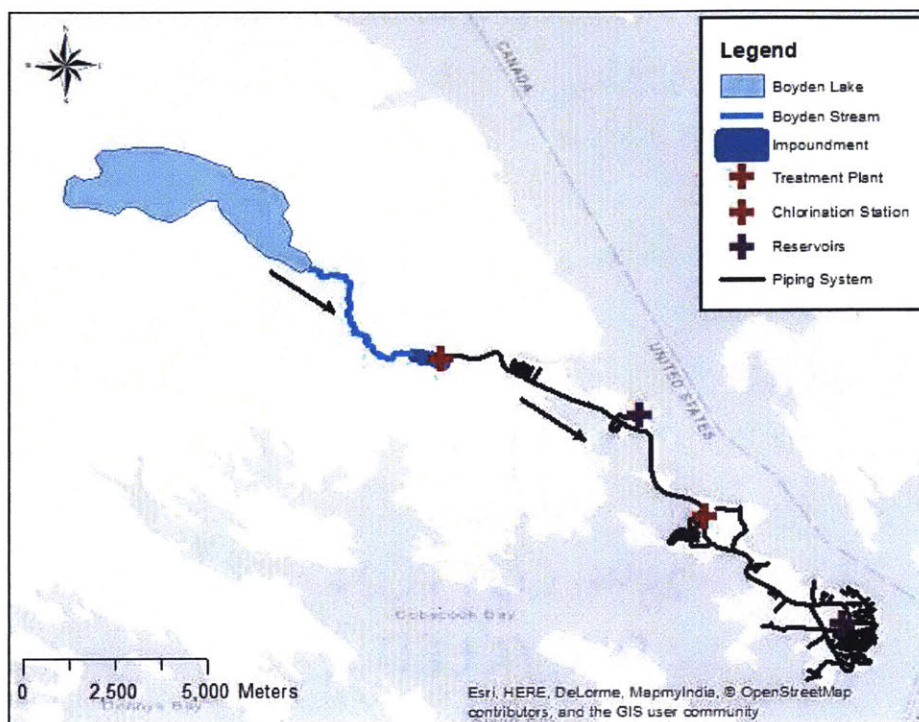
Figure 1-2: Schematic of PWD system. Arrows indicate flow in Boyden Stream and the piping system.

1.2.2 Source Waters

Boyden Lake supplies water to the PWD reservoir and is part of the Boyden Watershed. Table 1.3 displays lake parameters. Water flows to Boyden Lake from the Penknife Lakes and the western part of the watershed. Boyden Lake is a relatively shallow lake, and occupies 11% of the watershed. Lake water quality is monitored by the Sipayik Environmental Department, a part of the Passamaquoddy tribal government. A 1991 study found that lake clarity decreased from 1984-1991, implying more sedimentation or algae growth in the lake [Harper, 1991]. However, while lake water quality may have continued to decrease, data indicate that Boyden Lake is mesotrophic [Harper, 1991].

Various water quality concerns exist relating to Boyden Lake due to its multiple uses. Boyden Lake is used for fishing, boating, and swimming; boating in particular may contribute

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harmful pollutants through release of motor oil directly to the water [Harper, 1991].

From the northeast outlet of Boyden Lake, water is transported down Boyden Stream until it reaches a dammed reservoir, referred to as the Impoundment in Figure 1-2. The PWD intakes water from the reservoir and treats and distributes it for consumption.

Raw water quality varies seasonally, and depends on rainfall and other weather factors. During periods with low flow, alkalinity and pH of raw waters increase, likely due to low water levels causing an increase in groundwater release into waters [AE Hodsdon Engineers, 2010].

Table 1.3: Boyden Lake

Parameter	Value[a]
Average depth	2.7m
Maximum depth	10.4m
Volume	$18.16 * 10^6 m^3$
Drainage Area	$35.74 km^2$
Flushing rate	1.22 flushes per year
Peak discharge	380cfs
Residence time	0.8years

[a]Source: [Harper, 1991]

1.2.3 Treatment Process at the PWD Facility

Figure B-1 displays a schematic of the full water treatment process at PWD. Following is a brief description of methods employed at the treatment plant; refer to [AE Hodsdon Engineers, 2010] for a more detailed explanation.

Water passes through a screen at the intake point in the treatment facility to remove large debris, then passes through a roughing filter composed of three beds of progressively finer gravels to remove particulate matter and algae. Water then flows by gravity to a clear well where it is pumped through the water treatment plant. Pumping rates at the plant are approximately 275 gallons per minute.

Alum, an aluminum sulfate solution, and a positively charged polymer are added to the water as coagulants and flocculents to bind together small particles. Alum dosage varies

between 18 to 40ppm, and polymer dosage varies between 0.02 and 0.1ppm. Water then passes through a static mixer, which increases mixing of the alum and polymer in the water.

Water then passes through one of several clarifiers, which are vessels filled with fine stone. Following the clarifiers, water passes through filters which contain progressively finer layers of sand and gravel. Sodium hypochlorite is added to the resulting water to disinfect the water, and a residual of chlorine is maintained in the distribution system. The pH is also adjusted at this point via lime addition; the pH is raised to 7-7.4. Sodium fluoride is also added to water before it enters the distribution system.

Through this treatment process, 25% of Total Organic Carbon (TOC), 10% of Dissolved Organic Carbon (DOC) and 75% of particulate carbon are removed. 97% of color is removed as well, which is primarily caused by iron [AE Hodsdon Engineers, 2010].

1.2.4 Environmental Protection Agency Drinking Water Regulations

Table 1.4 displays National Primary Drinking Water Regulations for arsenic and lead; the standards for other metals are shown in Table B.2. All public water utilities are required to comply with the Maximum Contaminant Level (MCL) standard for each metal, and noncompliance must be remedied as soon as possible [Environmental Protection Agency, 2009]. The Maximum Contaminant Level Goal (MCLG) refers to the concentration at which that metal poses no health risk [Environmental Protection Agency, 2009].

The lead standard is based on a treatment technique rather than a maximum value as is specified by the Lead and Copper Rule of 1991. The Lead and Copper Rule (LCR) requires a public utility to test household water for lead and copper. For small water utilities such as the PWD (<3300 users), 20 sites must be monitored initially, until it has been proven that the water has not violated the LCR for lead and copper for one year of monitoring. Ten sites may be monitored following that, and after three consecutive years of no exceedances, the utility may monitor for lead and copper once every three years, rather than annually. An exceedance occurs when $\geq 10\%$ of houses monitored exceed the action level of $15\mu g/L$ for lead or 1.3mg/L for Copper [Federal Register, 1991].

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Table 1.4: EPA Guidelines for Arsenic and Lead

Metal	MCL[ab]	MCLG[c]	Health Risks	Common Sources
Lead	0	TT: 15[d]	delays in physical & mental development of infants & children; kidney problems and high blood pressure in adults	corrosion of household plumbing, erosion of natural deposits
Arsenic	10	0	skin damage; problems with circulatory systems; cancer	erosion of natural depositions, runoff from orchards, or glass & electronic productions waste

[a]Adapted from EPA National Primary Drinking Water Regulations [Environmental Protection Agency, 2009]
[b]Maximum Contaminant Level (ppb)
[c]Maximum Contaminant Level Goal (ppb)
[d]TT = Treatment Technique

If the action levels is exceeded, the water utility must implement corrosion control, and if that method is not effective, replace 7% of utility-owned lead service lines annually. In the case of an exceedance, the LCR recommends consideration of the following methods of corrosion control: alkalinity and pH adjustment, calcium hardness adjustment, or addition of phosphate or a silicate based corrosion inhibitor [Federal Register, 1991].

The MCL for arsenic is $10\mu g/L$, and public water utilities must comply with this value. Because arsenic is carcinogenic, the MCLG, representing the level at which no effects will occur, is zero.

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1.3 Literature Review

1.3.1 Lead Release from Piping Systems

High lead concentrations in drinking water have been observed in diverse water systems and piping materials. The most notable case of lead contamination in recent history is that of Flint, Michigan, where lead levels were found to exceed several hundred $\mu g/L$ and an increase occurred in child blood lead levels [Pieper et al., 2017]. As shown in Table 1.4, exposure to high lead may cause developmental damage to children and kidney problems in adults [Environmental Protection Agency, 2009].

Lead release from piping systems depends on pipe materials and age, hydraulic properties within the piping system, and chemical properties of the water. These properties may change within distribution systems. Based on piping alone, there are three potential regions for lead contamination to occur: main water distribution lines, household service lines (sometimes called laterals), or household interior plumbing. Piping material and age can vary between these areas, and thus will impact lead release and water properties. Because piping material and hydraulic properties are unique to individual houses, the lead profile within a distribution system can vary significantly at the household level [Wang et al., 2014]. Thus, there is the risk that monitoring by public utilities of select households (0.006% or 0.003% of houses in small utilities) may overlook high lead content in other areas of the distribution system [Federal Register, 1991].

Lead and copper form a corrosion scale when present in piping, and this scale can trap and accumulate other toxic elements such as arsenic [Kim et al., 2011]. The release of lead from this corrosion scale depends on water chemistry factors such as pH, alkalinity, temperature, concentrations of chlorine residual, dissolved oxygen, chloride, sulfate, phosphate, and organic matter [Kim et al., 2011]. Lead release also depends on piping material, water age, and residence time in piping [Kim et al., 2011, Masters et al., 2015]. The relative importance of these factors in governing Pb release varies by system.

One of the main controls on lead release is pH: lead levels increase as pH drops [Kim et al., 2011]. Because of this, the main method of corrosion control that is suggested by the LCR is pH adjustment [Federal Register, 1991]. Increasing the pH before distribution is

expected to decrease lead levels.

Temperature also impacts lead dissolution rates by control of equilibrium constants and kinetics. Increased temperatures will increase equilibrium constants and reaction rates, increasing lead release [Wang et al., 2014].

Household age also correlates with high lead. Wang et al. found that houses built between 1970 and 1986 with interior copper plumbing systems are more likely to contain high lead levels [Wang et al., 2014]. This relationship with age is likely related to implementation of the Lead and Copper rule in the 1980s. Before the LCR, most piping installed contained a 50/50 lead/tin solder between joints which is a potential source of lead. Since the LCR, lead is no longer permitted in drinking water piping, and houses built since this time period will likely not have any lead solder or piping. Even within old houses, however, there is the possibility that interior plumbing or service lines have been replaced with lead-free piping, meaning house age is not a perfect indicator for the presence of lead piping.

A relationship between water age, stagnation times, and lead release has also been suggested. While older water has been suggested to leach more lead [Wang et al., 2014], Masters et al. found that this result varies greatly depending on system characteristics; older water increased lead levels in 13% of cases and decreased lead in 33% of cases [Masters et al., 2015]. Entangled with the idea of water age is the stagnation time, or the length of time water sits unmoving in piping before consumption. Certainly the longer water sits in piping, the older it will be, while in other cases water age is a function of distance and travel times between a house and the treatment plant.

Stagnation events (up to and longer than 24 hours of still water) have been found to increase lead release when conditions are generally favorable for lead release by allowing more time for diffusion of lead from the piping [Xie and Giammar, 2011]. Xie et al. found that pH was constant throughout stagnation events, and that increased leaching was not caused by pH decreases over time. However, low flow rates were ultimately more effective in dissolving lead from piping by increasing concentration gradients between the water and piping and thus increasing leaching [Xie and Giammar, 2011]. High flow rates are generally correlated with the lowest lead values, except in rare events where the high flow mechanically removes lead from piping walls [Pieper et al., 2017], or potentially when high levels of iron

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oxides are present in the water [Kim et al., 2011].

Organic matter content also impacts lead levels by accelerating reductive dissolution [Masters et al., 2016]. A study of drinking water systems in Washington, D.C. and Rhode Island found 2+ times higher lead levels in the summer than in winter due to higher organic matter content in summer [Masters et al., 2016].

The presence of free chlorine also impacts lead dissolution due to the high oxidizing power of chlorine. Kim et al. found that chlorine participated in the formation of insoluble lead oxides in piping systems, decreasing lead water content [Kim et al., 2011]. Under stagnant conditions, higher free chlorine levels resulted in less lead leaching [Xie and Giammar, 2011], and chloramine decay through a water system was found to correspond with higher lead levels [Wang et al., 2014].

1.3.2 Arsenic in Ground Water

Arsenic has been observed at high concentrations in over 80 countries, and arsenic presence in groundwater poses a significant health risk internationally [Nordstrom, 2002, Ng et al., 2003, Barringer and Reilley, 2013]. Health risks of arsenic ingestion include harm to cardiovascular, dermal, gastrointestinal, hepatic, neurological, pulmonary, renal and respiratory systems [Substances and ATSDR, 2007], as well harm to the reproductive system [Mandal and Suzuki, 2002]. Arsenic is also a known carcinogen [Substances and ATSDR, 2007, Ng et al., 2003], and as such, its levels in drinking water are regulated by governmental agencies [Barringer and Reilley, 2013]. Most countries, including the United States, have established a maximum contaminant level of $10\mu g/L$ [Barringer and Reilley, 2013].

Arsenic is present in groundwater largely as arsenate(V) and arsenite(III). Arsenate dominates in oxic water, and arsenite dominates in anoxic, reducing waters [Welch et al., 2000]. Arsenite is the more toxic ion and thus presents larger health risks when present [Barringer and Reilley, 2013].

Potential anthropogenic sources of groundwater arsenic include the mining and processing of ores, manufacturing that requires use of sulfides, and arsenical pesticides. Because arsenical pesticides were banned in the 1980s and 1990s, this arsenic source would be due solely to legacy usage [Barringer and Reilley, 2013]. Additionally, some have suggested that

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the use of phosphate fertilizers on land containing historical arsenical pesticides may result in phosphate replacing arsenic in soil and leading to arsenic mobilization [Welch et al., 2000].

However, the most common source of arsenic in groundwater in Maine is geogenic. Over twenty minerals may contain arsenic [Barringer and Reilley, 2013]. Arsenic content is higher in intermediate and felsic rocks than in mafic [Barringer and Reilley, 2013]. In Maine and New Hampshire, studies have found high arsenic in pegmatites, granites, and metamorphic rocks [Barringer and Reilley, 2013]. Bedrock type is also a good predictor for presence of groundwater containing $>10\mu g/L$ As regionally [Yang et al., 2009, Ayotte et al., 2003, Ayotte et al., 2006, Foley and Ayuso, 2008].

1.3.3 Mechanisms of As release

One source of arsenic in groundwater is oxidation of arsenic-bearing sulfides, resulting in dissolution of the sulfide mineral and release of arsenic [Lengke et al., 2009]. Oxidation of sulfide minerals resulted in arsenic concentrations up to 215 $\mu g/L$ in groundwater in Pennsylvania and New Jersey [Peters and Burkert, 2008, Barringer and Reilley, 2013]. Sulfide minerals in bedrock were found to be the primary source of groundwater arsenic in Northport, Maine [Lipfert et al., 2006] and Central Maine [O'Shea et al., 2015]. Peters, 2008 found that arsenic from sulfide oxidation coincided with high pH, low iron concentrations, and either high electric potential (Eh) or dissolved oxygen (DO) [Peters, 2008].

Reductive dissolution of iron hydroxides may also result in dissolution and mobilization of arsenic. In this case, arsenic coincided with high iron concentrations, low Eh, no DO, and low nitrate and sulfate [Peters, 2008]. Higher pH has been found to increase arsenic desorption from iron and manganese hydroxides [Welch et al., 2000].

Microbes also play a role in arsenic mobility. Some microbes oxidize arsenic [Santini and Ward, 2012], some may reduce iron hydroxides under anoxic conditions and enhance arsenic mobilization [Islam et al., 2004], and some respire arsenic directly [Barringer and Reilley, 2013].

Overall, high arsenic waters generally have a pH greater than 6.5 [Peters, 2008], and high pH contributes to high arsenic especially where arsenic is decoupled from iron [Foley and Ayuso, 2008].

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While factors such as bedrock geology, precipitation, and slope can predict regions of high arsenic fairly reliably, arsenic concentrations vary greatly on local scales [Yang et al., 2012]. Locally ($<10^0$ km), the orientation, density, and hydraulic properties of bedrock fractures influence water flow and impact arsenic concentrations in groundwater at short distances [Ayotte et al., 2006].

Hydrogeological factors also impact As concentrations. Areas of high recharge with arsenic-bearing sulfide minerals may contain high arsenic concentrations due to oxidation of the sulfide minerals. Conversely, regions with little recharge may contain high arsenic coupled with high iron due to reduction of iron oxides [Bondu et al., 2017]. Additionally, marine inundation or rocks may result in high arsenic levels, as increased calcite dissolution will raise the pH and increase arsenic desorption [Ayotte et al., 2003].

