A Metals Study to Assess Human Health Risks in Drinking Water from Eastport, Perry, and Pleasant Point, Maine

by

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Submitted to the Department of Civil and Environmental Engineering on May 18, 2018 in partial fulfillment of the requirements for the degree of Master of Engineering in Civil and Environmental Engineering

Abstract

This study analyzed drinking water for a subset of health concerns expressed by residents in the towns of Eastport, Perry, and Pleasant Point. The town of Pleasant Point is located in the Passamaquoddy tribe's reservation, and all three towns are located in the Boyden Lake watershed in Maine. Water is consumed from several sources, including private wells, the Passamaquoddy Water District (PWD) public distribution system, and surface water sources. Arsenic occurrences in groundwater are known in the state of Maine, and at community meetings residents expressed their concerns about their drinking water quality and the possibility of negative health effects associated with their water. Community meetings were held to listen to these concerns and enlist community members in collecting water for analysis. Boyden Lake water and sediment samples as well as water samples from various points in the PWD distribution system were also collected. All samples were analyzed using an Agilent 7900 inductively coupled plasma mass spectrometer for a suite of metals that included arsenic (As) and lead (Pb), the metals of primary concern, as well as aluminum (Al), chromium (Cr), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), selenium (Se), and cadmium (Cd). Non-metal water quality parameters (e.g. bacterial counts, nitrate, etc.) were not within the scope of the study. The results indicated that EPA drinking water quality guideline exceedances occurred primarily for As and Mn in the well water samples from Perry and Eastport. Isolated Pb exceedances were observed in samples from Eastport wells and PWD water samples, and in Perry well water samples. However, test results also indicated that flushing water (running the water for at least two minutes prior to use) lowered metal concentrations, and hence any potential health risk, significantly. Two kinds of risk analysis studies were applied using sample results, namely the hazard index (a non-carcinogenic risk analysis) and a carcinogenic risk analysis, using standard risk models. For the metals in this study, PWD water had lower non-carcinogenic risk and a lower carcinogenic risk than well water sources. The calculated carcinogenic risk was higher, however, in PWD water than well water when trihalomethanes and haloacetic acids (TTHMs and HAA5) concentrations averaged from 2010-2016 from other studies of PWD water were included in the analysis. The total calculated risk level due to well and PWD water, including metals in this study plus average TTHM and HAA5 concentrations, is equivalent to less than one lifetime cancer incidence across all three communities. Arsenic, present in excess of EPA guidelines in several wells, was calculated to pose a risk of IQ deficit to some children;

calculations according to the model used in the study estimate that 6.6±2.3 children between 3^{rd} to 5^{th} grade are susceptible to having IQ deficits of the order of 6 points due to arsenic levels present in samples submitted of household well water. Overall, Pb and As exceedances were not observed in the PWD water distribution system, and the PWD treatment plant further improved water quality in the case of the metals studied. Household filtration also reduced concentrations of metals, with some exceptions, suggesting that some households would benefit from use of water filters, but that continuing maintenance of filters is critical. For reasons of data privacy, only generalized results of the study were included in this report, while individual household results were reported back to residents along with information on resources for remediation and recommendations.

Thesis supervisors: Harold Hemond and Kathleen Vandiver

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Chapter 1: Background

Area of Study

The Boyden Lake Watershed is located in northern Maine on the border of Canada, as seen in Fig 1. The watershed encompasses three communities within Washington County: Perry, Eastport, and Pleasant Point, where the latter is a Native American reservation where one band of the Passamaquoddy Tribe lives. The three communities are serviced by the same municipal water supply from the Passamaquoddy Water District (PWD), and the PWD sources its water from Boyden Lake. In addition to or instead of the PWD water, many residents have wells that serve as their source of drinking water. Perry only sources PWD water for its fire department, so residents rely on other water sources, while Eastport and Pleasant Point draw 250,000 gallons of water per day for residential purposes from the PWD (French, 2008). Through community meetings, it has become evident that residents also utilize bottled water and spring water for drinking, especially due to concerns surrounding PWD water quality ("Eastport Community Meeting," 2017; "Perry Community Meeting," 2017; "Pleasant Point Community Meeting," 2017).

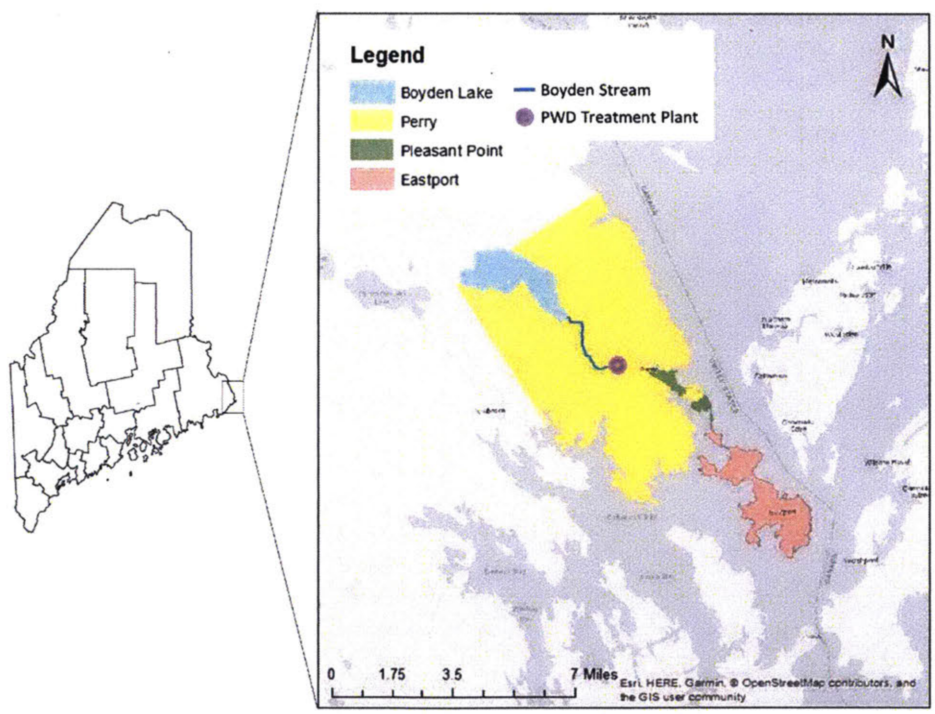

Fig. 1: **Map of the study area**: including the three communities of Eastport, Perry, and Pleasant Point, the location of Boyden Lake and the path of Boyden Stream to the PWD treatment plant. Images and shapefiles courtesy of (Metzler, n.d.; Wikipedia, 2005)

Boyden Lake is shallow, with an average depth of 2.7 m and a maximum depth of 10.4 m. It occupies 11% of the Boyden Lake watershed, which is 59.3 kilometers squared in area. Water flows to Boyden Lake from Penknife Lakes and the Western part of the watershed through tributaries such as Mill Brook and Penknife Brook (Harper, 1991). Water flows out of Boyden Lake to Boyden Stream, and then onwards to an impoundment leading up to the PWD treatment plant. Water is delivered first to Pleasant Point and then to Eastport (PWD Operator, 2017).

Historic Water Quality Concerns

Although Pleasant Point is Native American tribal land, under the Safe Drinking Water Act the EPA implements the Clean Water Act in most tribal land (US EPA OITA, 2015), including the PWD. The PWD is a non-profit municipal corporation with five trustees: three Passamaquoddy, one from Eastport, and one from Perry, meaning the tribal vote holds significant sway over the PWD, and in addition the tribe owns 8% of the watershed's land. A 1991 study on the Boyden Lake watershed showed there are conflicts of opinion surrounding whether Boyden Lake, as the primary drinking water source for the three communities, should be multi-use, allowing boating, fishing, swimming, etc. or single-use, solely for drinking water (Harper, 1991). At present, information gathered at community meetings indicates that the lake is multi-use. Unless explicitly stated that information was gathered from community meetings as part of this study, information pertaining to Boyden Lake and water quality in the region was gathered from scientific, government, and local news sources.

According to the 1991 Boyden study, water quality concerns can be traced back, at least in part, to boil orders for the PWD water in 1986 and 1987, which led to an upsurge in citizen concern about drinking water quality. However, in 1989 when the new treatment plant, which included major filtration upgrades, commenced operation, water quality concerns abated. Some residents continue to use bottled or well water, complaining of the poor taste of the PWD water, while others thought the money used on filtration and water treatment at the PWD plant should have instead been utilized on remedial action in Boyden Lake (Harper, 1991). Boil orders and turbid waters due to hydrant flushing still occur periodically, as seen by the notices on the PWD Facebook page and discussed by community members during outreach meetings, but the previous boil order occurred in 2013 and hydrant flushing in 2017 ("Eastport Community Meeting," 2017; "Perry Community Meeting," 2017; "Pleasant Point Community Meeting," 2017; PWD, n.d.).

Boyden Lake is listed on the threatened lake priority list of the government of Maine due to its use as a source of drinking water (MDEP, 2017), coupled with its shallow depth and algal blooms causing water quality deterioration (Harper, 1991). Indeed, algal blooms due to increases in the phosphorus level of Boyden Lake were present around the time of the Boyden Lake water quality report in 1991, while turbidity increased both in the Lake and well water in the 1980s. Furthermore, motorboats can leak oil and gas or stir up the sediment at the bottom of the lake, lowering water quality. Turbidity levels rise after rain, with sources including runoff from construction, roads, built-up areas, logging, and agricultural land, while phosphorous stems from septic tanks and agricultural runoff (Harper, 1991). Discussions with the PWD treatment plant operator indicated that turbidity levels continue to be a major issue, particularly during the spring, which presents challenges to the PWD treatment plant (see Note 1 in Appendix 1 on the PWD treatment plant) ("Eastport Community Meeting," 2017; "Perry Community Meeting," 2017; "Pleasant Point Community Meeting," 2017). Additionally, poor roadside ditching leading into brooks carried soil and sediment into the lake, with residential developments and exposed areas such as boat ramps also contributing to deteriorating water quality. Residents also reported on the following additional reasons for water quality deterioration in Boyden Lake: one or two submerged cars, cars on the lake for ice fishing, road salt, beaver dams in tributaries, and lower water levels due to absence of a dam at the outlet of the Lake. Another indicator of water quality in Boyden Lake is the closing of clam beds in the Little River Estuary in 1988 due to high levels of E. Coli., with potential sources of the coliform from sewage, septic tanks, and other forms of waste disposal. Overall, though, opinions were mixed in 1991 as to whether the water quality in Boyden Lake was deteriorating over time (Harper, 1991), but all publicly available data begins in 2010, so the deterioration cannot be verified.