Arsenic concentrations may vary seasonally, with a peak in spring due to increased recharge and oxidation of sulfide minerals, but this seasonality was small in private wells with low pumping rates [Ayotte et al., 2015].

1.3.4 Regional Bedrock Formations

Figure 1-3 displays the bedrock types and spatial distributions for the region of study. The primary bedrock type is a Devonian mafic to felsic volcanic rock which extends from Eastport over the western half of Perry. The secondary bedrock type is a sandstone rock that covers the eastern half of Perry. A small fraction of land is part of a Siluran Hersey Formation, which is a volcanic rock with interbedded pelite and sandstone [Osberg et al., 1985].

1.4 Project Aims

This project aims to determine lead and arsenic concentrations and sources in municipal (PWD) water and groundwater in Eastport, Pleasant Point, and Perry, Maine. Because arsenic is known to be present in high concentrations in Maine, we hypothesize that arsenic will largely be present in high concentrations in groundwater, and that lead will pose the larger health risk in PWD water.
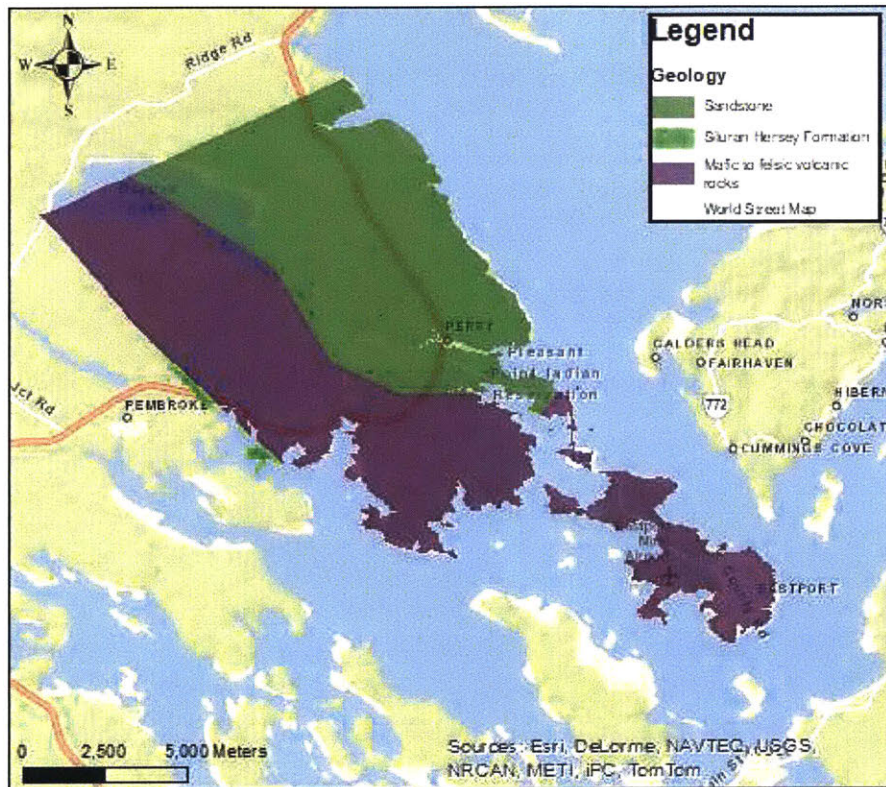
Figure 1-3: Bedrock Geology of the Region

Chapter 2

Methods

2.1 Community Engagement

The communities of Eastport, Pleasant Point, and Perry were engaged through several community meetings, a mailed flier, newspaper advertisements, and through a citizen science initiative. This study relied on community participation, as most samples used in analysis were submitted by community members, and community concerns drove the aims of the study.

2.1.1 Community Meetings

One community meeting was held in each of the three communities: Eastport, Perry, and Pleasant Point. All meetings followed a similar agenda. Team members were introduced and gave a short (approximately 15 minute) presentation explaining the research motivation, aims, and methods. Community members then discussed water quality concerns in small groups and answered the following questions:

1. What questions do you have for us?

2. What water quality concerns do you have?

3. What background knowledge do you have regarding water quality in this area?

The team then answered any community questions about project aims and logistics.

All meetings were advertised to residents of all three towns through posted fliers, an advertisement in the local newspaper The Quoddy Tides, and Facebook postings. A Quoddy Tides reporter attended the first community meeting in Eastport, and the newspaper later published an article regarding the first community meeting.

2.1.2 Sample Collection and Submission

Water sample kits were distributed to all residents who attended community meetings. Large plastic bins containing additional sample kits were placed in two local, public areas. One bin was replaced in the Passamaquoddy Tribal Office in Perry, and the other was placed in Moose Island Marine in Eastport. The plastic bins also served as satellite collection areas for completed kits.

Each sample kit contained two water collection bottles, instructions, and two copies of a Participation Form. Each bottle contained a label with spaces to fill in the following information: Name, Phone Number, Email Address, Water Source, Sample Type, Address, Collection Date and Time, and GPS coordinates. Bottles were purchased from Greenwood Products, Inc, and had 250mL capacity. The bottles were composed of HDPE. Appendix A contains photos of the kits and all information in the kits, as well as the presentation given at the community meetings.

Participants were instructed to collect two samples from their household faucets, denoted as running and standing samples. The instructions told participants to collect a standing sample by filling one collection bottle from a tap that had not been used for a minimum of six hours. The instructions also told participants to collect a running sample by flushing a tap for a minimum of two minutes and then filling another collection bottle. The instructions specified that the sample be collected from a tap without a filter, but some residents chose to submit two sets of samples from their home, a set each with and without the filter. The two sample types were kept distinct with pre-labeled colors, red and green on the bottle caps: standing sample bottles all had red tape across the cap, while running sample bottles all had green tape across the cap.

Samples were collected from the plastic bins by Sipayik Environmental Department members and stored in their laboratory refrigerator until they could be transported to the MIT lab in Cambridge. Samples were transported to Cambridge via car on three separate trips.

Upon arrival at MIT, samples were logged, labeled with sample numbers, and stored in the laboratory fridge at 4°C until further analysis.

2.1.3 Mail-out

To increase community participation, a flier was created to explain the project and describe the locations of sample kit pick-ups. Approximately 1700 fliers were distributed to all post office boxes and houses in Perry, Pleasant Point, and Eastport in mid-January 2018. A link to the project Facebook page was included on the flier.

Soon after the mail-out, participation increased exponentially and an additional several hundred sample kits were assembled and distributed through the communities. The final sample submission deadline was also extended by several weeks to accommodate the increased demand.

2.1.4 Results Reporting

Sample results were returned to each household along with a sheet of resources and interpretation of results. To protect the privacy of individuals, household results will be presented in an aggregate form in this thesis and at final community meetings on May 20 in Pleasant Point and May 21, 2018, in Eastport.

2.2 Sample Collection

2.2.1 Boyden Lake and Stream Water Samples

Water samples were collected from Boyden Lake and Boyden Stream by collecting surface water in 250mL polyethylene (HDPE) containers. GPS Coordinates were recorded at each site to five decimal places. Samples were transported back to the lab within several days and stored in a cold room at 4°C until analysis.

2.2.2 Sediment Samples

Sediment samples were collected from Boyden Lake surface sediment with an Ekman dredge. Because sediment could not be collected from a water depth greater than 10 feet due to the length of the Ekman dredge rope, most samples were collected close to lake banks and from

shallow regions. An excess of 10g of sediment was collected in plastic bags for each sample and stored in a cold room at 4°C until analysis.

2.3 Sample Analysis

2.3.1 Water Sample Analysis

Water samples were prepared for analysis by acidifying approximately 2mL of the water sample to 3.5% HNO_3 by addition of 35% HNO_3. An internal standard was added to all samples to a concentration of 1ppb. Initially, a Rhodium and Iridium internal standard was used, but recoveries were comparable between Rhodium and Iridium and so eventually only a Rhodium internal standard was used.

Water samples were then analyzed on the Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) in the Chemical Analysis Facilities Core at the Center for Environmental Health Sciences at the Massachusetts Institute of Technology.

2.3.2 Sediment Digestion

A 5g aliquot of each sediment sample was weighed into an aluminum boat and dried in an oven overnight. Dried weights were recorded and moisture composition determined. Approximately 0.25g dried sediment was measured into acid washed digestion tubes. Sediment weights were recorded to the hundredth of a gram for each sample.

Samples were prepared for digestion by addition of 6mL 69% HNO_3 and 2mL of 12N HCl, according to a modified version of EPA Method 3051 [Environmental Protection Agency, 2007]. Following addition of acid, samples were predigested in a fume hood for a minimum of thirty minutes to allow for venting of fumes. Sediment samples were then digested with an Ultrawave Digester. Digester settings are displayed in Figure B-2. The temperature increased to 175°C from room temperature over time minutes at a constant pressure of 120 bar. The temperature than increased to 220°C over ten minutes while pressure increased to 175 bar. Following digestion, samples were diluted to 5% Nitric acid by addition of 31mL of distilled water, the rhodium internal standard was added to 1 ppb, and the resulting analyte

was measured on the ICP-MS.

2.3.3 Calibration Solutions

ICP-MS calibration solutions were prepared from a stock solution containing all metals of interest in this study. The stock solution was purchased from VHG Laboratories. Of the metals of interest, aluminum was present at 500ppm; arsenic, cobalt, chromium, iron, manganese, nickel, lead, and zinc were all present at 100ppm; cadmium and selenium were present at 25ppm. Table 2.1 displays the initial concentrations of all metals.

Calibration solutions were made by a 10-fold dilution series from 10ppm to 100ppt, resulting in 6 calibration solutions. A blank was also prepared with fresh milliQ water to provide a 0 point on the curve. All calibration solutions were acidified to 3.5% nitric acid by addition of 10% of a 35% nitric acid solution, and the rhodium internal standard was added to 1ppb.

Table 2.1: Calibration Solutions

Metal	Stock Solution Concentration (ppm)	Cal. 1 (ppb)	Cal. 2 (ppb)	Cal. 3 (ppb)	Cal. 4 (ppb)	Cal. 5 (ppb)	Cal. 6 (ppb)	Cal. 7 (ppb)
Aluminum	500	0	0.5	5	10	500	5000	50000
arsenic	100	0	0.1	1	10	100	1000	10000
Cadmium	25	0	0.025	0.25	2.5	25	250	2500
Cobalt	100	0	0.1	1	10	100	1000	10000
Copper	100	0	0.1	1	10	100	1000	10000
Chromium	100	0	0.1	1	10	100	1000	10000
Iron	100	0	0.1	1	10	100	1000	10000
lead	100	0	0.1	1	10	100	1000	10000
Manganese	100	0	0.1	1	10	100	1000	10000
Nickel	100	0	0.1	1	10	100	1000	10000
Selenium	25	0	0.025	0.25	2.5	25	250	2500
Zinc	100	0	0.1	1	10	100	1000	10000

2.3.4 ICP-MS Analysis

The ICP-MS analyses were conducted with helium flow. The ICP-MS was tuned before every run, and machine outputs were verified with data quality parameters. A tune report was generated for every tuning session for future reference.

For every run, 3-5 blanks of milliQ water acidified to 2% nitric acid were run at the beginning to clear out any residual contamination from previous runs. The 7-point calibration curve was then run from low to high concentrations, and 3-5 blanks were run following calibration to remove any contamination. Additionally, one blank was run between every five samples to ensure no crossover between samples and that there was no build-up of contamination within the machine.

The ICP-MS was sensitive down to 100ppt for every metal. Counts per second of the calibration series varied less than 10% between different runs, and there was little machine drift over the longest runs of >8 hours.

2.3.5 ICP-MS Detection Limit

The Detection Limit (DL) was calculated as suggested EPA method 200.8. The EPA method requires the running of seven replicates at a concentration 2-5 times the estimate detection limit. The method detection limit (MDL) is then calculated by: $MDL = t * S$, where t is the student's t-value for a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom, and S is the standard deviation of the replicate analyses [Environmental Protection Agency, 1994]. Because the detection limit was predicted to be less than 0.1ppb, the standard deviation of seven replicates at a concentration of 0.1ppb was used for MDL calculations.

2.3.6 Concentration Calculations

Concentrations were calculated for each ICP-MS run separately. Calibration concentrations were log-linearly regressed to the Counts Per Second (CPS) measurements. The regression coefficients were then applied to the CPS values of all samples from the run to calculate metal concentrations. A log-linear fit was used for regressions because the regression coefficients are

calculated by a least-squares method, and concentrations varied by 6 orders of magnitude. The log-linear method reduces bias in the model fit, and without log adjustments the model was a poor fit at lower concentration.

The background internal standard CPS values were averaged across the calibration solutions to characterize internal standard measurements. Internal standard measurements in each sample were then compared to this background CPS, and recoveries were calculated. Metal concentrations were then multiplied by $\frac{1}{\text{sample recovery percentage}}$ to correct for interferences.

Average recoveries and model fit parameters were recorded for each run. The date of analysis was also stored with concentration data.

2.3.7 Replicate Testing

Samples with concentrations exceeding 7ppb arsenic or 8pbb lead after initial testing were re-prepared and analyzed for verification. The average deviances between replicates were calculated for all samples by calculating an ensemble mean and the averaging the percent deviation from mean for all replicates.

2.3.8 Replicate Deviances Calculations

The deviances between replicates were calculated by $deviance = \frac{\text{concentration - mean concentration}}{\text{mean concentration}}$. To determine change in concentrations over time, deviances from first values were calculated by $deviance_f = \frac{\text{concentration - first measured concentration}}{\text{first measured concentration}}$.

2.3.9 pH Measurements

The pH measurements were collected with a pH electrode. The electrode was calibrated with solutions at pH 7, 10, and 4. Samples were allowed to equilibrate with the electrode until measurements remained relatively stable (variation of 0.02 or less) for at least 15 seconds. The electrode was rinsed with DI water between every sample.

All 275 running (flushed) well samples were measured. A subset of about 30 PWD samples were measured; all PWD samples with high lead levels were measured, and the

remaining samples were chosen randomly from a mix of running and standing samples.

2.3.10   State Lab Comparison

Twenty samples of those tested in this study were sent to the Department of Health and Human Services Health and Environmental Testing Laboratory in Augusta, Maine. All twenty samples were tested for lead and arsenic by the lab. Several samples with lead and arsenic above EPA guidelines were selected for re-analysis, and the remaining samples were chosen randomly.

2.4   Spatial Mapping and Analysis

All spatial mapping was performed in ArcGIS 10.1. All samples from outside the study area of Eastport, Perry, and Pleasant Point were excluded from spatial maps and analysis.

2.4.1   PWD Piping System

A geographical schematic of the PWD piping system was provided by A.E. Hodsdon Engineers. This schematic was digitized by hand in ArcGIS, and the piping system was converted to a polyline shapefile.

The system was represented as a Network Dataset in ArcGIS using length as cost. An Origin Destination Cost Matrix was generated with the Network Dataset. The water treatment plant was specified as the origin, and all houses that submitted PWD samples were specified as destinations. The system was solved for and the shortest-distance length estimates were taken to be the household distance along piping. The shortest-distance estimates were output as units of degree.

2.4.2   Well and Bedrock Analysis

A bedrock map of the state of Maine was obtained from [Osberg et al., 1985] and digitized in ArcGIS for the study area. A points feature class containing the locations of all wells in

the study area was clipped to each individual bedrock area and converted to an Excel file to allow for comparisons of concentration between bedrock types.

Summary statistics of arsenic concentrations in running samples were calculated for each bedrock type, and a paired Student's t-test was performed for the two primary sets of bedrock using a built-in MATLAB function.

2.4.3 Well Depth Analysis

A shapefile containing information on well depth and yields for the state of Maine was obtained from the Maine Well Database [Maine Geological Survey,]. This shapefile was clipped down to the study area and converted to an Excel file. Any wells whose address in the Well Database file matched a well sample from this study were assumed to be the same well, and their information was combined.

2.5 Uncertainty Analysis

Uncertainty in all results was assessed by tabulation of uncertainties in laboratory equipment and the ICP-MS results.

Information on pipet uncertainties was located on supplier websites, and the poorest-performing pipet of any given size was used for uncertainty calculations.

The uncertainty in the log-linear model was assessed by calculating the percent deviation in the model from the true concentration at each calibration solution value. In this way, the uncertainties varied between concentrations, as is reasonable given a calibration curve that spans 7 orders of magnitude and could be expected to perform better at high concentrations.

Uncertainties in the ICP-MS CPS were also determined by the Relative Standard Deviation (RSD) reported for each sample by the ICP-MS. RSDs were averaged across each run to estimate an overall run uncertainty. RSDs were then averaged across all runs to provide an overall uncertainty for metal measurements on the ICP-MS.

Chapter 3

Results and Discussion

3.1 Community Meetings

Community members expressed a range of water quality concerns. The most common concerns were related to water color, smell and taste in PWD water, as well as bacterial contamination and chlorination by-products. People also expressed concerns about arsenic and radon in well water. Table 3.1 displays the main concerns by water source.

Notes from the Eastport community meeting on August 31 are located in Figure A-3.

Table 3.1: Community Water Quality Concerns

Water Type	Community Concerns	Detected Problems[a]
PWD	Fluoride Arsenic Bacterial contamination Parasites Petroleum products Septic systems in-ground near Boyden Lake Sulfur Chlorination by-products Color, smell, and taste Radon Lead	Chlorine by-products [b] Barium[a] Chromium[a] Manganese[a] Nitrate & nitrite[a] Aluminum[a,c] Chlorine[a,b]
Wells	Arsenic Radon Groundwater leakage	pH[d] Radon[c] Lead[c]
Springs	Arsenic Bacterial contamination Parasites	Bacterial contamination

[a]Contaminants that have been detected in past water testing of the region
[b][Yang et al., 2012]
[c]EPAb
[d]Report

3.2 Community Participation

Attendance at community meetings varied greatly by town. The first meeting was held in the largest town, Eastport, and over 30 community members attended. The following meetings held in Perry and Pleasant Point had fewer attendees, fewer than ten each. However, attendees at all meetings interacted with the research team productively. Table 3.1 displays community water quality concerns expressed during all three community meetings.

Total sample submission statistics are displayed by water source and town in Table 3.2. Overall, 22% of all households in the region submitted samples for the study. Participation rates were highest in Perry and Eastport, 27% and 23% respectively, and participation was lowest on the Pleasant Point reservation, with only 11% participation. Additionally, 32% of all wells were sampled, and 14% of all houses receiving PWD.

Table 3.2: Total Sampling Statistics by Community

Town	Households Sampled	Town Populations	Total Households	Percent Household Sampled
Eastport	159	1536	702	23%
Perry	97	922	360	27%
Pleasant Point	24	594	216	11%

There is the potential that the differing submissions rates will impact our results. However, variation is likely greater between well samples than PWD, as PWD water shares a common source and is treated; a PWD sampling rate of 14% is likely adequate to determine PWD water quality and key effects on water quality given an adequate spatial distribution and house type sampling. Additionally, total well water sampling of 32% in the region is high compared to a recent USGS study [Nielsen et al., 2010], and thus can likely provide greater information regarding well water.

Table 3.3: Sampling Statistics by Water Source

Well Sampling Rates

Town	Households Sampled	Percent Supplied by Well	Total Well Households	Percent Household Sampled
Eastport	58	11%	77	75%
Perry	83	97.2%	349	24%
Pleasant Point	1	4.2%	9	11%

PWD Sampling Rates

Town	Households Sampled	Percent Supplied by PWD	Total PWD Households	Percent Household Sampled
Eastport	94	89%	625	15%
Perry	6	2.8%	11	55%
Pleasant Point	18	95.8%	207	9%

3.3 ICP-MS Detection Limit

The detection limit was calculated to be <0.1ppb. However, because the lowest point on the calibration curve was 0.1ppb and uncertainty regarding the calibration curve is relatively high (about 20%), 0.1ppb is treated as the detection limit, and any reported concentrations below this limit were treated as a non-detect.

3.4 ICP-MS Recoveries

The ICP-MS recoveries were 101±1%. The uncertainty was calculated from a student's t-value at alpha = 0.05. EPA Method 200.8 specifies that recoveries should fall within 70-130%, so average recoveries are deemed acceptable [Environmental Protection Agency, 2007].

Because the sample concentrations were adjusted for the internal standard recoveries, the uncertainty associated with internal standard is assumed to be zero.

3.5 Uncertainty

3.5.1 Sample Preparation Uncertainty

Uncertainties in water sample preparation are 2%, calculated from pipet uncertainties. Similarly, the uncertainty in calibration solutions are 3.5%.

3.5.2 ICP-MS Uncertainty

The ICP-MS data included Relative Standard Deviations (RSDs) for all samples. The RSDs were averaged by run, and an assembly mean was calculated for all runs. The confidence intervals around the mean were calculated as in ICP-MS recovery calculations, according to the t-statistic. Table 3.4 displays the average RSDs and confidence intervals for each metal.

Uncertainties for the calibration curve fit were calculated for all metals. The percent deviances of the predicted value from the known value of the calibration solutions were averaged for each run, and an assembly mean was calculated. Confidence intervals were calculated as above. Table 3.4 displays the average deviances and confidence intervals for each metal.

Total uncertainties were calculated from the each component of uncertainty and are displayed in Table 3.4. Uncertainties range from 10 to 35%, and average 18%. The greatest uncertainty is incurred from the ICP-MS calibration curve, which is due to machine noise.

Table 3.4: ICP-MS RSDs and Calibration Curve Deviances

	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
Mean RSD	5%	6%	5%	3%	12%	5%	3%	2%	5%	11%	21%	%7
p95 RSD	13%	18%	15%	11%	45%	14%	10%	10%	14%	43%	150%	20%
Mean Calibration Curve Deviance	20%	9%	11%	30%	6%	14%	16%	35%	8%	25%	6%	6%
p95 Calibration Curve Deviance	31%	15%	16%	44%	9%	22%	26%	50%	11%	40%	10%	10%
Total Uncertainty	20%	12%	12%	30%	14%	16%	16%	35%	10%	28%	23%	10%

3.5.3 Replicate Analysis

Replicate samples were run for 34% of all samples, and 1.3 replicates were run per sample. The mean values across each replicate of a sample were calculated, and the average variation between replicates was calculated as described in the methods. These deviations from the mean were normalized by the mean value of the replicates. Deviations were greater than sample uncertainty for all metals except cadmium, selenium, cobalt, and chromium, all of which had low concentrations generally. Iron had the greatest replicate deviances, 75%. Table 3.5 displays the replicate sample statistics and Table 3.6 displays the deviances per metal.

Table 3.5: Replicate Sample Statistics

Total	Well			PWD			Other
	All	Running	Standing	All	Running	Standing	
209	126	60	66	50	26	24	33

Table 3.6: Replicate Deviances by Metal

	Al[a]	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
Deviances	47%	6%	25%	75%	1%	34%	34%	51%	14%	3%	2%	13%

[a]All values are percentages.

Correlations were determined between replicate deviances for arsenic and lead, days between reanalysis, days between collection and analysis, and iron concentrations. Table 3.7 displays the correlation coefficients and probabilities for these parameters. Overall, arsenic and lead deviances were positively correlated with days between reanalysis at significant p-values (p=0.01 for arsenic and p=0.03 for lead).

In standing samples, arsenic deviances were positively correlated with days between reanalysis (p=0.04) and iron concentrations (p=0.08), and lead deviances were not significantly correlated with any parameter. In well standing samples only, arsenic was also positively correlated with days between reanalysis (ρ=0.35,p=0.02) and iron (ρ=0.27, p=0.09), and lead was positively correlated with days between reanalysis (ρ = 0.34, p=0.05). Too few

Table 3.7: Replicate Deviances Correlation Coefficients

	All Samples				Standing Samples				Running Samples			
	n^a	Days[b]	Wait time[c]	Iron[d]	n^a	Days[b]	Wait time[c]	Iron[d]	n^a	Days[b]	Wait time[c]	Iron[d]
As[e]	104	0.25 (0.01)	0.13 (0.21)	0.11 (0.29)	45	0.34 (0.04)	0.01 (0.95)	0.28 (0.08)	51	0.21 (0.13)	0.23 (0.11)	0.02 (0.89)
Pb	65	0.27 (0.03)	0.04 (0.74)	0.14 (0.3)	49	0.3 (1)	0.02 (0.87)	0.15 (0.32)	10	0.29 (0.42)	0.24 (0.53)	0.5 (0.17)
Cu	185	0.31 (0)	0.18 (0.02)	0.24 (0)	91	0.55 (0.01)	0.29 (0.01)	0.46 (0)	79	0.29 (0.01)	0.14 (0.22)	0.01 (0.91)

[a]Number of samples above detection limit
[b]Days between reanalysis
[c]Number of days between collection and initial analysis
[d]Sample Iron Concentration
[e]Correlation significance denoted in parenthesis

samples were above the detection limit for arsenic and lead in PWD standing samples to allow for robust correlation calculations. Because arsenic is positively correlated with iron, it is likely that arsenic is precipitating out of solution with iron, and that this process is not occurring, or is occurring to a lesser degree, for lead.

In running samples, arsenic deviances were positively correlated with days between reanalysis (p=0.13) and wait time (p=0.11), but not iron. Lead deviances were positively correlated with iron, but at a lower probability (p=0.17). In well running samples, arsenic was positively correlated with days between reanalysis ($\rho=0.48$, p = 0.00), as was lead ($\rho=0.73$, p=0.06).

In general, arsenic and lead are correlated with the time between reanalysis, which would imply either settling or sorbing to the plastic container, but not the time between collection and analysis. One reason for this could be that the first 150 samples were not analyzed until 3-4 months after collection, but the remaining 500 samples were all analyzed within a month of collection. Because most samples were analyzed within the same time frame (either 1 or 3-4 months), a settling speed would not be observed with time. Additionally, the randomness of the order samples were ran may also swamp any signal of decreasing concentrations over time, since a decrease in concentration over time would not be observed if samples containing higher concentrations were ran later in time.

To determine the change measured in concentrations within a sample over time, a modified deviance statistic was calculated by comparing the first measured value to subsequent values, as described in the Methods. For ten samples, a significant increase in metal concentrations occurred between the initial measurement and subsequent measurements. In the majority of these cases, the sample was initially measured before January 19, 2018. After this date, all samples were shaken before analysis, and before this date, no samples were shaken. Because of this, the low initial concentration is likely due to settling of particulate metals which were subsequently suspended when the bottle was shaken. Several metals (Mn, Ni, and Zn) did not increase once shaking began, and thus are likely present in the dissolved form and thus would not be impacted by shaking. Table 3.8 displays the average and 95th percentile metal enhancements for these samples, and Figure 3-1 displays the change in concentration for one sample across four replicate measurements. Mean concentrations of all metals by method type (shaking or no shaking) and by approximate time between collection and analysis are displayed in Table B.6.

Table 3.8: Metal Enhancement Statistics

Metal	Al[a]	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Pb
Median[b]	0.7	-	-0.3	2.5	-0.2	-0.3	1.1	-0.1	0.1	4
p95 [c]	7.6	-	0.3	12	-0.2	0.1	120	110	2.7	7.8

[a]Reported as fractions rather than percentages
[b]All values are calculated from first value deviances
[c]The 95th percentile

The average first deviances for arsenic, lead, iron, and copper are displayed in Table 3.9. The enhanced deviations associated with lack of sample shaking were discarded for this analysis, since these do not correspond to permanent settling or sorbing of metals to the storage container. The median deviance for all metals is negative, indicating a decrease in concentration between the first measurement and subsequent measurements. The median decreases in arsenic, lead, and copper values are all comparable to uncertainties in samples, but consideration of the standard deviation indicates that many of these samples are outside the calculated uncertainty of values. The greatest decrease in concentrations is in lead, indicating that a large portion of lead may be present in particulate form that settles out. Because arsenic and copper deviances are positively correlated with lead, it is likely that
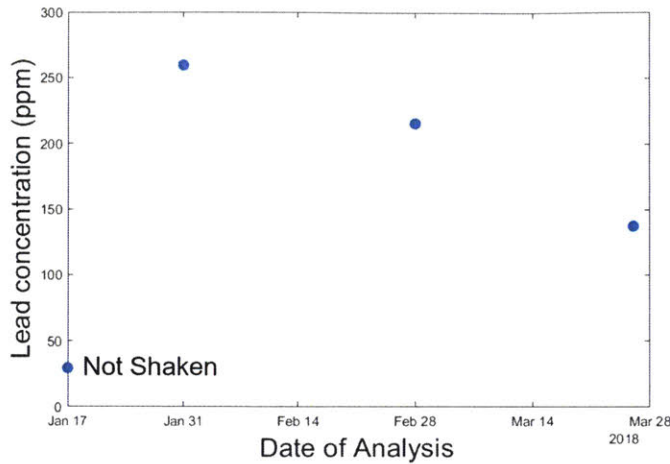
Figure 3-1: The change in concentration across four replicates of a sample. The low initial concentration is due to the sample not being shaken before analysis. The decrease in concentration for the third and fourth replicates are likely due to lead sorbing to the container walls.

similar processes are causing settling of these metals. Figure 3-2 displays histograms for the first deviances for arsenic, lead, iron, and manganese, including the samples that increased between initial and later measurements.

Table 3.9: Median Metal Deviances

	As[a]		Pb		Fe		Cu	
	median	std	median	std	median	std	median	std
Deviance	-0.11	0.31	-0.07	0.35	-0.6	0.49	-0.08	0.37

[a]Reported as fractions rather than percentages

To determine the accuracy of different replicates types with regard to health risk category and changes in concentration over time, the number of samples exceeding EPA guidelines were compared for the first replicate, the maximum replicate, and the last replicate. For arsenic, 4% of replicates exceeded the EPA guideline of 10ppb from initial analysis and fell below the guideline in the final analysis. 5% of replicates had a maximum measured arsenic value above the guideline that fell below the guideline during final analysis, as shown in Table 3.10. This results in 20% of samples that surpass the EPA guideline that do not in at least one other.

For lead, the shaking method resulted in a larger difference between the number of
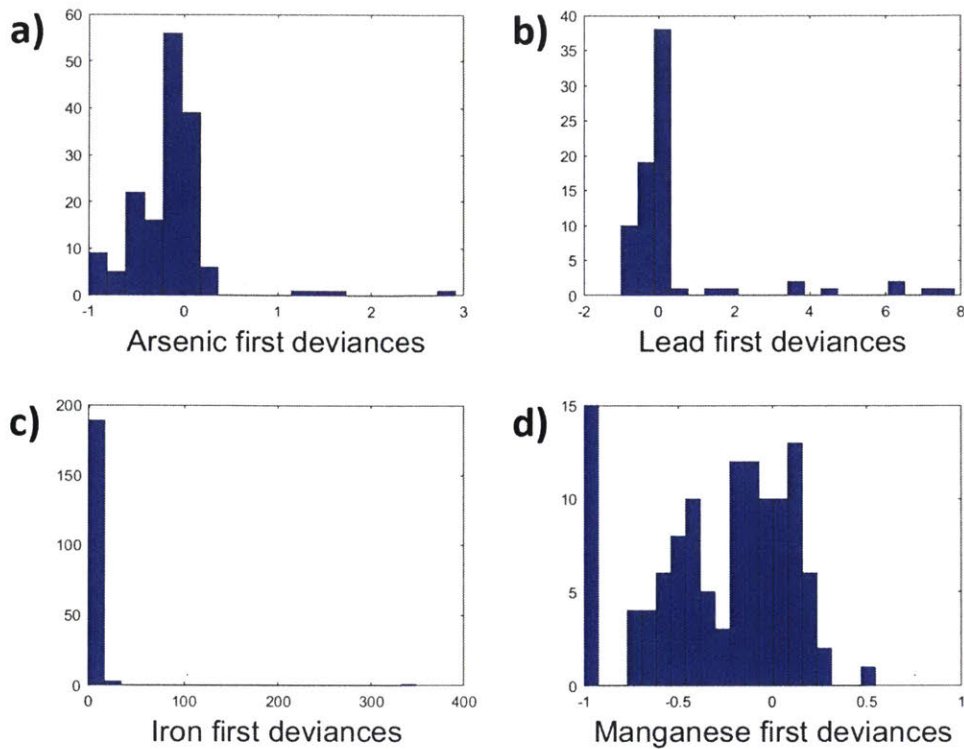
Figure 3-2: First deviances for a) Arsenic, b) Lead, c) Iron, and d) Manganese.

samples over the guideline when using the first, maximum, or last measured value. 3% of samples are miscategorized as below the guideline in its first measurement when compared to the maximum value, and 5% are miscategorized by the final analysis when compared to the maximum value.

A regression performed on arsenic first deviances by the days between reanalysis found a decrease in concentration of 0.4% per day, and if this relationship is constant across time, that would mean that samples that were collected 4 months before they were analyzed would lose 0.4% per day x 120 days = 50%. If all samples collected and analyzed in the first round are assumed to have lost 50% of their arsenic mass, then the number of samples exceeding the EPA arsenic MCL increases from 7 to 13, or from 5% to 10%. An exceedance of 10% is on par with the rest of the data, as is discussed in Section 3.11.1.