Health Issues in Washington County

From anecdotal, statewide, and county-wide data, there appear to be more health issues in comparison to population size in Washington County. At community meetings and during one-on-one conversations, community members discussed higher cancer incidence rates, abnormally high amounts of gastrointestinal issues, and other health challenges (see Note 2 in Appendix 4 for more details) ("Eastport Community Meeting," 2017; "Perry Community Meeting," 2017; "Pleasant Point Community Meeting," 2017). Additionally, Maine has a cancer incidence rate higher than the national average: 474.6 compared to 436.6 for every 100,000 people (US Cancer Statistics Working Group, 2017). In 2014, Maine had the fourth highest cancer incidence rate as a state (CDC, 2017). Indeed, Washington County, where Boyden Lake and the three communities are located, has the second highest cancer incidence rate in Maine (DHHS, NIH, & NCI, n.d.).

Although the community is concerned about health impacts pertaining to water quality, extensive literature indicates a plethora of other factors that could also or instead contribute to the high rates of cancer and disease in the Washington County community. For example, in 2012, there was a 36% obesity rate, in contrast to the 28% rate in Maine (T. Walsh, 2013). Additionally, the various health issues are likely exacerbated, either not identified or taken care of, due to high poverty rates in Washington County; 19.5% of individuals live in poverty (Maine DHHS, 2016).

Nonetheless, there are health issues surrounding metals. Between 2009 and 2013, 1.2% of children in Washington County had elevated blood lead levels. This value is, however, lower than the average 2.5% in Maine. Additionally, only 34.1% of private well owners tested their well water for arsenic, compared to the 43.3% in Maine, exacerbating the likelihood of consumption of unsafe drinking water (Maine DHHS, 2016).

Metal Concerns in Drinking Water

There are both social and technical concerns surrounding drinking water quality in the Boyden Lake watershed. These include scientific, governmental, and community concerns, with the latter discussed in the results section, summarized in Table 1. The government concerns correspond to the chemicals regulated by national primary and secondary water quality standards, whose purpose is to protect public health or public welfare and the environment, respectively. The guidelines are not specific to the water source and hence extend across the rows of sources in Table 1, with other columns extending across the sources similarly indicating those are concerns mutual to all water sources.

Scientific concerns correspond to concerns often associated with these water sources or past research indicating substantial reasons for concern in the area. There is evidence of chlorination by-products in the PWD water, including periodic exceedances of regulatory standards. Additionally, small amounts of metals, nitrites, and nitrates were detected. However, the facility was overall in compliance with federal regulations in 2017-2018 (EWG, 2017). Furthermore, lead leaching from piping is of concern due to the potentially antiquated piping system. According to community members, both Pleasant Point and Eastport recently replaced their main piping, but it is unclear when, while the piping between the PWD and Pleasant Point and lateral piping connecting to the individual houses were not. Additionally, pipes in Pleasant Point are overseen by the tribe, while pipes in Eastport are the responsibility of Eastport. Overall, as of 2008, 60-70% of old piping had been replaced (French, 2008).

Furthermore, in 2013 a new standpipe mixer was installed which reduced chlorine demand in the distribution system, decreasing the likelihood of exceedances due to chlorination by-products. Also, a new control panel was installed, automating the treatment plant and increasing reliability of water quality. At the time of the report, PWD was in the process of installing low lead meters (the scientific function of the meters was not specified, but the intended outcome is to reduce lead health risks) (Maine DHHS, 2015). Wells pose bacterial concerns, in addition to As, F, U, Rn, Pb, and Mn concerns, because they are factors for which the State of Maine recommends regular testing (Maine Center for Disease Control and Prevention, n.d.). The arsenic concerns are corroborated by the fact that USGS studies have shown that Eastport had a median of 1.2 ppb of As (with a max of 24 ppb) across 10 samples and Perry had a median of 2.2 ppb (max 80 ppb) across 78 samples. Perry has an estimated 900 self-supplied population, or 349 households, while in Eastport 70 households are self-supplied (these are estimates for 2008) (Nielsen, Lombard, & Schalk, 2010).

Additionally, Pembroke mine, located in the northern area of the watershed, contains zinc, copper, silver, and lead, indicating that these could be present in groundwater, contaminating well water, or can be washed into Boyden Lake or spring water (USGS, 2002).

<table>
<tr><td>Water Source</td><td colspan="2">Scientific Concerns[3]</td><td>Government Concerns[1,2]</td></tr>
<tr><td>PWD</td><td>DBPs, Ba, Cr, Mn, nitrate, nitrite</td><td rowspan="3">Pb, Zn, Cu, Ag</td><td rowspan="3"><u>Primary Standards:</u>
Microorganisms, disinfectants, DBPs, inorganic chemicals (Sb, As, Asbestos, Ba, Be, Cd, Cr, Cu, cyanide, F, Pb, Hg, nitrate, nitrite, Se, Th), organic chemicals, radionuclides
<u>Secondary Standards</u>: Al, Cl, Cu, F, Fe, Mn, Ag, Zn, etc.</td></tr>
<tr><td>Well</td><td>Bacteria, As, F, U, Rn, Pb, Mn</td></tr>
<tr><td>Spring</td><td>Coliform</td></tr>
</table>

Table 1: Scientific and government concerns surrounding drinking water in the Boyden Lake watershed (US EPA OW, 2015a[1], 2015c[2]; USGS, 2002[3]).

Metals of Interest in the Study

Considering the above concerns, this investigation focused on metal contamination in drinking water. Given existing data from Perry and Eastport, As is known to be in the groundwater in the region and is thus a major concern for well users. Additionally, there are large health risks associated with As, including cancer, as seen in Table 2. Furthermore, Pb was chosen because it is a concern for community members consuming PWD water given the national concerns surrounding Pb leaching from piping. Lead consumption has implications in the development of children and also can lead to negative health outcomes in adults. Additional metals were tested because of the combination of community, governmental, and scientific causes for concern. These include aluminum, chromium, manganese, iron, cobalt, nickel, copper, zinc, selenium, and cadmium. Also, the methods used in this study (see Chapter 2) allow for simultaneous analysis of multiple metals. Although As is a metalloid, the term metals is used throughout this study to refer to all metals and metalloids analyzed in this study.

Some of these metals are regulated by primary standards, which contain some level or guideline limits. Maximum Contaminant Level Goals (MCLGs) are "the level of contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals." Maximum Contaminant Levels (MCLs) are legally enforceable standards that are set as close to MCLGs as feasible considering the best available treatment technology and cost. Some chemicals are regulated by treatment technique (TT), as opposed to concentrations (US EPA OW, 2015d).

MCLs are set based on known or likely adverse health effects, defined as changes in body function or cell structure that can lead to health problems, with the value accounting for sensitive populations, and the technological feasibility, effectiveness, and cost of removing the contaminant. MCLs can change with new technologies and studies and are set so that carcinogenic risk from a contaminant is between 10^{-4} and 10^{-6}, corresponding to low increased excess risk and no apparent excess risk, respectively. For non-carcinogenic risk, MCLs are such that no adverse health effects are expected below it (US DHHS ATSDR, 2005)

Additionally, secondary standards exist for drinking water that aim to protect public welfare and the environment and include many metals (US EPA OW, 2015b). While chemicals regulated by primary and secondary standards can increase certain health risks if the guideline is exceeded, the primary standards generally regulate against more severe effects, while the secondary standards regulate additional chemicals that contribute to smell or discoloration of the water.

Table 2 is expanded on in Appendix 1 as Table 3 with all metals included in the study, with CSF referring to cancer slope factor, a variable necessary for measuring carcinogenic risk, and RfD standing for reference dose, a factor in non-carcinogenic risk. These values are discussed in more detail under the Risk Assessment section of the Background.

Metal	MCL (ppb)	MCLG (ppb)	CSF (mg/kg-day)$^{-1}$	RfD (mg/kg-day)	Health Risk	Common Source
Pb	TT: 15	0	0.0085 (CA OEHHA, 2016)	N/A	Delay in physical and mental development of infants and children; kidney problems and high blood pressure in adults	Corrosion of household plumbing, erosion of natural deposits
As	10	0	1.5	0.0003	Skin damage, problems with circulatory systems, cancer	Erosion of natural depositions, runoff from orchards, or glass & electronic productions waste

Table 2: MCL and MCLG EPA concentration limits for Pb and As and associated sources and health risks (US EPA OW, 2015b, 2015d), including carcinogenic slope factors and non-carcinogenic references dose. All RfD and CSF values are from (US EPA ORD, 2018) unless otherwise indicated.

Arsenic and Lead Health Concerns

Studies have shown that the lifetime cancer risk from an arsenic intake of 10 ug/kg/day varies with cancer type. For example, a study found that men and women had higher cancer risk for liver and kidney cancer, as opposed to bladder and lung cancer. Also, excess lifetime cancer risks of 10^{-5}, 10^{-6}, and 10^{-7} were estimated for drinking water with 0.022, 0.0022, and 0.00022 ug As/L and for consuming aquatic organisms in water containing 0.175, 0.0175, and 0.00175 ug As/L (Tchounwou, 2008).

Another health effect of arsenic is lower IQs. In a study conducted by Wasserman et al. on the association between arsenic concentration in well water and the IQ of children in Augusta, ME between 3rd and 5th grade, after adjusting for maternal IQ and education, the HOME environment index,[1] school district, and the number of siblings, arsenic levels above 5 ug/L were associated with reduction of 5-6 points in Full Scale IQ (6.09± 1.98 points) and other Index scores, including perceptual reasoning (4.97± 2.14), working memory (4.88± 2.24), and verbal comprehension (6.22± 2.49). Maternal IQ and education were also associated with lower levels of arsenic concentrations in well water, and well arsenic, maternal IQ, and education were associated with school district. Different ranges of arsenic concentrations in well water (e.g. 5-10 ug/L, 10-20 ug/L, and >20 ug/L) were not correlated with a further decrease in Index scores, indicating that 5 ug/L might be a threshold level (Wasserman et al., 2014).

[1] HOME environment was measured by the HOME Inventory method, consisting of interviews and direct observation that assess the level of support for child development that is linked to child intelligence (Wasserman et al., 2014).