Similarly, a regression performed on lead first deviances by the days between reanalysis found a coefficient of 0.7% per day, meaning samples that were collected 4 months before

Table 3.10: Arsenic and Lead Replicates Above and Below EPA Guidelines

	Total replicates	Replicates first measurement above guideline[a]	Maximum above guideline	Replicates below the guideline in the final measurement
Arsenic	209	42	44	33
Lead	209	7	13	11

[a]The arsenic guideline is 10ppb and the lead guideline is 15ppb

they were analyzed would lose 0.7% per day x 120 days = 80%. Assuming that all samples collected in the first round have lost 80% of their lead mass, then the number of samples exceeding the EPA action level increases from 1 to 10, or from 0.8% to 8%. This level of lead exceedance is much higher than observed in the rest of the data (see Section 3.10.1 and 3.11.2), and because of this, lead settling or sorbing rates are likely below this.

While the most conservative approach to determining health risk would be to use the maximum measured concentration for each metal, the maximum values for the different metals are not necessarily from the same replicate. It is preferable that all metal concentrations be from the same sample to allow for comparison between metals, and thus, only the first measured value for each sample was retained in further analysis, as the miscategorization of health risk is less for first samples than for other replicates.

3.6 Comparison to State Laboratory

In state lab data, 50% of samples were under the laboratory detection limit for arsenic, and 55% of samples were under the lead detection limit. The state laboratory detection limit for arsenic was 1ppb, and the detection limit for lead was 0.5ppb. For these samples, the ICP-MS results also fall under these limits.

For state lab values that fell above the detection limit, the deviance between their values and ICP-MS values was 100±10% for arsenic and 120±40% for lead. Table B.7 displays results from state lab and ICP-MS.

Agreement was generally good between the state-certified lab and ICP-MS analysis, es-

pecially for arsenic. Deviations fell within the uncertainty range for ICP-MS arsenic measurements, confirming both the arsenic uncertainty and general reliability of results. While deviances are significantly larger for lead samples, this is due at least in part to the few (only 9) samples that exceed the detection limits and allow for direct comparison. In one sample, the state lab measured 2ppb lead, while ICP-MS lead was measured as 5ppb, a deviation of 250%; the next greatest deviation is 140%. If this one point is excluded, the lead deviations reduce to 100±20%, which is more similar to sample uncertainties. Additionally, it is possible that the ICP-MS is more sensitive to measuring lead than the method employed at the state lab, which would result in a consistent underestimate at the state lab, as is observed.

3.7   Boyden Lake and Stream

Samples were collected at 6 points between Boyden Lake and downstream release to the ocean, and at two points in the PWD distribution. Figure 3-3 shows the locations of samples, with the exception of the PWD samples. The PWD samples were collected from the outflow of the water distribution plant located beside the Impoundment and from the Re-chlorination Station in Eastport; these locations are displayed in Figure 1-2.

Concentrations of lead and arsenic did not exceed EPA guidelines in any location. Arsenic levels were also low, and peaked in the Cove at 3.8ppb, 2ppb higher than any other sample. Lead concentrations remained very low (<0.4ppb) in all samples. Iron levels were lowest in Boyden Lake, but increased in Boyden Stream, the Impoundment, and were highest in the downstream Little River sample. Concentrations of all other metals remained low in all samples. Table 3.11 displays results for all Boyden water samples.

Arsenic levels were lower in the treatment plant sample than in Impoundment by about 1ppb, suggesting that treatment removes a percentage of arsenic, and remained steady between the treatment plant and the re-chlorination station. Because lead levels were low in all samples, no significant difference can be seen between Impoundment levels and post-treatment, although a slight increase does occur between the treatment plant and the re-chlorination station. Iron levels decreased by more than 50ppb between the Impoundment and the treatment plant, suggesting efficient removal in agreement with the Hodsdon report
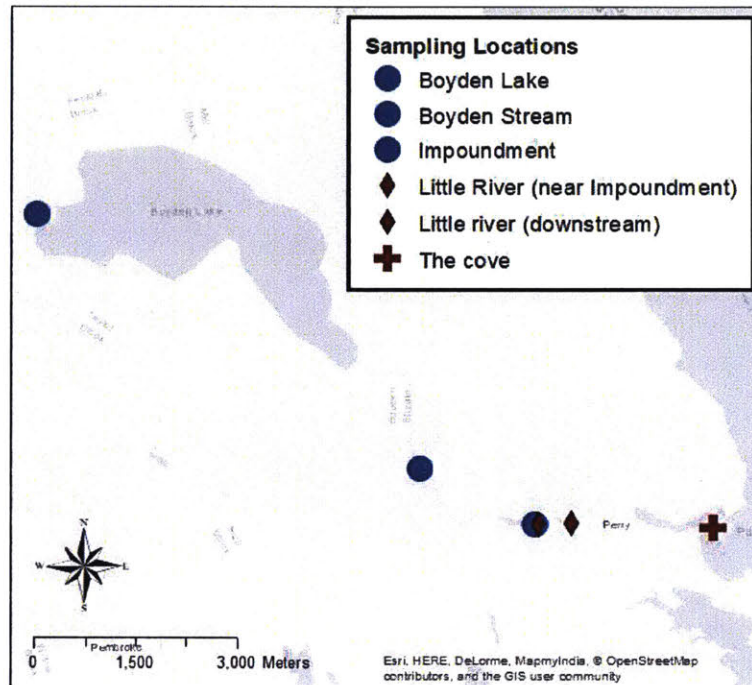
Figure 3-3: Sampling Locations for Boyden Lake, Boyden Stream, and Little River. Blue circles indicate areas before PWD water intake, red diamonds represent areas following PWD water intake, and the red plus represents ocean.

[AE Hodsdon Engineers, 2010]. Iron levels increased by 0.7ppb between the treatment plant and the re-chlorination station, suggesting that piping may leach a small amount of iron between these locations. Copper levels increased by 4.6ppb between the Impoundment and the treatment plant, and increased a further 2.7ppb by the re-chlorination station. Aluminum increases by about 5ppb between the Impoundment and the treatment plant, and increases a further 2.5ppb by the re-chlorination plant. The increase at the treatment plant is expected because aluminum is used as a coagulant in treatment [AE Hodsdon Engineers, 2010]. The increases in lead, iron, copper, and aluminum between the treatment plant and the re-chlorination station suggest that piping may contribute small amounts of these metals to water.

Table 3.11: Boyden Lake and Stream Results

	Boyden Lake[a]	Boyden Stream	Impoundment	Treat-ment plant[b]	Re-chlor-ination Station[b]	Little River (near Im-pound-ment)	Little River (down-stream)	The Cove
As	1.5	1.8	1.6	0.5	0.5	1.3	0.8	3.8
Pb	0.1	0.2	0.1	0.1	0.4	0.2	0.1	0.1
Fe	4.2	97	54	2.9	3.6	31	104	2.9
Cu	0.8	0.9	0.4	5.0	7.7	2.4	0.5	0.7
Mn	0.4	0.5	1.2	0.7	0.6	0.8	0.9	0.5
Cr	0.1	0.2	0.2	0.1	0.2	0.2	0.2	1.7
Al	0.8	1.6	2.1	7.0	9.5	0.6	1.2	1.7

[a]All units are ppb)
[b]Gray color indicates sample is taken following treatment

3.8 Sediment Results

Table 3.12 displays average sediment results. Averages are bounded by the student's t-confidence intervals. Iron was the most prevalent metal, followed by aluminum and manganese. The remaining metals were present at values less than 10mg/kg, and cadmium was not measured above the detection limit.

According to Table B.1, no limits exist for aluminum, manganese, iron, and cobalt levels in sediment. Chromium, nickel, copper, zinc, arsenic, cadmium, and lead levels fall far below soil limits, and within the low risk range for aquatic health. Selenium levels are below soil guidelines. These all suggest that metal contaminations in Boyden Lake sediments pose little risk to organisms in the lake, and are likely not a major concern even under optimal release conditions.

Figure 3-4 presents spatial patterns of sediment concentrations for iron, arsenic, manganese, and lead. The light blue arrows represent inflow from tributaries, and the dark blue arrow represents outflow through Boyden Stream. Metal concentrations are lowest on the northern bank near the tributary entrances. Concentrations are higher on the southwestern bank, far from any inflows or outflows, although the increase varies between metals. In the southeastern park of the river near Boyden Stream, metal concentrations are higher for

Table 3.12: Sediment Results

Metal	Median (mg/kg)
Aluminum	1300±280[a]
Chromium	7±1
Manganese	100±30
Iron	12000±2800
Cobalt	2.0±0.4
Nickel	4.0±0.8
Copper	1.0±0.4
Zinc	9±2
Arsenic	2.0±0.6
Selenium	1.0±0.3
Cadmium	0
Lead	4±2

[a]Average values are bounded by the p95 confidence interval around the mean.

lead, iron, and arsenic, but remain low for manganese. Spatial maps of all other metals are displayed in Figure B-5.

3.9 PWD Results

3.9.1 Lead

Lead Concentrations

The majority of water samples (85%) contained lead at levels below the method detection limit of 0.1ppb. Only 5% of running (flushed) samples and 25% of standing samples contained lead above 0.1ppb. A paired t-test found that the distributions of running and standing lead values were significantly different at the 0.01 confidence level, but no running samples exceeded the lead action level of 15ppb, and only two standing samples exceeded the threshold. Overall, less than 1% of houses surpassed the lead action level. Table 3.13 displays the summary statistics of running and standing samples.

Distributions were also similar between Eastport, Perry, and Pleasant Point. Paired t-tests conducted for each pair of towns found no significant difference in lead distributions,
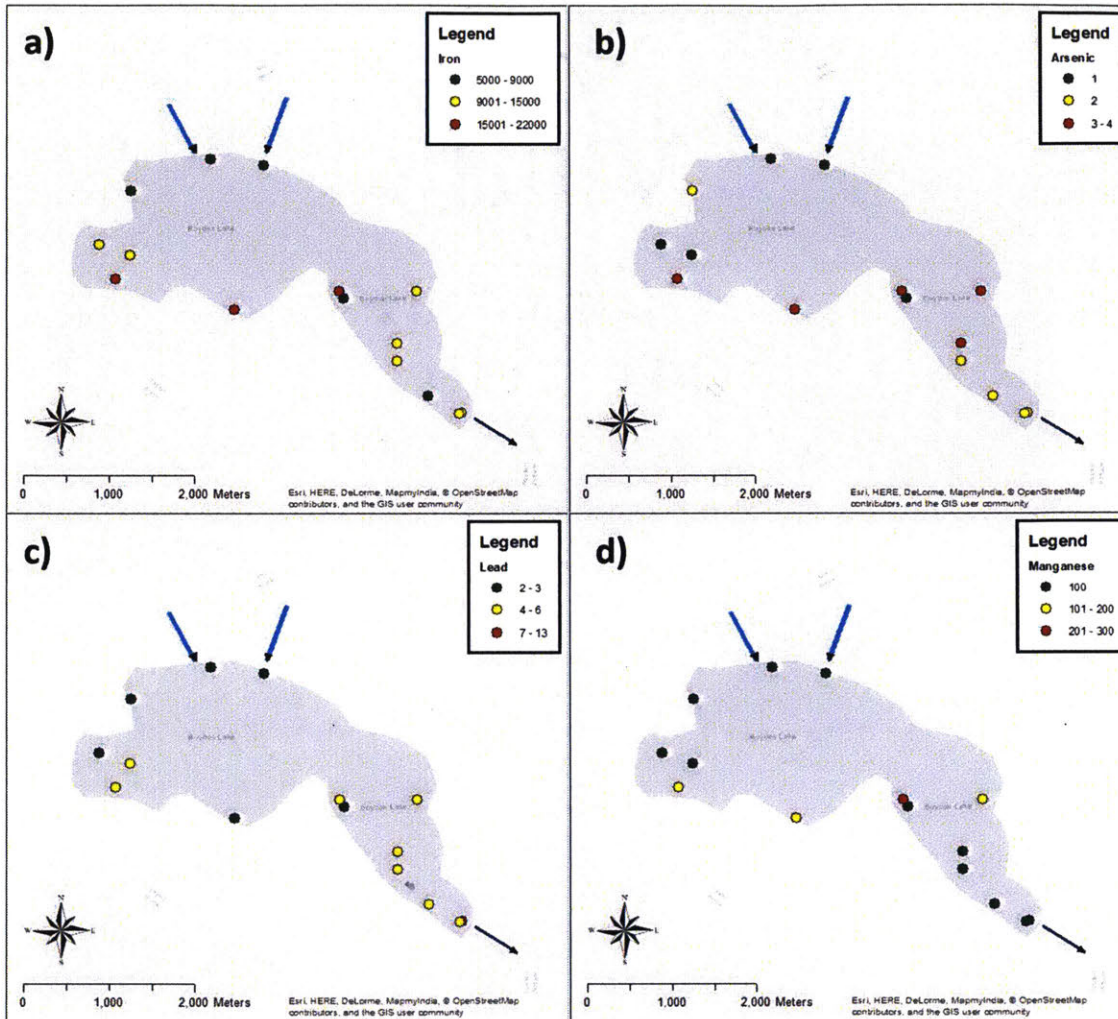
Figure 3-4: Spatial Distributions of Metals in Boyden Lake: a) Iron, b) Arsenic, c) Lead, and d) Manganese. Arrows indicate inflow and outflow.

although both exceedances occurred in Eastport. Table 3.14 displays summary statistics for lead concentrations by town.

Lead Enhancements in Standing Samples

The lead increases from running to standing samples were calculated for all samples. 74% of sample pairs had lead below the detection limit in both running and standing samples. Of the remaining 26% of samples, the median lead increase was 2.7ppb, and the maximum increase was 36.5ppb. Because the majority of running sample concentrations were below the detection limit, this average enhancement still resulted in low overall lead levels, and the

48

Table 3.13: PWD Lead Results by Sample Type

Sample Type	n	n above DL[a]	min	median	p95	max	Percent Exceedance
Running	120	5	<0.1	<0.1	1	8	0%
Standing	120	22	<0.1	<0.1	8	34	1%

[a]DL = Detection Limit

Table 3.14: PWD Standing Sample Lead Results by Town

Town	n	min	median	p95	max
Eastport	96	<0.1	<0.1	7.8	36.5
Perry	6	<0.1	<0.1	6.5	6.5
Pleasant Point	18	<0.1	<0.1	9	12

median lead concentration of standing samples was below the detection limit.

One sample showed a decrease of 8.1ppb between its running and standing sample, which is likely due to sample mislabeling at the time of collection. Values for the running and standing samples are likely reversed, and there was therefore an increase of 8.1ppb from the running to standing samples in this case. However, even accounting for this increase, the sample did not surpass the action level of 15ppb.

pH

Table 3-5(a) displays a histogram of pHs for all measured samples. The median pH was 8.1, and the range of pH was 7.12-8.70. Given that the pH is amended at the treatment plant to be 7.0-7.4, the pHs increased significantly within the distribution system. pH values were also not correlated with distance from the treatment plant.

Distance along piping

There is no significant relationship between lead levels and water travel distance or length of service lines. Figure B-6 displays the relationship between lead levels and travel distance, and Figure B-7 displays the relationship between lead and service line length.

Inspection of the physical locations of all samples with lead above 10ppb (n=4) reveals that two high lead samples are located at endpoints within the piping system, where water
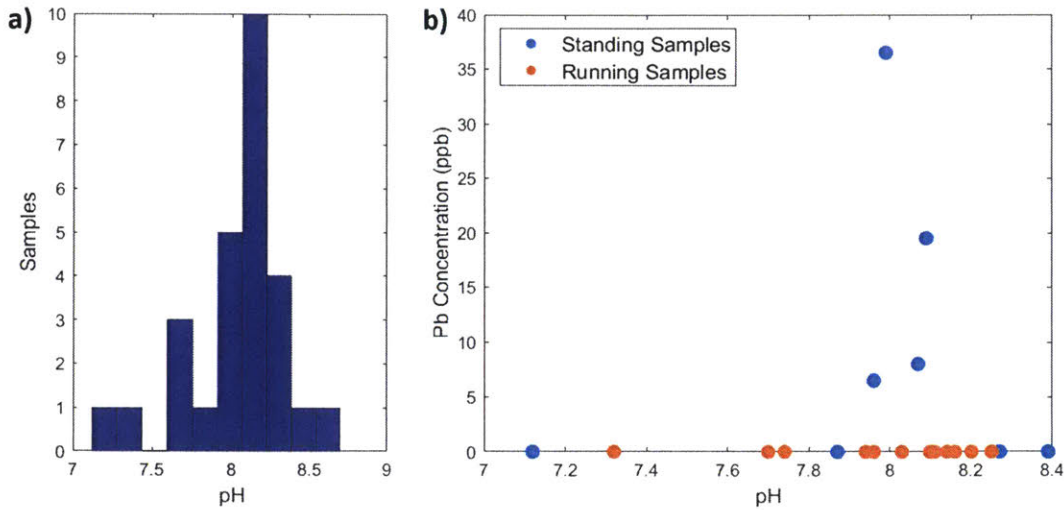
Figure 3-5: PWD lead and pH Statistics: a) pH Distribution for PWD samples and b) pH vs lead concentrations.

is more likely to experience long stagnation events. One of these samples co-occurs with high copper levels (>3ppm), which exceeds the Secondary EPA guideline (as shown in Table B.3), meaning there is the possibility of altered taste and color in the water [Environmental Protection Agency, 2009]. The remaining two high lead samples are not located near piping endpoints. One of these samples co-occurs with high zinc (>1ppm), but no adverse taste is expected at this zinc level [Environmental Protection Agency, 2009]. Two of the high lead samples do not occur with any other elevated metals.

3.9.2 Arsenic

Arsenic concentrations in PWD water were mostly below the detection limit. Only 4 PWD samples had measurable arsenic, and no sample exceeded 2.2ppb arsenic.

Table 3.15: PWD Arsenic Results by Sample Type

Sample Type	n	n above DL[a]	median	max	Percent Exceedance
Running	120	3	0	2.2	0%
Standing	120	1	0	1.3	0%

[a]DL = Detection Limit

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3.9.3 Other metals

With the exception of several samples that exceeded EPA guidelines for copper and manganese, all other metal levels in PWD samples were low and did not exceed EPA guidelines. Table B.8 displays summary statistics in PWD samples for all metals.

3.10 Well Results

3.10.1 Arsenic

Results by Sample Type

The median arsenic concentrations for both running (flushed) and standing samples were 1.3ppb. The 95th percentile values for both types of samples exceed the 10ppb EPA guideline, and the maximum value falls above 50ppb for both sample types. Percent exceedances of the EPA guideline are similar for both samples types, and a paired t-test found no significant difference between the two sample types. Twenty two running samples and 20 standing samples exceeded the EPA guideline. Table 3.16 displays arsenic statistics by sample type.

Table 3.16: Well Arsenic Results by Sample Type

Sample Type	n	min	median	p95	max	Percent Exceedances
Running	149	<0.1	1.3	17.2	61.0	15%
Standing	146	<0.1	1.3	22.3	65.0	14%

Arsenic Results by Town

Median arsenic concentrations for Perry and Eastport are between 1 and 2ppb. The 95th percentile for both towns falls above the EPA guideline. For Eastport, the maximum arsenic value exceeds 50ppm. For Eastport, eight running samples exceeded the EPA guideline, and 14 running samples exceeded the EPA guideline in Perry. Pleasant Point only had one well sample, and this sample did not exceed the EPA guideline. Table 3.17 displays summary statistics for arsenic by town.

Table 3.17: Well Running Sample Arsenic Results by Town

Town	n	min	median	p95	max	Percent Exceedances
Perry	83	<0.1	1.6	20.4	40.4	17%
Eastport	65	<0.1	1.2	13.9	61.0	12%
Pleasant Point	1	-	-	-	-	0%

Arsenic Results by Bedrock Type

Over 60% of samples were located in the Devonian bedrock formation, which covers Eastport and the Western region of Perry. The remaining samples were mostly from the sandstone formation in Eastern Perry, and only two samples were located in the Hershey formation in western Perry.

Arsenic concentrations were highest in the Sandstone formation, and the percent exceedance was highest as well (20%). Exceedances were 11% in the Devonian formation and 0% in the Hershey formation. However, t-tests between bedrock types found no significant difference between arsenic concentrations between all bedrock combinations. Table 3.18 displays the arsenic concentration statistics by bedrock type.

Table 3.18: Well Running Sample Arsenic Results by Bedrock Type

Town	n	min	median	p95	max	Percent Exceedances
Dev	95	<0.1	1.2	14.1	61	11%
Dpss	55	<0.1	3.2	25.5	40.4	20%
Sh	2	<0.1	0.5	1	1	0%

Because bedrock type plays a key role in arsenic levels, concentrations are generally expected to differ between bedrock types. While past studies of New England groundwater have found that felsic volcanic rock resulted in highest arsenic levels, sandstone other sedimentary rock type have been found to contain elevated arsenic levels globally [Ayotte et al., 2003, Yang et al., 2009, Peters, 2008, Barringer and Reilley, 2013]. Thus, it is reasonable that both bedrock types contain arsenic.

pH

The pH values in well samples ranged from 6.3 to 10.3, with a mean of 8.23±0.05. Figure 3-6(a) displays a histogram of pH values for all well samples.
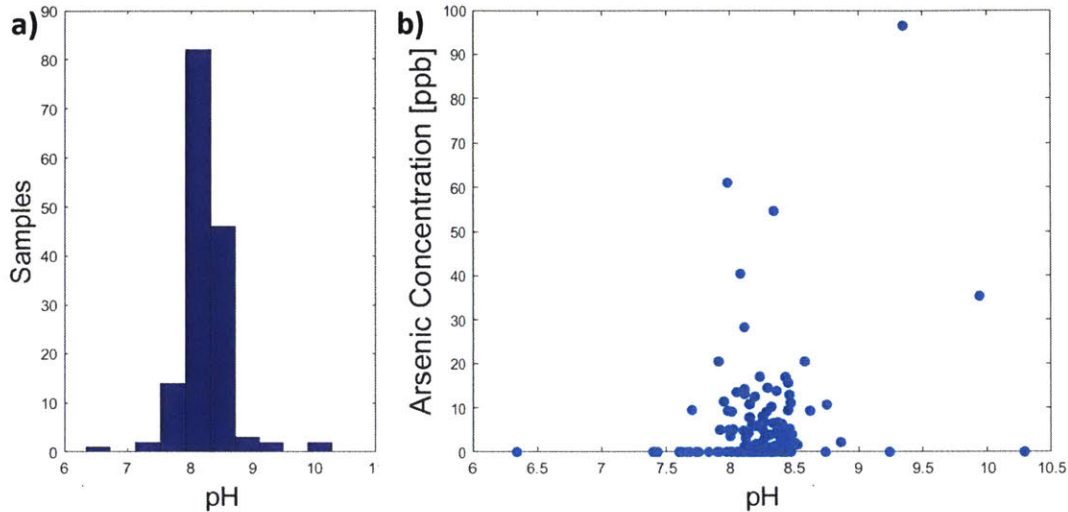

Figure 3-6: Well arsenic and pH statistics: a) pH distribution for all running well samples and b) pH vs arsenic concentrations in running samples.

There is a slight positive correlation between pH and As that is significant at alpha=0.10, but has an R^2 value of only 3%. Figure 3-6(b) shows a scatter plot of pH values against arsenic concentrations. Arsenic in groundwater generally correlates with increasing pH levels, but pH is a small factor in arsenic variation in this case. Because of the randomness of travel within bedrock fractures, pH is still likely an important factor in arsenic desorption, but contact time with arsenic-contaminated bedrock (which occurs heterogeneously even within bedrock with high arsenic levels) also plays a key role. Even water with favorable conditions for arsenic desorption may not contain any arsenic if it does not come into contact with arsenic-contaminated rock.

Well Depth

Of the 186 wells in the Maine Well Database for Eastport, Perry, and Pleasant Point, only 13 could be confirmed as the same well from this study. Most wells did not contain specific addresses, and thus could not be confirmed to be the same well in the study even when

co-located with a well sample from this study. However, a paired t-test found with p=0.66 that the well depths between the subset and overall data were from the same distribution.

Well depth may generally be a factor in arsenic concentrations. Deeper wells imply a greater water travel distance to the well through potentially arsenic-contaminated rock, increasing leaching time and potential between water and rock.

There is a slight positive correlation between well depth and arsenic concentrations, but because of the few data points, this was not a significant correlation (p = 0.44). There is also a slight positive correlation between well depth and pH, but this was not significant (p=0.27). Scatter plots of well depth, arsenic, and pH are displayed in Figures B-9 and B-10.

3.10.2 Lead

Median lead concentrations were below the detection limit for both running and standing samples. However, the maximum and 95th percentile of standing samples were much greater than in running samples, and the percent exceedance of 15ppb is 5% greater in standing samples. Table 3.19 displays statistics for lead results by sample type. A student's t-test found significant difference between well and PWD standing concentrations (p=0.02, t=-2.3, and df=189).

Table 3.19: Well Lead Results by Sample Type

Sample Type	n	min	median	p95	max	Percent Exceedances
Running	133	<0.1	<0.1	2.8	19.0	1%
Standing	133	<0.1	<0.1	19.3	112	6%

Both Eastport and Perry had standing samples that exceeded the EPA action level, 6.6% of samples in Eastport and 4.8% of samples in Perry. Lead distributions did not differ significantly between the two towns, based on a student's t-test (p=0.40, t = -0.85, df = 112). Pleasant Point only had one well sample, and this sample measured non-detect for lead.

55% of paired samples had lead below the detection limit in both running and standing samples. Of the remaining 45% of samples, the median lead enhancement is 3.5ppb, the

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Table 3.20: Well Standing Sample Lead Results by Town

Town	n	min	median	p95	max	Percent Exceedances
Eastport	61	<0.1	<0.1	19.2	20.9	7%
Perry	84	<0.1	<0.1	15.9	112.4	5%
Pleasant Point	1				<0.1	0%

95 percentile is 21.6ppb, and the max increase is 112ppb. A paired t-test found significant difference between the running and standing lead distributions, as displayed in Table B.11.

A negative correlation was observed between lead levels and pH; ρ=-0.14 and p=0.11. Lead desorption is expected to increase at lower pH levels in general [Wang et al., 2014], so this relationship is in agreement with the literature.

Statistics for enhancements of other metals are included in Table B.10 and histograms are displayed in Figure B-10.

Chapter 4

Summary and Conclusions

4.1 PWD Water

Of all the metals measured in PWD water, lead is of the most concern. However, EPA guideline exceedances were very low (<1% in standing samples), implying that there is not a widespread lead problem within PWD water. Additionally, because lead is not correlated with water travel distance, service line length, or pH, and because lead levels at the treatment plant and re-chlorination station are low, it is likely that several individual houses have old piping systems that contribute the majority of lead in their water. Therefore, the ideal remediation of lead in these houses would be achieved by replacement of household or service line piping. A temporary solution for lead exposure could be achieved through flushing of the pipes; no running samples exceeded the lead action level of 15ppb, and therefore flushing for 2-3 minutes before consumption of water would greatly reduce risk. Segev 2015 found that filters were efficient in removing lead from drinking water, and thus installation of filters can also greatly reduce risk.

4.2 Well Water

4.2.1 Arsenic

Arsenic concentrations exceeded EPA guidelines in 15% of samples, which is below previous predictions well exceedances of 20-30% for the state of Maine [Ayotte et al., 2006]. This suggests that either Maine exceedances have been overestimated, or that this region is at lower risk of arsenic contamination than other regions in Maine. Given that the well sampling rate for this study was 32%, it is possible that the samples collected and studied may be biased towards lower arsenic-containing wells. However, previous studies have had sampling

rates much lower than this amount [Nielsen et al., 2010], and therefore this study likely provides greater accuracy regarding arsenic guideline exceedances.

Because arsenic concentrations in the wells did not vary significantly with any of the measured parameters and the concentrations varied greatly even over short distances, it is likely that bedrock fracture geometry plays a large role in groundwater arsenic concentrations. As such, it is recommended that all well owners have their well tested for arsenic, and that those with high arsenic concentrations either switch their drinking water sources or install filters capable of removing arsenic from water. Additionally, alternative water sources such as bottled waters may be used for consumption by more at-risk populations, such as children.

4.2.2   Lead

Six percent of houses with wells exceeded the EPA action level for lead in standing samples, and 1% of houses exceeded the EPA action level in running samples. In most samples, however, lead levels were very low in the running sample, and only exceeded the threshold in the running sample, suggesting that lead within the household piping is the source of lead within their drinking water. Thus, remediation of lead of these houses could be achieved through the same methods: through replacement of household piping, installation of filters, or in the short term, by the recommended flushing of water before consumption.

4.3   Other Metals

Concentrations of the metals measured besides arsenic and lead were low in both well and PWD water, with the exception of 2-3 samples that contained copper and manganese concentrations exceeding the EPA guidelines. Because these metals generally do not exceed EPA guidelines, they pose less health risk than arsenic and lead.

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Appendix A

Community Materials
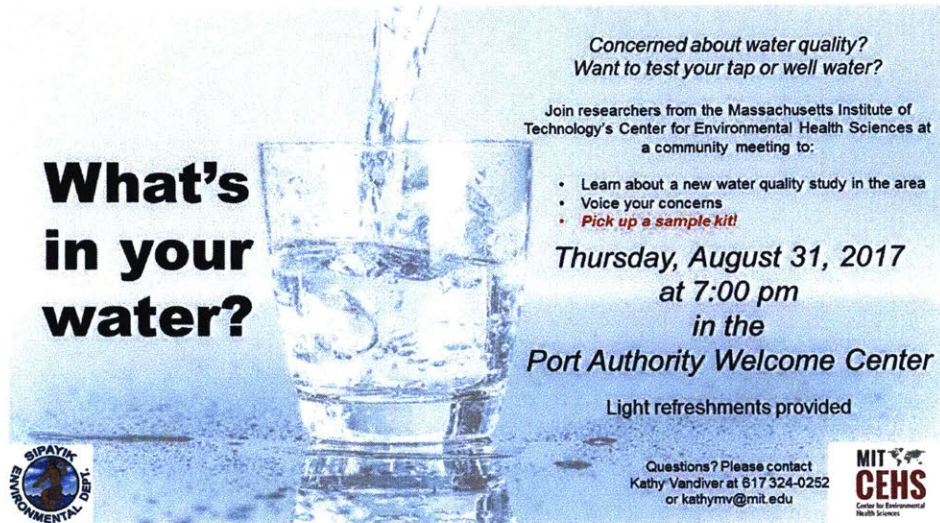
Figure A-1: Flier used to advertise first community meeting

Questions and Responses

Community Meeting in Eastport, ME. Aug 31, 2017   **Responses typed up here.**

Questions written on the papers on the tables. People at the tables discussed and recorded responses. Typed up here:

Table notes
1 in black   Boyden lake resident. .
2 in red.   Students wrote questions not spaced out on the big sheet. Thus the answers were less organized. (a person wrote H^2O incorrectly on paper 3 in blue   Robin's table and PWD table.
4 in purple.   Most technical group had Steve , Aquaculture and his RN wife, Pam)

1) **What questions do you have for us?**
   - Why not take a spring season sample? (run off , heavy rain, stagnant water?)
   - Can we get the results from the springs sooner? (because the people drive to the springs for drinking water)
   - Are there any mines in the watershed?
   - How is the septic waste handled at Boyden Lake?
   - Can you please demonstrate how to get the GPS coordinates from the sample points?
   - For water collection, how close to the Oct 6 date should we take the sample?
   - Where there is a boil order, how should the community be notified?
   - Why Eastport?
   - Difference between drilled wells and shallow wells as it pertains to water quality results.
   - Wells drilled in sandstone vs. granite / ledge
   - What happens if the test results are really bad?
   - Water quality differences various PWD areas- water pipe issues/ replacement
   - Upon completion of the analysis what will the results be used for?
   - Where there any red flags that caused you to choose Eastport/ Boyden Lake?
   - Will the action plan include remediation of the problems?
   - Who is funding the analysis ?
   - *Public Health Concerns * High cancer rate here

2) **What water quality concerns do you have?**
   - Fluoride , Arsenic,
   - Bacterial (boil notices!) camps on Boyden Lake
   - Parasites in water
   - Oil tanks on edge of Boyden Lake, septic systems on Boyden Lake
   - Smell and taste,   Sulfur
   - Is surface H2O more contaminated than municipal water?
   - Is swimming allowed in Boyden Lake?
   - What is the impact of cloudiness- turbidity?
   - Contaminants that would affect development of children
   - Taste
   - Color of water- sediment?
   - Bacterial contamination
   - Can water cause issues w. fetal development
   - Carcinogens

Figure A-2

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- Radon
- Boyden Lake dam. How to maintain healthy water level
- Ground water / wells   - leakage of ground water into wells
- Fluoride? What concentration?
- Chlorination?
- Carcinogens? Man- made of naturally occurring?
- Petroleum products from recreational boating on the Boyden Lake (inadequate sanitation systems surround Boyden Lake ? up to date?)