Similar studies in Bangladesh showed a negative correlation between IQ in children and exposure to arsenic in drinking water for six and ten year olds, with stronger associations in the 10 year olds (Wasserman et al., 2004, 2006). Urinary arsenic concentrations were also correlated with lower child intelligence (Calderón et al., 2001; O'Bryant, Edwards, Menon, Gong, & Barber, 2011; Rosado et al., 2007; von Ehrenstein et al., 2007). Studies further indicate that urinary arsenic may be better correlated with decreased IQ than arsenic concentrations in well water (Nahar, Inaoka, & Fujimura, 2014). A study on preschoolers found that there was no significant effect of arsenic exposure on the IQ of boys, while there was a significant effect on the IQ of girls (Hamadani et al., 2011). Using data from Bangladesh on dose-response relationships between arsenic concentration in urine and decreases in IQ scores, Tsuji et al. showed that possible reference doses ranged from 0.0004–0.001 mg/kg-day, higher than the 0.0003 mg/kg-day set by the EPA, indicating that given the present scientific literature, the EPA guideline may be protective against neurotoxicological impacts (Tsuji, Garry, Perez, & Chang, 2015). However, this finding contradicts the 5 ppb (0.005 ppm) threshold identified by Wasserman, as the EPA guideline for As is at 10 ppb (0.01 ppm).

Regarding Pb, it is now believed that there is no safe lead concentration, especially for children. The Flint Michigan water crisis brought the issue of Pb contamination to the public's eye, and has led to heightened concerns over Pb health risks. Flint, upon switching water sources from Lake Huron to Flint River due to economic reasons, discontinued corrosion-control treatments required by EPA's Lead and Copper rule. In addition, the city added ferric chloride to the water to reduce trihalomethanes, further increasing the water corrosivity. The result was that in 6 of the 9 city wards Pb concentrations above 15 ug/L were observed in 20-32% of homes (Bellinger, 2016). In children in Flint, the percent of children with blood lead concentrations above the referenced 5 ug per deciliter set by the Center for Disease Prevention and Control rose from 2.4% to 4.9% between 2013 and 2015 (Hanna-Attisha, LaChance, Sadler, & Champney Schnepp, 2016). Flint, where 4 out of 10 families live below the poverty line, is an example where low SES meant the children were more susceptible to elevated blood Pb levels even prior to the switch of water sources, with the incidence of blood lead concentrations >5 ug per deciliter triple in Flint children, in comparison to children in neighboring municipalities with higher socioeconomic status (Hanna-Attisha et al., 2016).

Risk Assessment

There are three major components to risk assessment: hazard identification, dose-response relationship, and exposure assessment. Hazard identification is qualitative and determines whether a chemical causes adverse effects to humans, while dose-response assessments quantitatively relate the effects to dose levels. Exposure assessments estimate human exposure to the chemical, in conjunction with or absent regulations. Risk assessments then combine hazard identification or dose-response assessments with exposure assessments (*Risk Assessment in the Federal Government*, 1983).

To assess carcinogenic risk, the carcinogenic oral slope factor is used. The units are expressed as per mg/kg-day and the value represents an estimate of increased cancer risk due to oral exposure of a 1 mg/kg-day dose. When multiplied by estimates for lifetime exposure (usually 70 years), one can estimate lifetime cancer risk (US EPA ORD, 2014a). The slope factor is the proportion of people affected per unit dose and is a measure of relative potency of different chemicals (US EPA ORD, 2014b)

Carcinogenic risk is the probability that an individual will develop cancer over a lifetime due to their exposure, or the likelihood of getting cancer, and assumes that carcinogens are non-threshold chemicals (i.e. any exposure is unsafe). Risk assessment measures excess cancer risk, as there is a background risk of approximately 25% likelihood of getting cancer. To account for uncertainties in scientific studies on carcinogenicity, risk values are plausible upper limits of risk. Risk is based on conservative assumptions aimed at protecting public health (US DHHS ATSDR, 2005).

Non-carcinogenic risk is quantified through hazard indexes (HI), which are the sum of hazard quotients for different chemicals. A hazard quotient is the ratio of estimated exposure dose to the Reference Dose (RfD) or Minimal Risk Level (MRL) exposures (US DHHS ATSDR, 2005). Another way to view HI is as a ratio of exposure to a dose limit that should not be exceeded due to non-carcinogenic health risks. Exposure is expressed in terms of the daily intake, while the limit is given by the EPA's reference doses (P. Walsh, Killough, & Rohwer, 1978).

If the hazard index exceeds one, there is potential for adverse health effects due to the combined exposure to multiple chemicals, and less than one indicates no likely adverse health effects. RfD is an estimate of daily exposure to humans, including sensitive populations, below which no non-carcinogenic adverse health effects are expected over a specified exposure duration. The RfD has uncertainty attached to it, which is accounted for by safety factors that are used to protect public health, lowering the RfD. Oral RfDs and MRLs are developed when sufficient information exists from animal and/or human studies and are expressed in mg/kg-day (milligrams contaminant per kilogram body weight per day). The RfD is developed by the EPA for chronic exposures (>7 years), while MRLs are developed by the ATSDR for acute (<14 days), subchronic (2 weeks to 7 years), and chronic exposures. Another metric, Reference Exposure Levels, is developed by California's Office of Environmental Health Hazard Assessment, under their EPA, for acute <24 hour exposures and chronic >8 year exposures (US DHHS ATSDR, 2005). For arsenic, the chronic MRL for oral exposure to inorganic arsenic is the same as the EPA's RfD (US DHHS ATSDR, 2007; US EPA ORD, 2018).

Bioaccumulation of Arsenic in Fish

Due to potential contamination of Boyden Lake, it is possible for fish populations to bioaccumulate the contaminants. Of specific concern is arsenic, which has approximately 1 ppb levels in Boyden Lake, which is not above the drinking water guidelines. However, the concentrations of arsenic in Boyden Lake still fall below the freshwater national recommended aquatic life criteria: 340 and 150 ug/L for acute and chronic exposures, respectively (US EPA OW, 2015c). The bioaccumulation of arsenic in fish is of special concern due to the importance of fish consumption to the Passamaquoddy culture. The Passamaquoddy have historically relied on a multitude of water bodies for fishing (Bassett, 2014).

Different species of fish bioacumulate arsenic at different rates. However, even with the same species, depending on the study and location of the freshwater body, there is great variation in bioaccumulation rates. In Boyden Lake, there is a wide variety of fish, including landlocked salmon, brook trout, rainbow smelt, smallmouth bass, yellow perch, chain pickerel, minnows (golden shiner and fallfish (chub)), white sucker, hornpout (bullhead), banded killifish, pumpkinseed sunfish, American eel, and alewife (USGS, 1995). The presence of these species and others is corroborated by online fishing sites (Lakelubbers, n.d.) and discussion with tribal members.

Literature in the field shows that in the upper trophic level of freshwater, estuarine, fish, and shellfish have bioaccumulation factors ranging from 5 to 5000 L/kg. Furthermore, experiments show that anywhere from 85% to above 90% of arsenic found in edible sections of marine fish is organic arsenic, but less is known about freshwater fish. (US EPA OW, 2003). The toxicity of arsenic to species themselves varies depending on whether arsenic is in the inorganic or organic form (Ventura-Lima, Bogo, & Monserrat, 2011).

Sediment Quality

There are no American guidelines for sediment quality for the protection of human or aquatic health. However, Canada has sediment quality guidelines with the goal of protecting ecosystems. The guidelines have three levels: below the threshold effect levels (TELs), which denotes the minimal effect range within which adverse effects rarely occur, between the TEL and probable effect levels (PELs) where effects are possible and adverse effects sometimes occur, and above the PEL, where adverse aquatic life effects frequently occur. Table 4, below, shows the metals with relevant PELs and TELs (or in the absence of the TEL the interim marine sediment quality guidelines (ISQGs)) (Canadian Council of Ministers of the Environment, 2018).

Metal	ISQG/TEL [mg/kg]	PEL [mg/kg]
Arsenic	5.9	17.0
Cadmium	0.6	3.5
Chromium	37.3	90.0
Copper	35.7	197
Lead	35.0	91.3

Table 4: Canadian metal sediment quality guidelines for freshwater (Canadian Council of Ministers of the Environment, 2018)

Chlorination Byproducts

There are also ongoing discussions and concerns surrounding the taste of PWD water. For the water to remain sufficiently chlorinated to avoid formation of pathogens in the water as it is transported from the treatment plant to Eastport, chlorine is added. A new chlorination facility between the treatment plant and Eastport was installed, after Pleasant Point, to reduce the amount of chlorination required initially, increasing the water quality that reaches both Eastport and Pleasant Point (PWD Operator, 2017). However, some tribal members remain unsatisfied with the water quality, and the tribal chief is looking into utilizing wells to replace PWD water, according to both the local newspaper and discussion with tribal members (French, 2011).

The PWD has struggled balancing chlorination with microbial safety. As seen in the data compiled by the Environmental Working Group from the EPA and Maine DHHS, chlorination by productions (CBPs) frequently come close to or exceed regulatory limits (EWG, 2017), with notices of exceedance being issued as recently as this year. All of the CBPs are carcinogenic and have primary standards, as seen in Table 5. They are categorized under total trihalomethanes (TTHM) and haloacetic acids (HAA5).

Chemical	CSF (per mg/kg-day)	RfD (mg/kg-day)	MCLG (ppm)	MCL (ppm)
TTHM				0.08
Chloroform	$1*10^{-2}$	$1*10^{-2}$	0.07	
Bromodichloromethane	$6.2*10^{-2}$	$2*10^{-2}$	0	
HAA5				0.06
Dichloroacetic acid	$5*10^{-2}$	$4*10^{-3}$	0	
Trichloroacetic acid	$7*10^{-2}$	$2*10^{-2}$	0.02	

Table 5: Chlorination by product CSF, RfD, and MCLG for CBPs detected in the PWD water (US EPA ORD, 2018; US EPA OW, 2015d)

Socioeconomics

Various studies have shown different degrees of correlation between socioeconomic status (SES) and arsenic concentrations in wells or urine. A study in Mexico investigating correlations between socioeconomic status and arsenic concentrations in urine found the two were correlated. Rosado et al. created a socioeconomic status (SES) index encompassing crowding, housing conditions, and family possessions. Urinary arsenic concentrations in low SES children were higher than in medium and high SES children, while nutritional status indicators were not correlated with urinary arsenic concentrations (Rosado et al., 2007).

One study used education, land and television ownership, weekly household cooking oil consumption, and a food index for SES. The study showed that premalignant skin lesions and arsenic exposure are associated with lack of land ownership, which was the best indicator of arsenic-associated health effects (Argos et al., 2007). In contrast, another study found that the environmental distribution of arsenic concentrations is socioeconomically random, but that exposure disparities due to SES arose from different rates of arsenic treatment and/or testing. The researchers found at the town level with $p<0.05$ a slight positive association between household income and arsenic occurrence in New Jersey. However, depending on the metric the results varied, as the researchers found with $p<0.01$ a slightly negative correlation between population below the poverty level and arsenic occurrence, so Flanagan et al. determined that arsenic distribution is socioeconomically random. These same associations were not observed in Maine. The researchers found that ever testing a well, testing for arsenic on the last test, and use of a system capable of removing arsenic are predicted by income and education in both states (Flanagan et al., 2016).

Hypothesis

Generally, communities with the lowest socioeconomic status in the US and abroad have higher concentrations of metals in their drinking water. This thesis' hypothesis is that the socioeconomic indicators for the three communities all point towards Pleasant Point having lower SES, and hence higher concentrations of metals in the water. The estimated median and mean household income for Eastport in 2016 was $33,836 and $50,144 respectively and in Perry $47,222 and $53,978, while in Pleasant Point it was $27,500 and $42,329. In Pleasant Point, 45% of the population was below the poverty line compared to Eastport's 18.8% and Perry's 19.2%. The percent of the population that has graduated high school is 91.2% in Eastport, 90.4% in Perry, and 81.5% in Pleasant Point. In terms of unemployment rates, Eastport had an unemployment rate of 8.6%, Perry 8.5%, and Pleasant Point 11.8% in 2000 (US Census Bureau, n.d.).

Hence, the hypothesis was that Pleasant Point would have higher concentrations of metals and health risk than Eastport PWD water associated with the lower SES factors (Perry households are not serviced by the PWD). In terms of well water, since across the indicators of unemployment, graduation, and poverty rates Eastport and Perry are nearly identical, but Perry has higher mean and median incomes, the hypothesis was that Perry would have lower concentrations of metals and associated health risks.

Although socioeconomic data was not available for tribal and non-tribal populations, census data and research suggests that over a quarter of American Indian and Alaska Native populations live in poverty, which is double the general population's rate. Additionally, 71% of American Indian and Alaska Natives possess a high school or GED diploma, compared to 80% of the general population (Sarche & Spicer, 2008). Therefore, the hypothesis was that the tribal well water would have higher concentrations of metals, in particular arsenic, and that PWD tribal water would have statistically higher concentrations of metals and greater risk than non-tribal PWD water.

Similar to what the SES studies in the previous section suggest, the scientific basis for the hypothesis is that lower SES communities are less likely to know about their water quality issues and are less likely to have the means to repair the issues. In particular, tribal and Pleasant Point sub-groups were predicted to be less likely to repair and replace piping that leached metals into the water.

Chapter 2: Methods

Community Outreach

Three community meetings were held to encourage public participation in the study. Meetings were held in Eastport, Pleasant Point, and Perry in August, October, and November, respectively, to try to reach all three communities and both tribal and non-tribal populations.

At the community meetings, the purpose of the research was shared, in addition to what the area of study encompassed (see Appendix 2 for the presentation slides used and handouts distributed in Fig 2 and 3). The focus on metals was described, with input requested from community members as to what contaminants they are concerned about or would like to be included in the study. The final list of metals analyzed was narrowed down based on citizen scientist feedback. The goals and timeline of the project were discussed, and extensive discussion focused on how citizen scientists can get involved, including where to pick up and drop off kits, how to collect samples, etc. Kits were distributed to residents in attendance (Appendix 2, Fig 4) and residents were encouraged to take additional kits for their neighbors. After the presentation, small-group discussions surrounding the following three questions were conducted:

1) What questions do you have for us?

2) What water quality concerns do you have?

3) What information would you like to share with us?

The results of the discussion were recorded (Appendix 3, Notes 2) and used as background information in this thesis as relevant and were incorporated under qualitative data in the results and discussion section.

The meetings were advertised through posters at central community locations and through word of mouth, with the help of the Sipayik Environmental Department (SED). A few advertisements were placed in the local newspaper reminding residents of upcoming deadlines for sample submission and informing them of the contents of community meetings (Coopersmith, 2017; The Quoddy Tides, 2018). Additionally, flyers were sent to all community members with mailboxes or P.O. boxes to increase participation rates (Appendix 2, Fig 5). A Facebook page[2] was created to keep the community informed of upcoming deadlines, community meetings, and results. To increase tribal participation, extensive in-person outreach was done by the SED, and the sample return deadline was extended for tribal members.

Sample Collection

Samples were divided into two categories: samples collected from houses by the households, or citizen scientists, and samples collected by the researchers from natural water bodies. Sample collection kits were distributed to citizen scientists, and each kit contained two

[2]The Facebook page can be accessed here: https://www.facebook.com/BoydenWaterSamples/

250 mL HDPE bottles, one for standing samples and one for running samples. Citizen scientists were instructed to collect the standing sample after the tap was not used for at least 6 hours. The running samples were collected after the tap was flushed for 2-3 minutes (see Appendix 2 Fig 6 for the detailed instructions). Each bottle had a label that requested the following information: name, address, phone number, email, GPS coordinates (optional), water source (well, PWD, or other [with a request to describe]), whether the sample was standing or running, and the date and time the sample was collected (see Appendix 2 Fig 7). Sample drop-offs were available in two locations, one on the reservation in Pleasant Point, the tribal office, and one in a store in Eastport, Moose Island Marine. Samples were then collected and refrigerated after drop-off within an unknown amount of time that varied between samples, but likely on the order of a week. Samples were then kept refrigerated at all times prior to analysis except when transported from Maine to the lab.

Consent forms were distributed with most sample kits, although the MIT Committee on Use of Humans as Experimental Subjects did not require this and did not list the study as a use of human subjects (see Appendix 2, Fig 8 for the participation form).

Water samples were collected from Boyden Lake, from Boyden Stream, and at the treatment plant and after the chlorination booster station. Sediment samples were collected from Boyden Lake using an Ekman dredge.

Sample Preparation

Water and sediment samples were analyzed on an Agilent 7900 Inductively Coupled Plasma Mass Spectrometer (ICP-MS). 0.2 mL 35% nitric acid was added to 1.8 mL of each water sample after membrane filtration to remove particulates if necessary (for some samples, 2.5 mL and 0.5 mL water sample and nitric acid, respectively, were used and the appropriate dilution factor and internal standard volume were accounted for). Necessity of filtration was determined by visual inspection: if the water was discolored or contained particles visible to the naked eye. 0.2 μL of 1 ppm internal standard Rh-103 was added to each sample (some samples also had Ir-191 and Ir-193 as internal standards in addition to Rh-103). The ICP-MS was calibrated with calibration solutions at 0 ppb, 0.1 ppb, 1 ppb, 10, ppb, 100 ppb, 1 ppm, and 10 ppm, except for cadmium where the concentrations are a quarter of these values, and aluminum where the values are quintupled. An important part of the method when using the ICP-MS was washing the probe every 5 samples for an extended period of time to avoid cross-contamination of samples in addition to the standard rinsing between samples.

Sediment samples were prepared by combining approximately 0.25 g of sediment with 6 mL 69% nitric acid and 2 mL concentrated hydrochloric acid, following a ratio guideline laid out in EPA method 3051a (US EPA, 2007). Samples were digested on a Milestone UltraWave microwave sample-digestion system with the following parameters: temperature increased to 175 Celsius over ten minutes from room temperature and continued to increase to 220 Celsius until minute 20. Samples were pressurized at 120 bar until minute 10 and then pressure increased linearly until 170 bar was reached at minute 20. The digestion parameters were a merge between EPA method 3051a and standard operating parameters for the Milestone UltraWave digester. Samples were then diluted with 30 mL of MilliQ water. Next, 1 mL of the sample was combined with 2mL of water and 30 μL of the same internal standard used for the water samples and analyzed on the ICP-MS using the same parameters and calibration curve.

Any sample with internal standard values multiple orders of magnitude below the values of the calibration curve was discarded, as it was presumed internal standard was accidentally not added to them. Additionally, the 0 ppb calibration curve point was removed because the calibration curve was constructed on a log-log scale, which does not reach zero. The ICP-MS has an advertised sub-ppt detection limit (CEHS, 2018). However, 0.1 ppb was used as the detection limit for this methodology given that it is the lowest point on the calibration curves.

Sample Results

Individual household results were kept private and returned only to the individual household. Results were mailed to the address included on the label attached to samples, and results that were returned were sent over email. A template letter containing a disclaimer reminding citizen scientists that the analysis was not comprehensive and omitted factors such as microbial contamination was sent out. The letter also contained links to resources to help citizen scientists understand their results, including a website that provides potential health effects and remedial action based on inputted concentrations, the phone number of the Maine DHHS well water consultants, factsheets on arsenic and lead, and more (Appendix 2 Fig 9). General results and interpretations are included in the thesis and will be included in follow-up community meetings.

Chapter 3: Data Analysis

Demographics

All demographic data was drawn from the 2010 census data available for the three communities, unless otherwise stated (US Census Bureau, n.d.). Tribal membership was not self-reported. All Pleasant Point samples were tallied as tribal, and tribal members assisted in identifying additional tribal samples that were not from Pleasant Point.

Health Risk

Risk assessment for metals can be calculated using equations (1)-(3) for non-carcinogenic risk. The risk for non-cancer health impacts is also called the Hazard Quotient (HQ) (Manzoor, 2015; US EPA Office of Pesticide Programs, 2001). The HQ is a probability of experiencing health effects due to the metal in question. Summing the HQs for the various metals yields a Hazard Index (HI). If HI is greater than one, there is concern that the exposed population may experience adverse health effects, while below one this is unlikely to occur (Kamunda, Mathuthu, & Madhuku, 2016; Sultana, Rana, Yamazaki, Aono, & Yoshida, 2017; Wongsasuluk, Chotpantarat, Siriwong, & Robson, 2014). This model assumes that contaminants sum linearly and do not interfere with each other when a person is exposed to the contaminants simultaneously (Guerra, Trevizam, Muraoka, Marcante, & Canniatti-Brazaca, 2012).

$$(1)\ DI = \frac{C_w x IR}{BW}$$

$$(2)\ HQ = Risk_{non-carcinogenic} = \frac{DI}{RfD}$$

$$(3)\ HI = \sum_{all\ metals} HQ$$

DI stands for daily intake (mg/kg body weight/day), C_w concentration of water (mg/L), IR daily water intake rate (L/day), and BW body weight (kg).