3) **What information would like to share with us?**
- For years fish scales were dumped on fields – from pearl essence plants cleaned with chemicals close to the pumping station.
- More geese are around
- People spend time and gas to drive to the springs for water in Robbinston and Pembroke
- Maine DEP study of water quality done for years in Boyden Lake i.e./ Pb. /Dissolved oxygen / fecal coliform/ clarity/
- Toilet has to be cleaned often, why?
- We receive PWD reports on irregular basis and usually many months after the problem was discovered and remediated = we don't know about it at the time it occurs-
- Boil water alerts not timely and or well- communicated

Figure A-3: Notes from Eastport Community Meeting

Meetings Notes from PWD treatment facility tour on 8/31
With Howard Johnson

- Measure pH of incoming water vs outgoing
- 4 sets of "train"
- Eastport and Pleasant Point reservoirs
- Pump - 300 gal/min
- Highest turbidity: 0.45 Tu. If turbidity exceeds that, they stop pumping
  - Alarms go off when pumps, pH, turbidity exceeded/errors
- Chlorine levels spike after plant first turned on; pumps turn on when water in standing pipes gets too low
- Rinses for 30 min before going through system
- If there is more turbidity, more chlorine is added
- Aim for break point chlorination: if too much or too little Chlorine, there will be an odor
- Whenever there is heavy rain, it stirs up water, "treatment plant goes haywire"
- Target pH 7.1-7.2
- Fluoride levels 0.5-0.7
- Used to use lime to adjust pH, but not anymore
- Use Aries 1144 polymer, which is Alum
  - Coagulates particles together so they can be filtered out
  - Viking Technology set up water treatment methods; AE Hodsdon Engineers chose mainly the same treatment techniques as before in their review
- Clarifier: filters out particles. Has 7-8 layers of sand
- Seasonality:
  - Winter (Nov-Apr) best conditions
  - Summer worst - color changes, lake turns over, leaves go into it, color becomes a problem
- They backwash tanks and discard the waste every 10 years
- A building in Eastport adds more chlorine to water
  - It is 12 miles away, and water takes 3 days to reach there

Figure A-4: Notes from PWD Facility Tour

Water Quality Study of the Boyden Lake Watershed

Tap Water Sampling Procedure:

1. **Read and sign the _PARTICIPATION FORM_** in the kit.
   Place one of the signed forms in the Ziploc bag with the water samples.
   Keep the second copy for your records.
   Note: this form is the only paper in this kit that is not waterproof. Keep it dry, please! Thanks.

Now for the Water Collection:

2. Identify the most-used tap for drinking water in your house.
3. Remove any covers or filters from the tap.
4. Collect 2 separate samples by different methods:
   a. **Sample A Bottle: Standing water sample.** Allow water **_to stand_** in pipes for approximately 6 hours or more. This would be best to collect either first thing in the morning or after returning home from work.
      To collect sample: turn on tap, immediately fill water Bottle A to the top and cover. (No flushing of the water.)
   b. **Sample B Bottle: Flushed water sample.** Can be collected anytime.
      To collect sample: turn on tap, allow to run for 2-3 minutes, then fill water Bottle B to the top and cover.
5. Carefully complete the label for each sample with the supplied pencil. Be sure to list the address of the water source on the label rather than a mailing address.
6. Make sure labels are attached with tape & return 2 bottles in the supplied Ziploc bag.
7. Drop the bag off at one of the collection sites (See location of sites below.)

How to find your GPS coordinates (Ok to bring in samples without this)
Google Maps:
1. Find your house/location/water site on the map.
2. Press down on the location and hold. A pin will appear. A box at the bottom of the map will also appear. It includes the GPS coordinates. Copy   8 numbers : 8 numbers

App: Download the app called "GPS coordinates" and use it to record the location of your home.

Dates and Locations for pick-up and drop-off of water samples:
Tap Water Sample Kits available for pickup until February 2018.
Drop-off for the completed samples ends **Feb. 15, 2018.**

Two Sites: 1) _Tribal Office:_ 136 County Rd., Perry   2) _Moose Island Marine:_ 5 Sullivan St., Eastport
   Open Mon to Fri, 8:00 - 4:30   Open Mon to Fri, 8:00 – 5:00

****

For research study questions contact MIT Center for Environmental Health Sciences.
Team email for Abby Harvey, Tchelet Segev, and Kathy Vandiver: BoydenWaterSamples@mit.edu

For questions about drop-off and pick-up locations, contact Asha Ajmani, Sipayik Environmental Department, Passamaquoddy Tribe at Pleasant Point, at 207-853-5138 or aajmani@wabanaki.com

MIT | Civil and Environmental Engineering

MIT CEHS
Center for Environmental Health Sciences

Figure A-5: Sampling instructions included in the kits

PARTICIPATION IN WATER QUALITY STUDY

By submitting your water sample, you are consenting to participate in a research study conducted by Abigail (Abby) Harvey and Tchelet Segev from the Massachusetts Institute of Technology (MIT) for their Master theses in Civil and Environmental Engineering. The purpose of this research is to gain knowledge regarding water quality in the Boyden Lake Watershed, including the towns of Perry, Eastport, and Pleasant Point and provide individuals information on their water quality. Existing laws require that all participants be informed of the nature and purpose of this study and that written consent is obtained. Participation is voluntary and there will be no monetary compensation for participating.

We will measure concentrations of heavy metals and potentially other contaminants in your water samples at MIT and return the results to you with interpretation no later than June 1, 2018. We will not measure biological agents such as coliform bacteria. We are not a state-certified laboratory and our results cannot be used to meet any legal water testing requirements. The water testing will be paid for by a grant to MIT from the National Institutes of Health.

Your name, address, phone, and other identifying information will be kept confidential. Only generalizations of the data will be published, so your results are not linked to your home address. If you decide to take part, you are free to withdraw at any time before May 1, 2018.

I have read the information above and I voluntarily agree to participate in this study. A second copy of this form is for your records.

_____   _____
Printed name of participant   *Phone*

_____   _____
Signature of participant   *Date*

Please contact Tchelet Segev, Abby Harvey, and Kathleen Vandiver at BoydenWaterSamples@mit.edu with any questions or concerns.

If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.
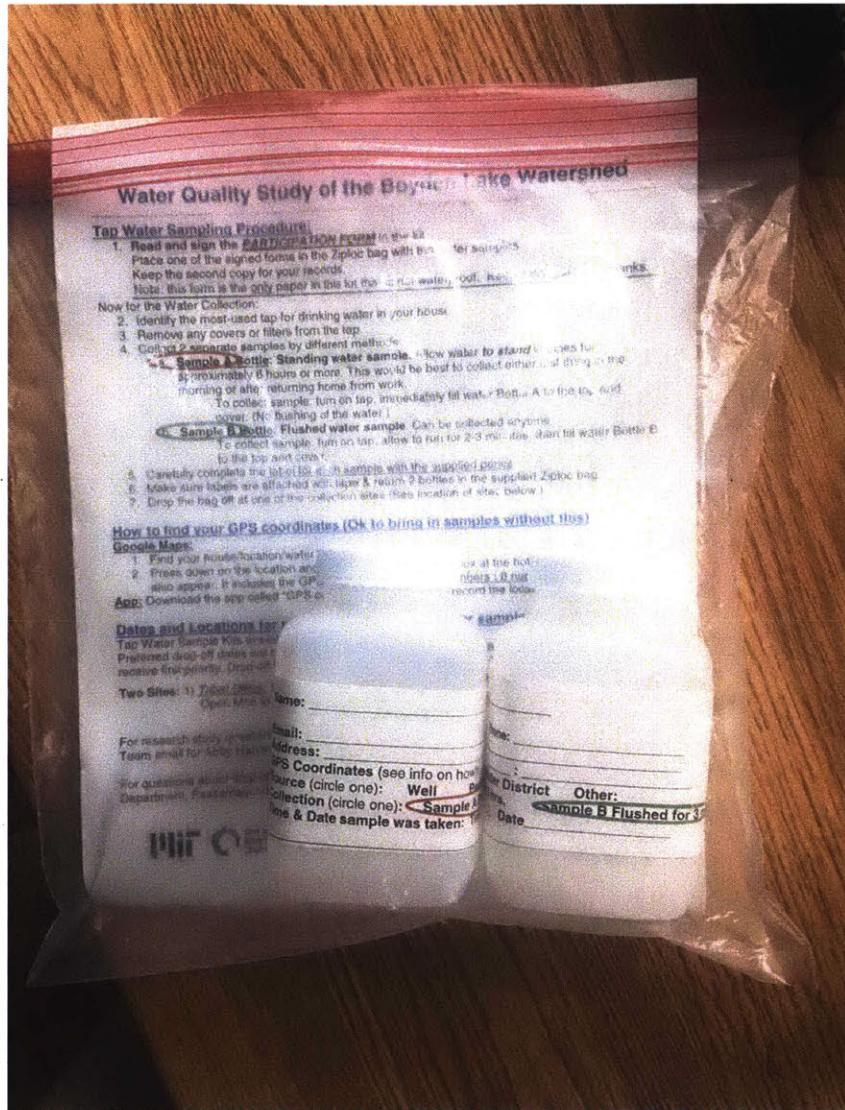
Figure A-6: Consent form included in the kits
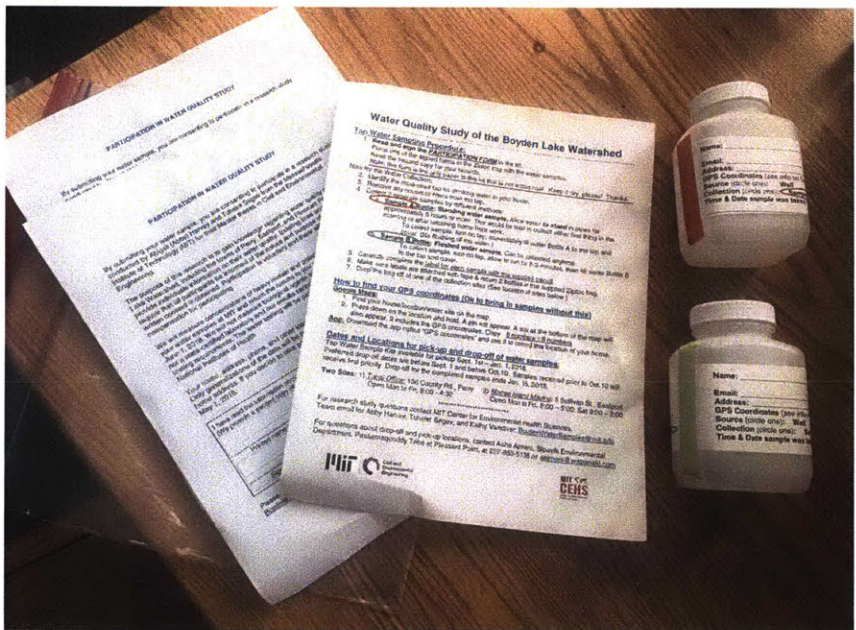
Figure A-7: Photo of assembled kit

Figure A-8: Photo of disassembled kit

Massachusetts Institute of Technology
Center for Environmental Health Sciences
77 Massachusetts Avenue Building 56-669
Cambridge, MA 02139

March 23, 2018
Dear Name,

Thank you for participating in the Water Quality Study of the Boyden Lake Watershed conducted at the Massachusetts Institute of Technology (MIT). We are sending results to all samples turned in prior to the end of January.

On page 3 of this letter, we report the concentrations of metals measured in the Water Source water sample you submitted for Address table. The same table also includes the national water quality standards. To help you interpret these numbers, we have provided a list of helpful resources on page 2.

This study was conducted by two Master's student researchers at MIT's Civil and Environmental Engineering Department. The study analyzed only specific metals, and did not test for bacteria, organic chemicals, or chlorination byproducts in the water. Therefore, these results provide a partial picture of your drinking water quality.

Thank you again for participating in the study. We invite you to our final community meetings, where we will discuss general results from the study. There will be two meetings covering the same materials:
- Sunday May 20th at 7:00pm at the Community Center in Pleasant Point
- Monday May 21st at 7:00pm at the Eastport Welcome Center

Regards,
Abby Harvey and Tchelet Segev

MIT Environmental Engineering Master's Students
Email: BoydenWaterSamples@mit.edu
Facebook: https://www.facebook.com/BoydenWaterSamples/

1

Figure A-9: Page 1 of the results letter

For More Information

Below are some websites that provide additional information:

Results Interpretation

For more information on how to interpret your results, health effects, and possible remedial actions, please visit the Ohio Watersheds Network: https://ohiowatersheds.osu.edu/know-your-well-water/well-water-interpretation-tool

Wells

If you own a well, you can call 866-292-3474 (toll-free in Maine) or 207-287-4311 to talk to an expert about your results and visit wellwater.maine.gov to learn more about well water testing and drinking water quality.

For water with elevated Arsenic levels, you can also refer to the following Arsenic factsheet from the Maine Department of Health and Human Services: http://www.maine.gov/dhhs/mecdc/environmental-health/eohp/wells/documents/arsenicresultstipsheet.pdf

Maine Housing's Arsenic Abatement Program provides grants to eligible single-family homeowners or landlords with private well water if there is evidence of high levels of arsenic contamination. You can find more information about the program here: http://mainehousing.org/programs-services/HomeImprovement/homeimprovementdetail/arsenic-abatement-program

Lead in Water

For water with elevated Lead levels, please refer to the following factsheet from the Environmental Protection Agency: https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water

2

Figure A-10: Page 2 of the results letter

Results

Below are the results for your standing and flushed samples.

- The standing sample is water that stood in pipes for at least 6 hours, and shows the effects of piping water quality.
- The flushed water sample is the water you collected after letting the tap run for 2-3 minutes, and shows your water quality without the effect of the piping.
- The Primary Standard Maximum Contaminant Level is the highest level of a contaminant allowed in drinking water to protect the public health.
- Secondary Standard Maximum Contaminant Levels are optional water quality standards established for considerations such as taste, color, and odor. These contaminants do not present a risk to human health.
- The results are reported in units of micrograms per liter (μg/L).

	Your Results		EPA Standards	
Name of Metal	Standing Sample Concentration (μg/L)	Flushed Sample Concentration (μg/L)	EPA Primary Standard Maximum Contaminant Level (μg/L)	EPA Secondary Standard Maximum Contaminant Level (μg/L)
Lead (Pb)	«Pb206_right»	«Pb206_left»	15	None
Arsenic (As)	«As_right»	«As_left»	10	None
Copper (Cu)	«Cu63_right»	«Cu63_left»	1300	1000
Manganese (Mn)	«Mn_right»	«Mn_left»	None	50
Iron (Fe)	«Fe_right»	«Fe_left»	None	300
Cadmium (Cd)	«Cd_right»	«Cd_left»	5	None
Zinc (Zn)	«Zn_right»	«Zn_left»	None	5000
Aluminum (Al)	«Al_right»	«Al_left»	None	50-200
Selenium (Se)	«Se_right»	«Se_left»	50	None
Cobalt (Co)	«Co_right»	«Co_left»	None	None
Nickel (Ni)	«Ni_right»	«Ni_left»	None	None

3

Figure A-11: Page 3 of the results letter

Drinking Water Quality Research in the Boyden Lake Watershed

MIT CEHS
Center for Environmental
Health Sciences

Civil and
Environmental
Engineering

SIPAYIK
ENVIRONMENTAL DEPT.

Community Meeting
Perry Elementary School
Sunday, October 8, 2017

Presentation by: Kathleen Vandiver, Abby Harvey & Tchelet Segev
Massachusetts Institute of Technology

The Agenda

4:00 - **Welcome, Refreshments, and Introductions**

4:15 - **Purpose of meeting and Importance of Citizen Science**

4:20 - **Presentation of Research Work Plan so Far**

4:35 - **Group Discussion**

4:45 - **Groups Report Back**

4:55 - **Wrap-Up**

5:00 - **Adjourn and Sample Kit Distribution**

The Community Effort

Investigation made possible by...

Citizen scientists - you!

Figure A-12

The Purpose

Provide independently tested drinking

water quality information to Boyden

Lake Reservoir communities

The Locations

Validate existing data and fill information gaps

Lakes

Rivers

Tap water

Well water

Springs

Penknife Lakes

Boyden Lake

Perry

Pleasant Point

Boyden Stream Reservoir

We collect (lake, river)

You collect (tap, well, springs)

Moose Island

Eastport
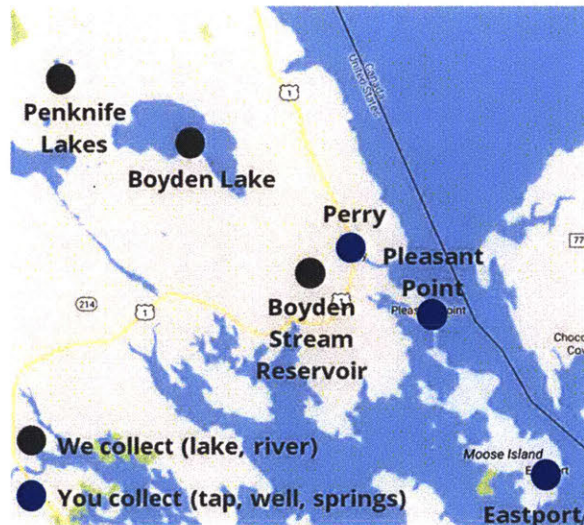
The Pollutants to Test

Barium
Chromium
Manganese
Arsenic
Lead
Mercury
Cadmium

What do you want to test for?