Additionally, carcinogenic risk assessment can be calculated for metals using equation 4. The risks can similarly be added together for all the metals analyzed to give a total risk.

$$(4)\ Risk_{carcinogenic} = \frac{C_w x IR x EF x ED x CSF}{BW x AT}$$

The carcinogenic risk is the excess probability of contracting cancer over a 70 year lifetime (unless it is normalized to another lifetime). EF is exposure frequency (or 365 day/yr), ED exposure duration, usually assumed as 30 years, CSF cancer slope factor (per mg/kg/day), and AT average time for carcinogenic exposure, or 25,550 days (70 years) (Liang, Wang, Kao, & Chen, 2016).

The EPA provides guidelines for parameter values when conducting risk assessments. Usually 70 kg and 2 L/day are used, but the EPA recommends a mean adult weight of 80 kg and 1.033 L/day, essentially 1 L/day, or half of the current standard, water consumption for all ages (US EPA, 2011). Alternatively, other values can be used from additional agencies or research. This study uses the standard 70 kg body weight and 2 L/day water consumption to allow for comparison with other scientific literature.

Filtration

Some citizen scientists turned in kits that contained a filtered and unfiltered sample, instead of standing and running samples. These samples were used to analyze filter efficacy by comparing the differences in metal concentrations between unfiltered and filtered water. The type of filter used for each sample is unknown.

Bioaccumulation in Fish

Predicting bioaccumulation in fish, and hence human exposure to arsenic from fish, requires the conversion of arsenic concentration in water to concentration in fish tissue. To convert the concentration of arsenic in water to the predicted concentration in fish, the concentration of water is multiplied by a bioaccumulation factor (BAF) as follows (US EPA OW, 2003):

$$(5)\ C_f = C_w \times BAF$$

BAFs (L/kg) are the ratio of a chemical in wet-weight tissue concentration to its water concentration and includes all routes of exposure (diet and the natural environment), accounting for potential biomagnification (Arnot & Gobas, 2006). C_f is expressed as mg/kg, and the IR for bioaccumulation models is in kg/day. Different fish have varying bioaccumulation factors, and even those values vary within the same species based on species location. Bioaccumulation factors for fish species found in Boyden Lake are given in Table 6, Appendix 3.

For fish intake rate, values were based off of both the quantities used by the EPA after the Maine Department of Health and Human Services (DHHS) value for tribal fish consumption was overturned and the overturned Maine DHHS intake rate. The EPA used a value of 286 g/day, as opposed to Maine DHHS' 32.4 g/day (US EPA OW, 2016). The risk calculations are then the same as in equations 1-4, except the fish intake rate and concentration of the contaminant in fish are used (Liao & Ling, 2003).

Trihalomethanes and Haloacetic Acids

The dataset for trihalomethanes and haloacetic acids was sparse, with measurements taken monthly or on an every other month basis. The dataset is shown in Fig 10, below. Hence, averages were found for every month using the six year dataset, and an average was taken across the months that samples were submitted for this study. The final value was used as an indication of average concentration PWD users were exposed to during the course of the study. However, this measure does not account for seasonal fluctuations and therefore does not account for varying exposure levels throughout the year.

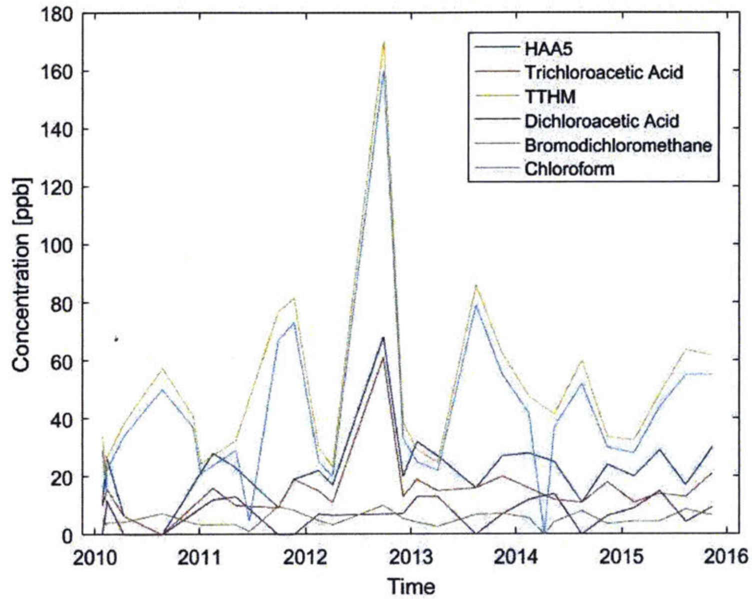

Fig 10: Historical TTHM and HAA5 data from 2010-2016.

Statistical Analysis

It is appropriate to use the student t-distribution if the concentrations for each metal are not normally distributed if the number of samples is greater than 20. However, for non-normally distributed datasets with sample sizes less than 20, the student t-distribution is not appropriate, so the Mann–Whitney U Test is used instead throughout this paper, as some of the sample sizes are smaller than 20, as seen in Appendix 3, Table 7 (MacFarland & Yates, 2016). Also, sample distribution appeared to vary by metal and population. The Mann-Whitney Test is appropriate for smaller samples of size 5-20 with unknown or non-normal distributions, in addition to larger sample sizes. It tests the null hypothesis that the two samples are the same. This research used a one-tailed test to demonstrate which of two samples has a larger median, if there is a statistically significant difference (Nachar, 2008). For the Mann-Whitney Test, rank sums, z values, and p-values are reported. Rank sums are the values of the Mann-Whitney Test statistic, while z values are computed from the z-statistic. Documentation on the function in Matlab used to execute the test can be found at (MathWorks, 2018). The Wilcoxon rank sum test function in Matlab was used, which is equivalent to the Mann-Whitney U Test.

To account for testing multiple hypotheses (specifically when analyzing concentration differences across the metals), the Benjamini–Hochberg–Yekutieli procedure was used, which attempts to control for multiple dependent hypothesis being tested (Benjamini & Yekutieli, 2001). The procedure was not used for risk and hazard index analysis because of the smaller number of hypotheses tested (8 vs. 82).

The following legend was used across p-values resulting from the Mann-Whitney U Test to indicate the level of significance: *($p<0.1$), **($p<0.05$), ***($p<0.01$), and ****($p<0.001$).

However, Table 9 used the following corrected p-values to account for multiple hypothesis testing: *($p<0.00617$), **($p<0.00226$), ***($p<0.000261$), and ****($p<0.0000166$).

Sample Uncertainty

Sample uncertainty was calculated through error propagation. Uncertainties of pipettes were taken from the manufacturer, and where multiple brands of pipettes were used, the brand with the largest uncertainty was chosen in the error analysis (Fisher Scientific, n.d.; Gilson Inc., n.d.; VWR, n.d.). For sample preparation, volumes of solutions and internal standard concentration were accounted for. Average deviations in counts per second for the samples and internal standards were used in the uncertainty analysis. Average uncertainty in the calibration curve was found through plugging back into the log-log linear fit the known concentrations of the calibration solutions and finding the percent error between the theoretical resulting counts per second and the experimental counts per second. Overall sample concentration uncertainty for water samples was found to be ±34% and ±46% for sediment samples.

It is important to note that this uncertainty does not account for temporal variations in metals concentrations and does not account for variation in replicate samples, beyond averaging across replicates. For a more in-depth analysis of replicates, refer to the MIT thesis by Abigail Harvey, 2018 that analyzes sources of metals in the same samples.

Replicate Analysis

To check the impact the wait time between sample collection and sample analysis had on the water quality, the difference in days between when replicates were analyzed was plotted against the difference in concentration. There appears to be no trend across all metals, with some replicates exhibiting concentrations that resulted in an increase or decrease in metal concentrations over time, but most samples were zero (Appendix 3, Fig 11). Hence, no corrections were made for replicate analysis and deviation was attributed to random error, with replicate concentrations averaged out to give a final concentration for a sample.

Method Accuracy

Method accuracy was analyzed by sending samples to a state lab for testing, and comparing the resulting concentrations to the ones found for the same sample when tested in the MIT lab. Overall, there was only one sample where the difference in concentrations reported by MIT vs. the state lab changed whether the water quality was above or below the EPA guideline; this was for sample 373 for As. Percent error ranged from 0% to 46%. Although 46% is a significant amount of error, in the context of concentrations, the largest difference was 13 ppb for sample 48's As. Although it is not possible to quantify an average percent error across samples as some sample results from the state lab were listed as <0.5 ppb or <1 ppb, the overall parallel between state and MIT lab values indicate consistent levels of accuracy, as seen in Table 8 in Appendix 3.

Chapter 4: Results and Discussion

To portray the results in a scientifically rigorous manner and also to convey the results so that community members without a scientific background in environmental health and statistics can benefit from the outcomes of the study, results overviews are provided for community members in italics at the beginning of each subsection of Chapter 4.

Demographic Distribution of Samples

The study participations rates for Eastport, Perry, and Pleasant Point were 25.8%, 27.6%, and 8.99%, respectively.

Overall, a total of 596 samples were submitted, with 346 from Eastport, 200 from Perry, and 50 from Pleasant Point, as seen in Fig 12a. This value excludes spring, lake, and sediment samples and excludes samples submitted from communities outside of Eastport, Perry, and Pleasant Point. 290 of the samples submitted were well water, with 122, 166, and 2 from Eastport, Perry, and Pleasant Point, respectively, while 187, 12, and 36 PWD samples were submitted from each community. This amounted to participation rates of 25.8% for Eastport, 27.6% for Perry, and 8.99% for Pleasant Point of number of samples submitted relative to number of households. Overall tribal participation was a little higher at approximately 12.7% of all tribal households. The value was calculated by dividing the number of people of Native American descent by average household size for each community and comparing it to the number of tribal samples collected.

Fig 12b shows how samples were distributed differently between the communities, as compared to household distributions. Eastport and Perry had greater percent participation than percent households, while Pleasant Point was significantly lower. A similar trend in seen in Fig 12c, with percent tribal participation relative to community lower in the total and in Eastport, but in fact higher in Perry and Pleasant Point. Pleasant Point values are higher than the population distribution in Fig 12c because all Pleasant Point samples were considered tribal, although non-tribal members live on the reservation (e.g. partners of tribal members).

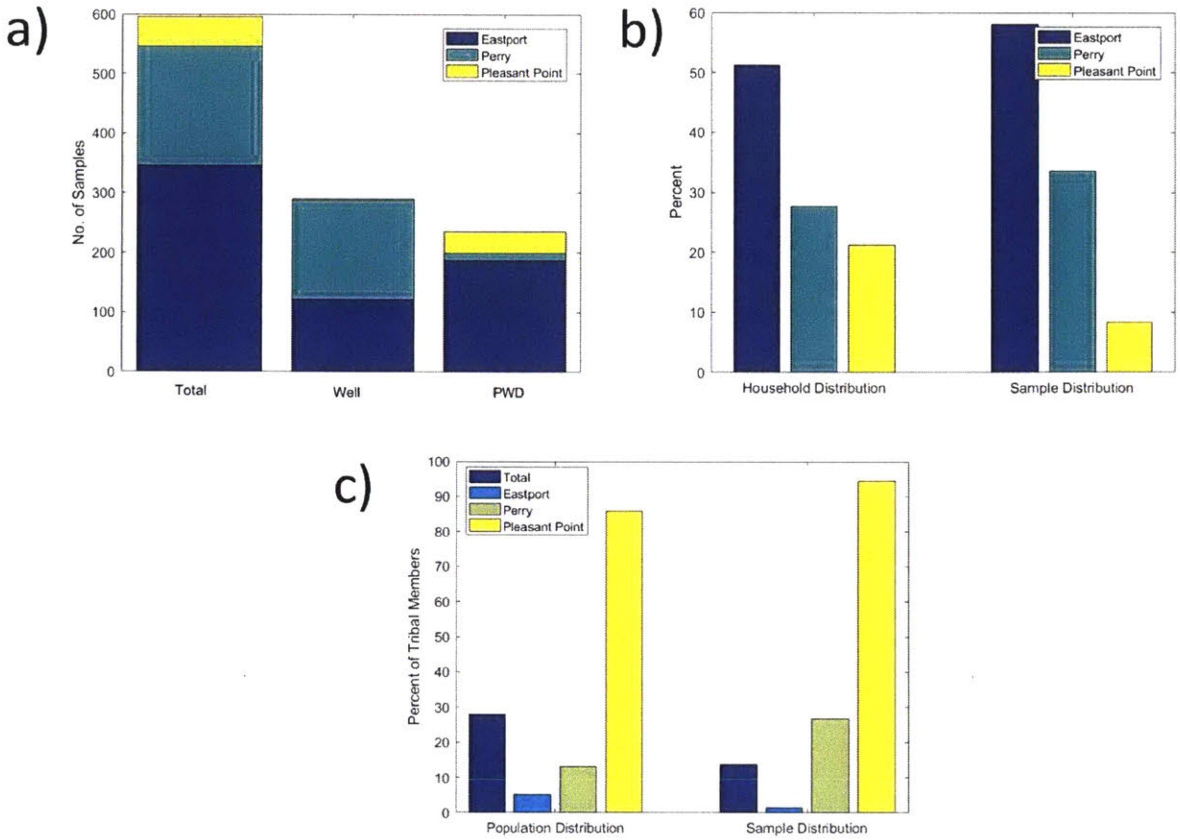

Fig 12. Demographic distribution of samples: a) Total number of samples (both standing and running) collected from the three communities and the distribution between well and PWD sources, b) distribution of samples versus households across communities, c) percent distribution of tribal members in communities and samples.

For the remainder of the results section, unless explicitly stated, the running sample was used in the analysis.

Violations of EPA Guidelines

15.0% of Perry wells and 9.84% of Eastport wells had As exceedances above the EPA guidelines. There were isolated Pb exceedances in PWD and well water, which can be remedied by flushing samples for two minutes.

The exceedances of EPA guidelines for well water are displayed in Fig 13a, with the exceedances in PWD water, which all occurred in Eastport, shown in Fig 13b. It is important to note that Pleasant Point has few wells (only one well sample was submitted), while Perry almost exclusively relies on well water (6 samples of Perry PWD water were submitted). For Mn, Eastport had 16.4% of wells exceeding guidelines, as compared to Perry's 1.8%, while for As Perry had 15.0% and Eastport had 9.84% exceedances. Fe, Cu, Zn, and Pb all also had exceedances, but to a lesser degree. Pb exceedances for Eastport well water were at 4.9% and at 3.0% for Perry well water. For the PWD samples, there were between 1 and 4 violations in Eastport for Al, Mn, Fe, Cu, and Pb across standing and running samples, but only Cu and Pb are primary standards, with the remainder secondary. It is important to note that aluminum has a range of 50 ppb to 200 ppb, and 200 ppb was used as the guideline in this section.

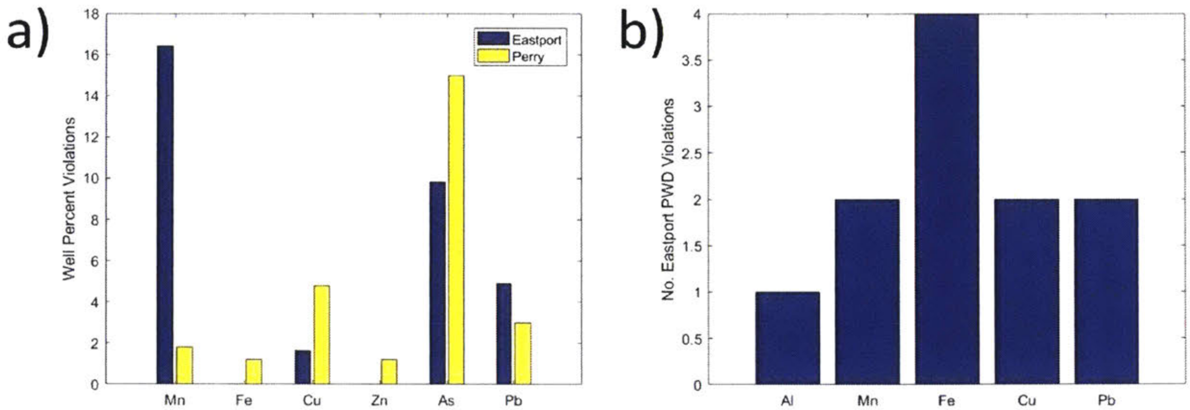

Fig 13. Violations of EPA guidelines in all well and PWD samples. All values (number of samples and percent violations) have uncertainties of 34%.

The 15.0% well exceedances of As in Perry aligns with past studies conducted by the USGS, which found that 20% of wells exceeded EPA As guidelines (Nielsen et al., 2010). Both studies had similar sample sizes at 83 (this study) and 74 (the USGS study). Hence, the 5% difference likely shows that the locations of wells in each study was reflected in the As contamination.

Although the percentage of well water exceedances for lead were small in comparison to As, Pb is a non-threshold metal (i.e. there is no concentration that is considered risk free) (ATSDR, 2017). Of running and standing samples submitted, 5 Eastport well samples, 4 Perry well samples, and 2 Eastport PWD samples indicate isolated instances of exceedances. Both Eastport and Perry had one running well sample that still exceeded EPA guidelines after flushing. The results indicate that flushing water samples for at least 2 minutes prior to consumption could bring nearly all water in compliance with EPA lead guidelines.

Arsenic and Lead Averages

Well water As averages ranged from 4.3 to 4.5 ppb, Pb in well water ranged from 0.9 to 1.2 ppb, and Pb in PWD ranged from 0.1 to 0.3 ppb, depending on the population.

Table 10 provides the mean, standard deviations, and medians for As and Pb; Table 11 in Appendix 4 provides the same information for all metals tested in this study, in addition to modes,[3] maximums, minimums and quartiles. All well water groups have mean As between 4.3 and 4.5 ppb, with the standard deviations ranging from 4.4 to 8.8 ppb, and all the medians fall between 1.2 and 1.5 ppb, except for tribal well water, with a median at 3.9 ppb. Hence, well water has a mean As concentration of 4.4 ppb, which is close to the 5 ppb threshold for cognitive impacts in children. However, the overall lower means relative to the medians indicate that wells

[3] Modes were calculated by rounding concentrations to the nearest whole number, and then finding the mode.

with high concentrations are skewing the mean upwards. The As was a non-issue for PWD water, with means, standard deviations, and medians all below 1 ppb, which is to be expected as As contamination is primarily associated with groundwater, and hence wells. Therefore, on the community level, As is below the EPA guidelines, but individual households have well water with As concentrations above 10 ppb, as indicated by elevated means relative to medians.

Although the mean and median lead values are below the 15 ppb EPA MCL, Pb is considered a non-threshold metal, so minimizing concentrations is important to public health. The mean values for well water ranged from 0.9 to 1.2 ppb, with tribal well water an exception at 0.3 ppb. PWD mean Pb values ranged from 0.1 to 0.3 ppb. All median Pb values for PWD and well water were 0.2 ppb or lower. Hence, although Pb values are below EPA guidelines, they are higher in well sources relative to PWD water sources.

Group	As (ppb)			Pb (ppb)		
	Mean	Stdev	Median	Mean	Stdev	Median
Well	4.4	7.4	1.3	1.0	3.2	0.2
PWD	0.2	0.2	0.2	0.2	0.8	0.06
Eastport Well	4.3	8.8	1.2	1.2	2.8	0.2
Perry Well	4.5	6.3	1.5	0.9	3.5	0.1
Eastport PWD	0.3	0.3	0.2	0.3	0.9	0.1
Perry PWD	0.2	0.1	0.2	0.2	0.3	0.1
Pleasant Point PWD	0.2	0.1	0.1	0.1	0.1	0.0
Tribal PWD	0.2	0.2	0.1	0.1	0.2	0.1
Tribal well	4.4	4.4	3.9	0.3	0.4	0.1
Non-tribal PWD	0.2	0.2	0.2	0.3	0.9	0.1
Non-tribal well	4.4	7.6	1.2	1.1	3.3	0.2

Table 10: Means, standard deviations, and medians for As and Pb for different groups

Statistical Differences in Concentrations

Well water has higher concentrations of As and Pb than PWD water. Eastport had higher concentrations of Mn than Perry PWD water, and higher Al, Ni, Cr, and Mn than Pleasant Point PWD water, indicating increasing concentrations of metals in water as it is transported from Boyden Lake to Eastport. However, the water reaching Eastport is (excluding 11 exceptions mentioned in the previous section) in compliance with EPA guidelines.