Others: Copper, Tin, Uranium, Iron, Cobalt, Zinc, Nickel, etc.

Figure A-13

The Goals

Concentration at source

Water concentration - tap, well, spring

Risk analysis - potential health impacts

Attempt identify potential pollution sources

Timeline: Aug 2017 - June 2018

Aug 31- Sept 1: community meeting/ sampling

Oct 7-11: community meeting/ sampling

Jan-May: we perform analysis

May/June: community meeting/ results/ interpretation

Sharing Results and Follow up

May/June: community meeting, results, interpretation

- Interpretation of results
- Email household results
- Share averaged results
- Future actions

Figure A-14

Your Participation

- Water collection kits
- Two sample types
- Sample Labeling
- Drop-off location

Your Participation

- Water collection kits
- Two sample types
- Sample labeling
- Drop-off locations

→ Take for yourself, your friends, & neighbors

Contains:
2 test bottles,
2 labels,
2 participation forms
& instructions

Your Participation

- Water collection kits
- Two sample types
- Sample labeling
- Drop-off locations

→ **Sample A:** Collect after letting water stand in pipes for 6 or more hrs

Sample B: Collect after letting water run for 2-3 mins

Figure A-15

Your Participation

- Water collection kits
- Two sample types
- Sample labeling
- Drop-off location

➡️

Name
Email
Phone
Address
GPS coordinate
Water Source
Sample A
Sample B
Participation
form

Your Participation

- Water collection kits
- Two sample types
- Sample labeling
- Drop-off location

➡️

Tribal Office
136 County Rd.
Perry

or

Moose Island
Marine
5 Sullivan St.
Eastport

Your Participation

- Water collection kits
- Two sample types
- Sample labeling
- Drop-off location
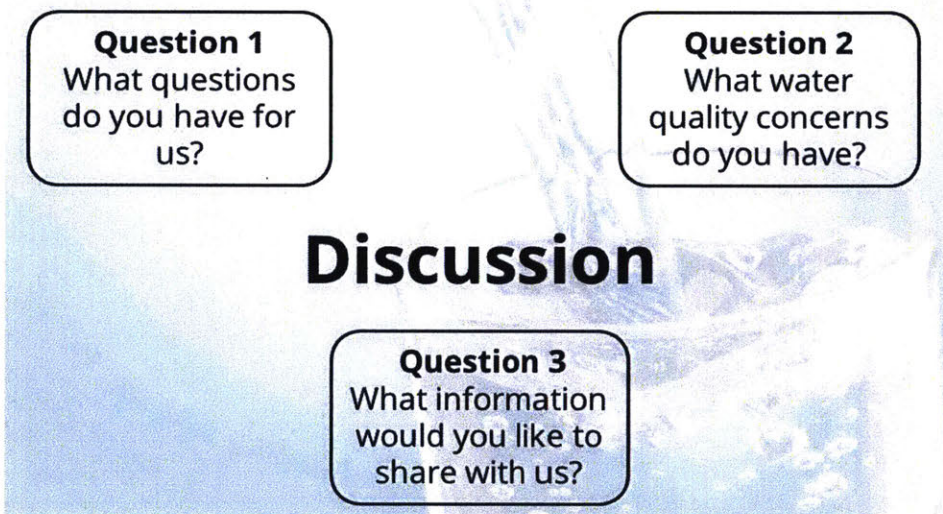
➡️

Preferred drop-
off date:
Monday
October 9

Figure A-16

Figure A-17: Presentation used for community meetings

Want your drinking water tested?

Free water sampling kits are available for local pickup

A research team from the Massachusetts Institute of Technology is conducting a pilot project on drinking water quality. Perry, Pleasant Point, and Eastport are the towns included in this community outreach program.

We are testing well water, district water, and spring water for:
Arsenic, Lead, Copper, Cadmium, Chromium, Iron, and Mercury.

Water sampling kits are available free of charge in Perry and Eastport. Please collect samples from the well water, district water, or spring water that you regularly drink. Return the kits to a pick-up and drop-off location below. Testing will be performed by the MIT research team free of charge, and household results will be returned by June 2018.

Pick-up and Drop-off Locations:
Moose Island Marine: 5 Sullivan St., Eastport
Open Mon to Fri, 8:00 -5:00
Tribal Office: 136 County Rd., Perry
Open Mon to Fri, 8:00-4:30

Deadlines:
Priority: January 31st
Last call: February 15th

Already sent in a water sample?
You can send in a water sample for a second time, but it's not necessary.

MIT CEHS
Center for Environmental Health Sciences

Contact us at:
 facebook.com/BoydenWaterSamples
 BoydenWaterSamples@mit.edu

Figure A-18: Flier sent by mail to town residents

Appendix B

Supplementary Data
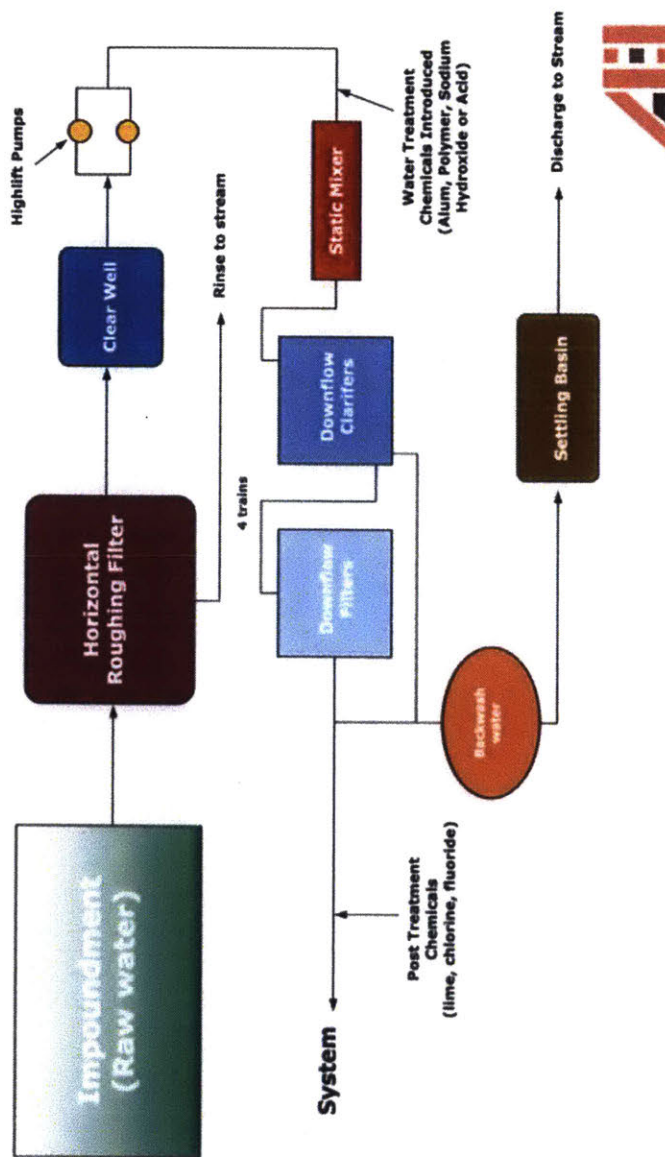
Figure B-1: Schematic of PWD Water Treatment. Source: [AE Hodsdon Engineers, 2010]

Table B.1: Regulatory limits on heavy metals in soils and sediment

Metal	Soil guidelines[a]	Sediment Guidelines for Aquatic Health [b]		
		Low Risk	Moderate Risk	High Risk
Arsenic	75	0-8.2	8.2-70	70+
Cadmium	85	0-1.2	1.2-9.6	9.6+
Chromium	3000	0-81	81-207	207+
Copper	4300	0-34	34-270	270+
Lead	420	0-46.7	46.7-218	218+
Nickel	75	0-20.9	20.9-51.6	51.6+
Selenium	100	-	-	-
Zinc	7500	0-150	150-410	410+

[a]Source: [NRCS, 2000]
[b]Source: [Sylman, 2015]

Table B.2: EPA Primary Drinking Water Regulations for all Metals

Metal	MCL^{ab}	MCLG^c	Health Risks	Common Sources
Lead	0	TT: 15^d	delays in physical & mental development of infants & children; kidney problems and high blood pressure in adults	corrosion of household plumbing, erosion of natural deposits
Arsenic	10	0	skin damage; problems with circulatory systems; cancer	erosion of natural depositions, runoff from orchards, or glass & electronic productions waste
Copper	1300	TT: 1300	gastrointestinal distress, liver or kidney damage	corrosion of household plumbing; erosion of natural deposits
Cadmium	5	5	kidney damage	corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromiume	100	100	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Selenium	5	5	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	discharge from petroleum refineries, erosion of natural deposits, discharge from mines

^{a}Adapted from EPA National Primary Drinking Water Regulations[Environmental Protection Agency, 2009]
^{b}Maximum Contaminant Level (ppb)
^{c}Maximum Contaminant Level Goal (ppb)
^{d}TT = Treatment Technique

Table B.3: EPA Secondary Drinking Water Regulations for all Metals

Metal	Secondary MCL (ppm)[a][b]	Effects above Secondary MCL
Aluminum	0.05 to 0.2	colored water
Copper	1	metallic taste; blue-green staining
Iron	0.3	rusty color; sediment; metallic taste; reddish or orange staining
Manganese	0.05	black to brown color; black staining; bitter metallic taste
Zinc	5	metallic taste

[a]Adapted from EPA National Primary Drinking Water Regulations[Environmental Protection Agency, 2009]

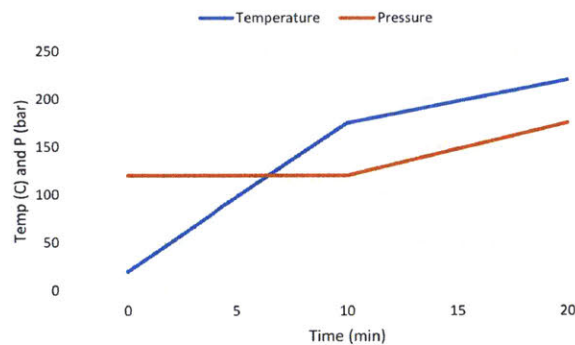[b]Maximum Contaminant Level (ppm)
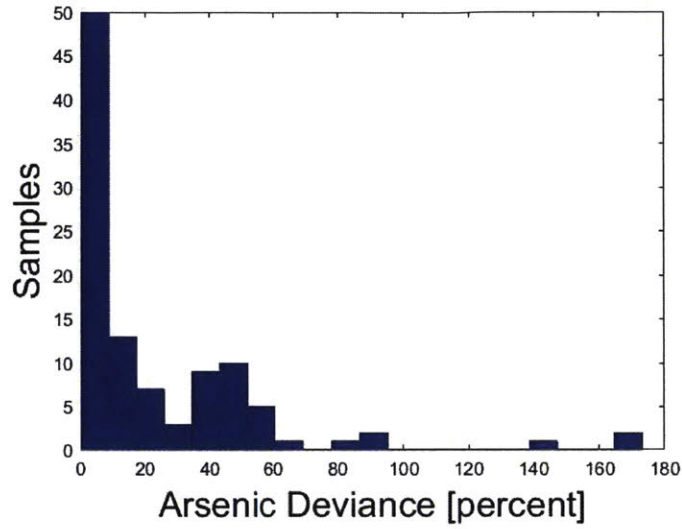

Figure B-2: Ultrawave Digester Settings

Figure B-3: Histogram of Arsenic Deviances Between Replicates
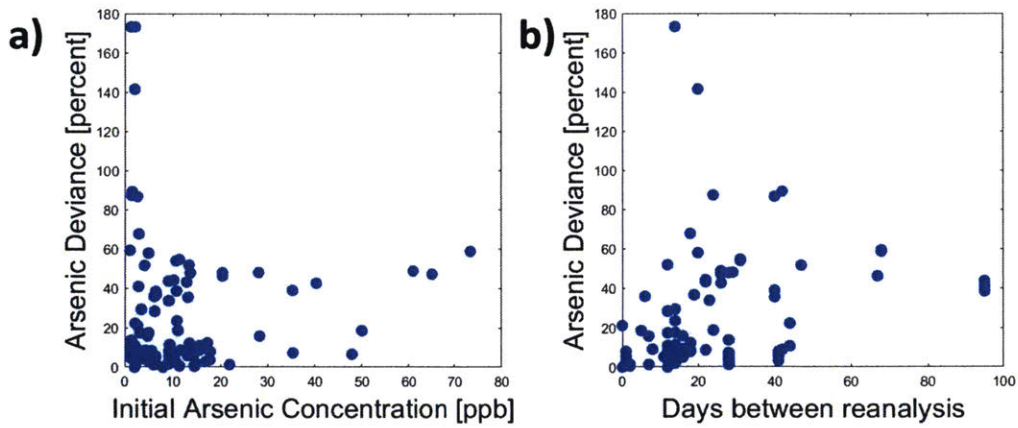
Figure B-4: Scatter plots of a) Initial Arsenic Concentration and Arsenic Deviances and b) Days between analysis and Arsenic Deviances

Table B.4: T-test statistics for replicate samples

Type 1	Type 2	Arsenic				Lead				Iron				Copper			
		h^a	p^b	tstat^c	df^d	h^a	p^b	tstat^c	df^d	h^a	p^b	tstat^c	df^d	h^a	p^b	tstat^c	df^d
All running	All standing	0	0.28	1.08	91	0	0.55	0.59	85	0	0.71	0.37	157	1	0.02	2.39	109
All well	All PWD	0	0.21	-1.59	3	0	0.38	0.9	27	0	0.28	1.09	84	0	0.43	0.79	92
Well running	Well standing	0	0.77	0.29	82	0	0.44	0.81	8	0	0.78	0.28	99	1	0.01	2.57	65
PWD running	PWD standing	-	-	-	-^{e}	0	0.78	-0.31	3	0	0.62	0.51	39	0	0.85	0.2	29

^{a}H=1 indicates distributions are significantly different
^{b}P-value: <0.05 indicates significance
^{c}t-value for metal
^{d}degrees of freedom
^{e}too few samples

Table B.5: Replicate Deviances Correlation Coefficients: All Metals

	All Samples				Standing Samples				Running Samples			
	n^a	Days^b	Wait time^c	Iron^d	n^a	Days^b	Wait time^c	Iron^d	n^a	Days^b	Wait time^c	Iron^d
As^e	104	0.25 (0.01)	0.13 (0.21)	0.11 (0.29)	45	0.34 (0.04)	0.01 (0.95)	0.28 (0.08)	51	0.21 (0.13)	0.23 (0.11)	0.02 (0.89)
Pb	65	0.27 (0.03)	0.04 (0.74)	0.14 (0.3)	49	0.3 (1)	0.02 (0.87)	0.15 (0.32)	10	0.29 (0.42)	0.24 (0.53)	0.5 (0.17)
Cu	185	0.31 (0)	0.18 (0.02)	0.24 (0)	91	0.55 (0.01)	0.29 (0.01)	0.46 (0)	79	0.29 (0.01)	0.14 (0.22)	0.01 (0.91)
Al	132	0.17 (0.06)	-0.12 (0.19)	0.1 (0.25)	62	0.2 (0.12)	0.01 (0.93)	0.07 (0.59)	57	0.09 (0.49)	-0.21 (0.12)	0.01 (0.95)
Mn	101	0.14 (0.17)	0.1 (0.33)	0.11 (0.31)	55	0.13 (0.35)	-0.21 (0.13)	0.26 (0.06)	37	0.14 (0.39)	-0.05 (0.76)	-0.03 (0.85)
Ni	86	0.07 (0.52)	0.27 (0.02)	-0.01 (0.96)	55	0.17 (0)	-0.12 (0.39)	0.09 (0.51)	21	-0.41 (0.07)	-0.62 (0)	0.11 (0.64)
Zn	177	0.14 (0.06)	0.07 (0.42)	0.1 (0.2)	93	0.29 (0.02)	0.14 (0.18)	0.16 (0.15)	70	0.06 (0.61)	-0.03 (0.83)	0.06 (0.65)