There are many statistically significant differences between communities, water sources, and tribal affiliation. The distributions of concentrations across those variables can be found in graphs in Figures 14-16 in Appendix 4 and the rank sums, z values, and p values for all hypotheses tested can be found in Table 9 in Appendix 4. Values for As and Pb are shown in Table 10, below. Although Table 9 in Appendix 4 contains asterisks based on the p-values correcting for multiple hypothesis, Table 10 contains ones for p-values at the 0.1, 0.05, etc. levels in order to highlight potential differences in the metals of particular concern, despite their omission under stricter hypothesis testing.

Well water has higher As and Pb concentrations at p values of 7.35E-22 and 4.47E-09 than PWD water, which is significant at both $p<0.001$ and $p<1.66*10^{-5}$ (i.e. after multiple hypothesis testing corrections) levels. For Pb, Eastport well water had statistically significant larger concentrations than Perry well water ($p<0.05$), as did Perry PWD water over Pleasant Point PWD water ($p<0.1$), and non-tribal well water relative to tribal well water ($p<0.05$). For As, Eastport PWD water had higher concentrations of As than Pleasant Point PWD water and non-tribal PWD water had higher concentrations than tribal PWD water, both at $p<0.05$. However, it is important to note there were no As violations in PWD water.

Nonetheless, the higher concentrations of Pb in well water in Eastport relative to Perry and in non-tribal relative to tribal negate the hypothesis that higher metal concentrations are associated with lower SES communities, as does the higher concentrations of Pb in Perry relative to Pleasant Point PWD. However, the higher concentrations of As and Pb found in well water when compared against PWD affirm the hypothesis, as well owners are less likely to have the financial resources to repair or replace household level piping, while the PWD has more financial resources for maintenance.

Metal	p-value						
	Well: Eastport> Perry	PWD: Perry> Pleasant Point	PWD: Eastport> Pleasant Point	PWD: Eastport> Perry	PWD: N-Tribal> Tribal	Well: N-Tribal> Tribal	Well>PWD
As	0.842	0.202	0.0105**	0.164	0.0265**	0.894	7.35E-22****
Pb	0.066**	0.086*	0.108	0.731	0.348	0.0460**	4.47E-09****

Table 10: results of hypothesis testing comparing concentrations of As and Pb in different water sources, towns, and tribal affiliations

For the remainder of the metals, the results are as follows. In comparing all PWD and well water samples, well samples had higher concentrations of Cu and Zn at $p<1.66*10^{-5}$, and Se and Cd at $p<0.00261$, as shown in Table 9 in Appendix 4. These results are not startling, as individual homeowners with wells have less incentive and finances than the PWD to maintain their water quality and piping system. In addition, the water comes from different sources: the PWD comes from surface water, while well water originates from ground water.

Comparing tribal and non-tribal well water quality shows no statistical differences. This disproves the hypothesis that tribal water has higher concentrations due to lower SES.

There was only one statistically significant difference at $p<1.66*10^{-5}$ between Perry and Eastport PWD water: Mn, which had higher concentrations in Eastport, and none between Perry and Pleasant Point PWD water. However, between Eastport and Pleasant Point PWD water there were a number of differences, all indicating Eastport has higher concentrations of metals. Specifically, Al and Ni ($p<0.00617$) and Cr and Mn ($p<0.000261$) all were significant at varying levels. This negates the hypothesis that Pleasant Point water would have higher concentrations based on SES factors. The differences between Eastport and Pleasant Point could connote a degradation of PWD water as it progresses through the distribution system and residential supply plumbing. However, the degradation is not significant enough to place Eastport PWD water in violation of EPA water quality guidelines, as most Eastport PWD samples were below the limits.

Finally, well water between Eastport and Perry was only significant for Mn, which was higher in Eastport, at $p<1.66*10^{-5}$. This confirms in part the hypothesis that Perry has lower concentrations of metals due to higher SES.

The higher concentrations consistently seen in Eastport could also be attributable to older piping. Fig 17, below, shows the distributions of house ages in Eastport, Perry, and Pleasant Point. The majority of houses in Eastport were built prior to 1939, or prior to the EPA ban in 1986 on using lead solder and piping (US EPA OW, 2015a). Hence, the housing age and piping quality may explain the higher concentrations of some metals seen in Eastport relative to Perry and Pleasant Point.

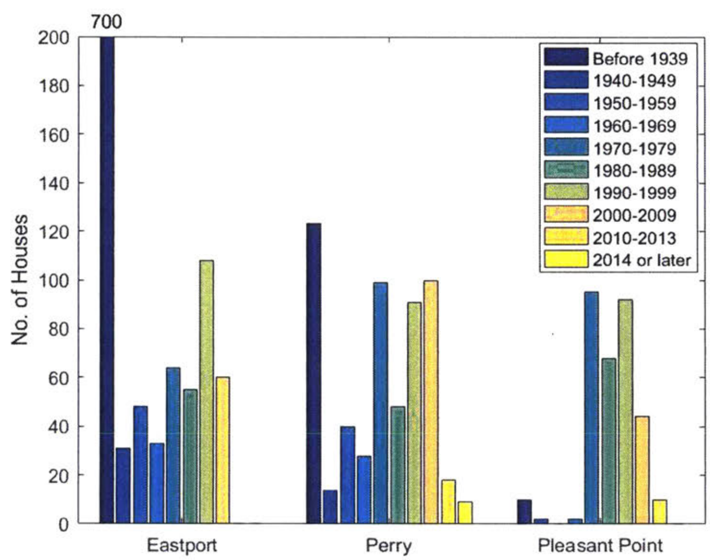

Fig 17. Distribution of house ages in Eastport, Perry, and Pleasant Point

It is important to note that the sample sizes of Perry PWD and tribal wells are at 6 and 12, respectively, so results from those samples may be less representative of the actual population. Appendix 3 Table 7 contains the sample sizes of all the groups used in this study.

Standing versus Running Samples

In general, flushing improves water quality by reducing concentrations of metals present, with an average improvement of 2.6 ppb for lead.

Table 12, below, indicates the mean, standard deviation, and median differences between standing and running samples across all the samples submitted in this study. A positive number indicates concentrations of metals removed, while a negative number is concentrations of metals added. For Al, Mn, Ni, Cu, Zn, and Pb, the means indicate that flushing the sample decreased the concentration of metals. For Fe, Co, As, and Se, the increases indicate that flushing increases the mean concentration of metals. The median indicates that only for Al and Fe was there a slight increase in metal concentration after flushing. The increases in concentration in some metals may be attributable to mislabeling of standing and running samples or could indicate that flushing for more than two minutes may be necessary in some houses.

Of relevance to public health is the reduction in Pb by 2.6 ppb when using the mean as a statistical indicator and by 0.2 ppb when using the median.

	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
Mean (ppb)	0.3	0.0	22.3	-11.7	-0.03	13.5	143.8	203.5	-0.3	-1.8	0.0	2.6
Stdev (ppb)	33.4	1.3	324.8	306.9	0.77	122.0	654.0	653.9	6.9	111.9	0.1	11.1
Median (ppb)	-0.1	0.0	0.1	-0.2	0.0	0.3	12.4	17.5	0.0	0.0	0.0	0.2

Table 12: The mean and median concentration differences between standing and running samples for all samples and metals.

Non-Carcinogenic Risk Assessment

Non-carcinogenic risk can be reduced if water is flushed before consumption. For over 75% of samples, there are no anticipated adverse non-carcinogenic health effects for both PWD and well water. Well water poses a larger non-carcinogenic risk than PWD water, and Eastport PWD water has higher non-carcinogenic risk than Pleasant Point PWD water, while non-tribal PWD water has higher non-carcinogenic risk than tribal PWD water.

Fig 18 shows the hazard index distributions for well samples (18a) and PWD samples (18b). For well water samples, the third quartile consistently fell below an HI of 1, meaning no adverse non-carcinogenic health effects are likely, while the third quartile for PWD samples fell below a 0.1 HI. These and later, box and whisker plots include the median (in red), the 1st and 3rd quartiles as either ends of the boxes, and the maximum and minimum as the tails, after excluding outliers (which were not included in the figures as including them would hide the remainder of the data). By definition, 25% of samples are below the 1st quartile, and 75% below the 3rd quartile.

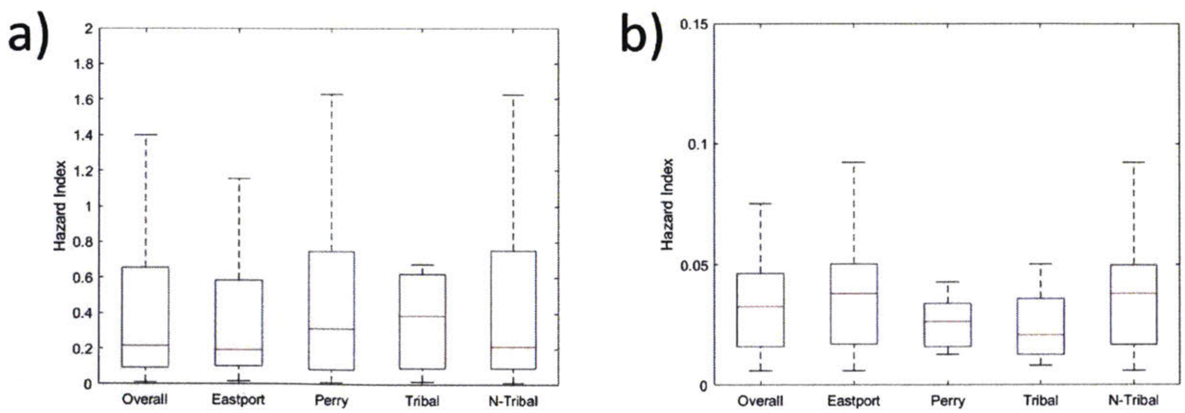

Fig 18. Hazard index distribution for well and PWD samples across different communities and tribal affiliations.

Overall, the number of households with hazard indexes exceeding 1 is shown below in Table 13. Well water has 22 exceedances, compared to PWD's one. The well water exceedances are distributed between Eastport and Perry 7 to 15, while 21 of the 22 well samples with HI greater than 1 are non-tribal.