^{a}Number of samples above detection limit
^{b}Days between reanalysis
^{c}Number of days between collection and initial analysis
^{d}Sample Iron Concentration
^{e}Correlation significance denoted in parenthesis

Table B.6: Mean concentrations of metals by method and time between collection and analysis

Not Shaken												
Samples sitting for 3 months												
	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
Mean	8.1	<0.1	36.3	4.8	<0.1	3.4	26.9	45.3	2.2	<0.1	<0.1	0.3
Samples sitting for 4 months												
Mean	7.3	0.1	122.0	100.3	0.3	4.2	92.9	88.9	5.9	0.1	<0.1	1.1
Shaken												
Samples sitting for 4 months												
Mean	10.1	0.1	1.6	2.1	<0.1	1.0	90.2	80.7	0.2	<0.1	<0.1	0.8
Samples sitting for 1 month												
Mean	17.3	<0.1	9.4	9.2	<0.1	5.1	179.8	158.1	2.9	<0.1	<0.1	1.8

Table B.7: Comparison of State Lab and ICP-MS results for 20 samples

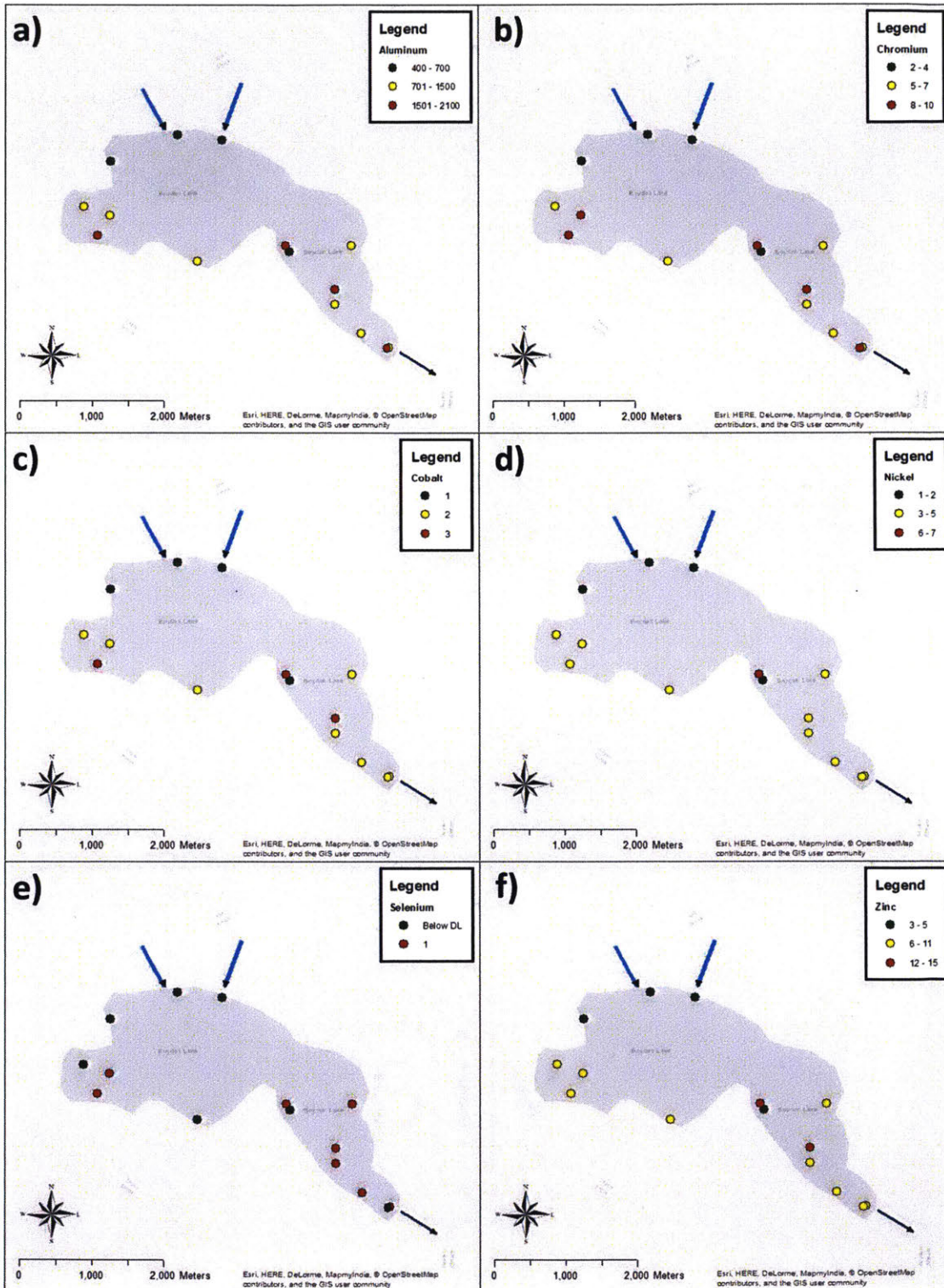| State Lab Arsenic	ICP-MS Arsenic	State Lab Lead	ICP-MS Lead
<1	0.7	<0.5	<0.1
4.2	3.5	240	238
48	61	<0.5	0.4
<1	0.3	21	30
2.7	2.7	<0.5	<0.1
11	11	<0.5	0.3
11	11	<0.5	0.3
32	31	<0.5	<0.1
<1	0.7	5.6	3.7
<1	0.2	13	10
<1	0.3	2	5
<1	0.2	<0.5	0.5
<1	0.2	<0.5	0.2
<1	0.2	21	19
<1	0.2	<0.5	<0.1
41	44	<0.5	0.2
13	7	<0.5	0.2
<1	0.2	12	12
28	28	1.1	1.4
15	14	1	1

Figure B-5: Spatial Distributions of Metals in Boyden Lake: a) Aluminum, b) Chromium, c) Cobalt, d) Nickel, e) Selenium, and f) Zinc
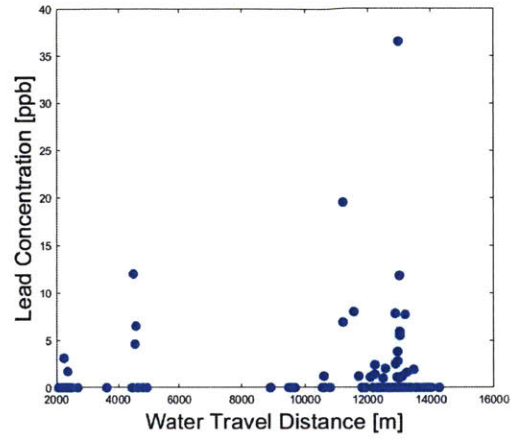
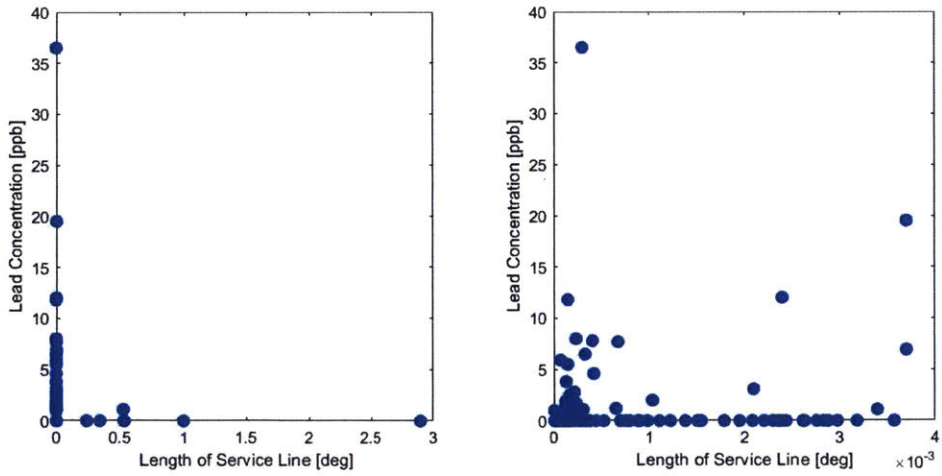Figure B-6: Scatter plots of Lead vs water travel distance

Figure B-7: Scatter plots of Lead vs Service Line Length for a) all samples and b) for distance < 0.2deg

Table B.8: PWD Metal Results

Metal	n above DL[a]	min	median	p95	max
Running					
Al	118	0	30.4	85.7	113.6
Cr	0	0	0	0	0
Mn	26	0	0	2.1	6400
Fe	87	0	1.6	17.3	7500
Co	1	0	0	0	9.3
Ni	15	0	0	2.7	23.4
Cu	65	0	1.2	9.6	120.1
Zn	48	0	0	20.1	53.8
As	3	0	0	0	2.2
Se	1	0	0	0	4.1
Cd	0	0	0	0	0
Pb	6	0	0	0.6	8.1
Standing					
Al	119	0	21.6	77.3	437
Cr	1	0	0	0	1.6
Mn	37	0	0	4.1	5100
Fe	71	0	1.3	8.9	2500
Co	1	0	0	0	6.7
Ni	41	0	0	10.6	131.2
Cu	113	0	7.9	122.5	6800
Zn	110	0	17.6	308.8	1200
As	1	0	0	0	1.3
Se	1	0	0	0	1.6
Cd	0	0	0	0	0
Pb	30	0	0	7.8	36.5

[a]DL = Detection Limit

Table B.9: Bedrock T-test Statistics, between Devonian & Sandstone Formations

Variable	H[a]	P[b]	tstat[c]	df[d]
pH	0	0.93	0.09	105
As	0	0.30	-1.04	120
Pb	0	0.47	0.73	134
Fe	0	0.96	0.05	140
Mn	1	0.01	2.52	97
Cu	0	0.19	-1.33	55
Al	0	0.38	0.89	143
Zn	0	0.5	-0.67	75
Cr	0	0.32	1	94
Co	0	0.32	-1	54
Ni	0	0.31	1.03	95
Se	0	0.05	1.98	94

[a]H=1 indicates distributions are significantly different
[b]P-value: <0.05 indicates significance
[c]t-value for metal
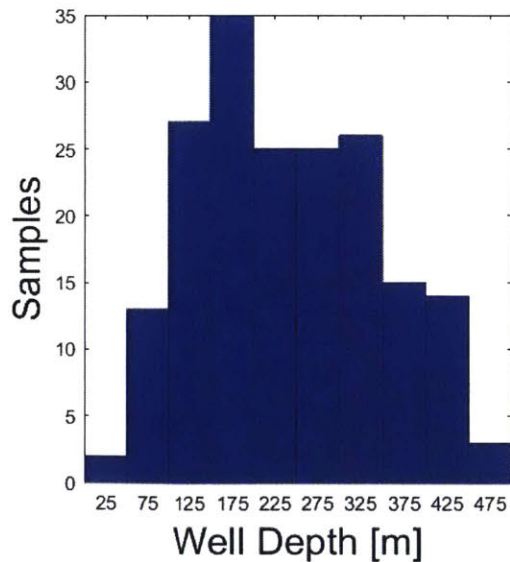[d]degrees of freedom

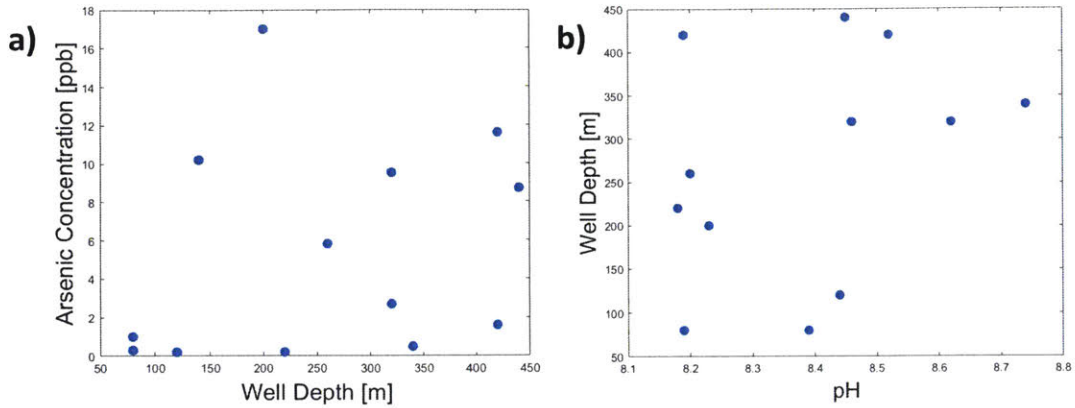Figure B-8: Histogram of well depths for all wells in the study area

Figure B-9: Scatter plots of a) Well depth and Arsenic concentrations and b) pH and Well depth
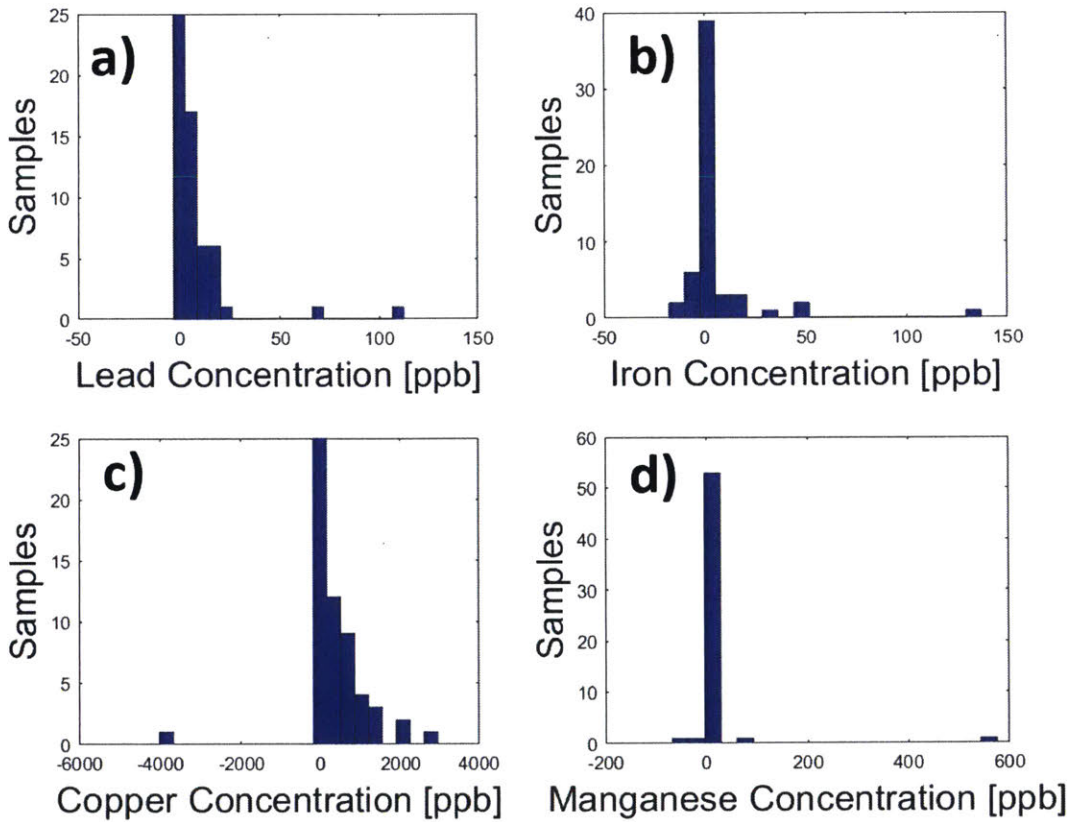

Figure B-10: Histogram of metal enhancements between running and standing samples: a) Lead, b) Iron, c) Copper, and d) Manganese

Table B.10: Well Metal Results by Sample Type

Sample Type	n	min	median	p95	max	Percent Exceedances[a]
Iron						
Running	133	<0.1	1.8	20.1	221	0%
Standing	133	<0.1	1.3	52.4	185	0%
Copper						
Running	133	<0.1	4.5	128	8600	3%
Standing	133	<0.1	44.6	1500	10000	8%
Manganese						
Running	133	<0.1	<0.1	90.3	738	10%
Standing	133	<0.1	<0.1	183	1500	10%

[a]Based on: Iron, Secondary MCL of 0.3ppm; Copper, Primary MCL of 1.3ppm; Manganese, Secondary MCL of 0.05ppm

Table B.11: T-test Statistics between well standing and running samples for metals

Variable	H[a]	P[b]	tstat[c]	df[d]
Pb	1	0.002	3.2	142
Fe	0	0.39	0.85	260
Cu	0	0.14	1.48	264
Mn	0	0.29	1.05	191

[a]H=1 indicates distributions are significantly different
[b]P-value: <0.05 indicates significance
[c]t-value for metal
[d]degrees of freedom