Water Source	Total	Eastport	Perry	Pleasant Point	Tribal	Non-Tribal
Well	22	7	15	N/A	1	21
PWD	1	1	0	0	0	1

Table 13: Number of samples with HI exceeding 1 by water source, community, and tribal affiliation

Fig 19 shows the distribution of the hazard index difference between standing and running samples. The hazard index in Fig 19 was calculated by using the difference between the concentrations of metals in standing and running samples and thus represents the hazard index delta. The hazard indices deltas are up to an order of magnitude larger than the running samples of well and PWD hazard risk distributions seen in Figure 18. As a HI greater than 1 indicates unsafe exposure to contaminants that can induce non-carcinogenic health effects, the data emphasizes the importance of flushing water before consuming it, to reduce cumulative non-carcinogenic risk from a variety of metals.

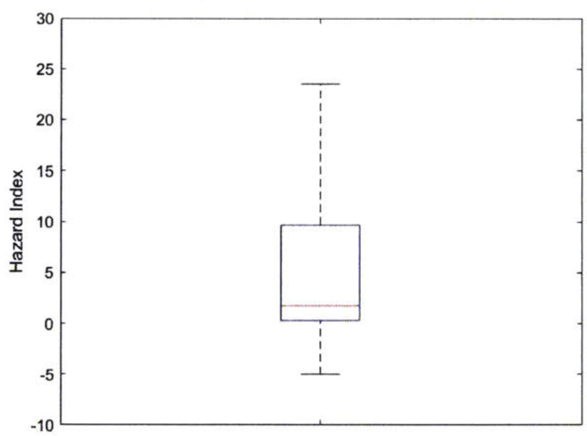

Fig 19. Hazard indices difference between standing and running samples

Comparing hazard indices between communities and water sources yields a number of statistically significant differences, as seen in Table 14. Well water has a higher hazard index ($p<0.001$) than PWD water when aggregated across communities. The inclusion of TTHMs and HAA5 in the hazard indices calculations for PWD did not alter the fact that well water had higher HIs than PWD water. Eastport PWD water similarly had a higher hazard index than Pleasant Point PWD water ($p<0.01$), reaffirming the earlier analysis of concentration data separated by metals. Finally, non-tribal PWD water had higher hazard indices ($p<0.01$) than tribal PWD water. All other comparisons between communities for PWD and well water did not yield statistically significant differences.

Test	Z Value	Rank Sum	p-value
Well>PWD	9.56	233335	5.65E-22****
Well: Eastport>Perry	-0.338	4442	0.632
Well: Non-Tribal>Tribal	-0.360	9799	0.641
PWD: Eastport>Perry	1.20	4830	0.116
PWD: Eastport>Pleasant Point	3.05	5697	0.0011***
PWD: Perry>Pleasant Point	0.833	88	0.202
PWD: Non-Tribal>Tribal	2.48	5965	0.0065***
PWD>Well with THM & HAA5	-0.948	15050	0.172

Table 14: Statistical significance of differences in hazard index between communities and water sources

Carcinogenic Risk Assessment

Carcinogenic risk can be reduced if samples are flushed. Carcinogenic risk is higher in well water than PWD water when accounting only for metals. Well water has higher carcinogenic risk than PWD water, while for PWD water, Eastport PWD water has higher risk than Pleasant Point PWD water and non-tribal PWD water has greater risk than tribal PWD water. However, when accounting for trihalomethanes and haloacetic acids, PWD water has higher carcinogenic risk than well water. As discussed in the next section, carcinogenic risk from all drinking water sources contributes to less than one cancer incidence across Eastport, Perry, and Pleasant Point during the lifetime of the current population.

Fig 20 depicts that community members consuming well water are exposed to carcinogenic risk on the order of 10^{-4}, while it is on the order of 10^{-5} for PWD water. Hence, As, the major contributor of carcinogenic risk in well water, likely increases risk by an order of magnitude relative to consuming PWD, when accounting only for metals.

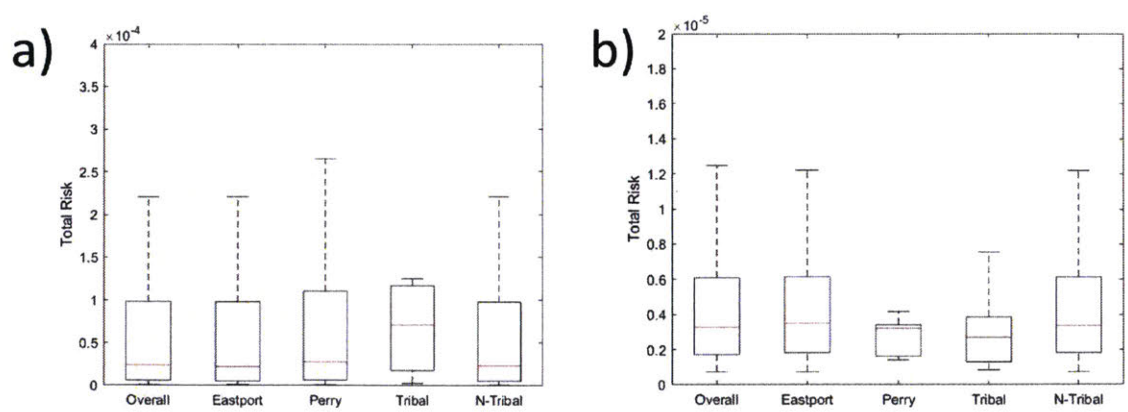

Fig 20: Risk distribution for (a) well and (b) PWD samples across different communities and tribal affiliations.

Similar to the situation with the hazard index, a significant reduction in carcinogenic risk can be achieved if water is flushed. As seen in Fig 5, standing water has additional risk beyond running water on the order of 10^{-3} depending on the sample, with Fig 21 representing the difference in total risk between standing and running samples.

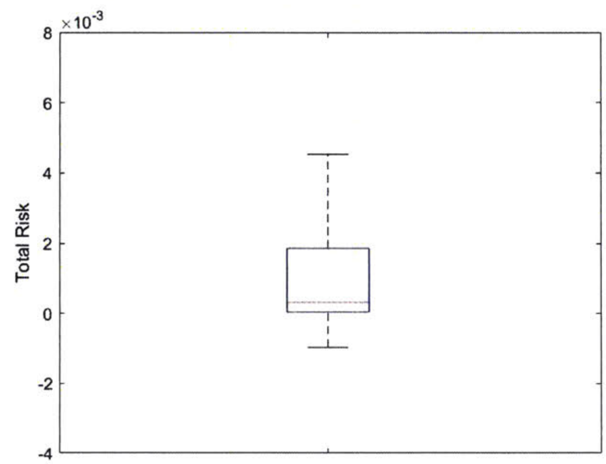

Fig 21: Boxplot of additional lifetime cancer risk difference between standing and running samples indicates flushing samples can reduce risk

Similar to the results indicated by the hazard index, well water has greater risk than PWD water ($p<0.001$), as seen in Table 15. However, when accounting for TTHM and HAA5, the trend reverses and PWD has greater risk ($p<0.001$). It is important to note that TTHM and HAA5 data were found by averaging monthly averages for the publicly available 6 year dataset and that there is a fluctuation in TTHM and HAA5 data, and hence risk, that these results do not capture. This indicates a challenging decision a homeowner could face if selecting between consuming PWD or well water: choosing between additional carcinogenic or non-carcinogenic risk. The same trends were observed with risk for Eastport vs. Pleasant Point PWD and tribal vs. non-tribal PWD, with Eastport experiencing higher risk ($p<0.01$) and non-tribal members facing more risk ($p<0.05$).

Variable	Z Value	Rank Sum	p-value
Well>PWD	13.6	99781	1.93E-42****
Well: Eastport>Perry	-1.05	4264	0.853
Well: Non-Tribal>Tribal	-1.24	9676	0.892
PWD: Eastport>Perry	1.02	4818	0.153
PWD: Eastport>Pleasant Point	2.34	5607	0.0096***
PWD: Perry>Pleasant Point	0.967	90	0.167
PWD: Non-Tribal>Tribal	1.98	5890	0.0237**
PWD>Well with THM & HAA5	8.12	75845	2.27E-16****

Table 15: Statistical significance of differences in risk between communities and water sources

Health Impact

There is less than one additional person likely to get cancer across all of Eastport, Perry, and Pleasant Point due to well and PWD water consumption over the lifetime of current residents. 6.6±2.3 children between 3rd and 5th grade are currently susceptible to a reduction in Full Scale IQ and other cognitive Indexes.

Although there are exceedances of EPA guidelines and differences in averages, risk, and hazard indices between communities, it is important to understand this in the context of additional estimated occurrences of disease. Since cancer risk is a probability of cancer incidence, multiplying that by the number of people can yield an estimate of projected cancer incidence due to drinking water. Taking the average and median risks as proxies for overall risk in the Boyden Lake communities and multiplying those values for well and PWD separately by the estimates for populations using them, there is a total increase in cancer risk that is less than one incidence across the three communities over a lifetime (70 years). Specifically, using the mean vs. median for the PWD analysis yielded 0.0075 and 0.0054 cancer incidence, while for the well analysis it is 0.11 and 0.032. Accounting for THM and HAA5 using the predicted values for the time period of the study and averaging across them yielded an additional cancer incidence rate of 0.13 for PWD consumers.

Nonetheless, there is a health risk posed by potentially reduced IQ from arsenic exposure to concentrations greater than 5 ppb. Fig 22 shows the percentage of households in each group that submitted well samples with As above 5 ppb, or above 25% for every sub-group. Although only 12 tribal samples were submitted, 4 of them contain concentrations of As exceeding 5 ppb. Overall, the data shows that 41 households in the study have concentrations of As in well water above 5 ppb. At one extreme is the assumption that all people in the households have consumed water with elevated arsenic when they were in 3rd through 5th grade (adults) or currently are (children). That gives an upper bound on the number of people with reduced IQ at the percentage levels seen in Fig 22. Alternatively, this analysis assumed all of Perry is on wells (which is approximately true) and found the proportion of Eastport well users by subtracting from total populations the number of households on PWD water times average household size and multiplying by the estimated number of children between ages 5-9 and 10-14 (the ranges in the census) that fall in 3rd and 5th grade. This yields 6.6±2.3 children currently susceptible to a reduction in Full Scale IQ and other Indexes, at the values described in Chapter 1 under the Arsenic and Lead section.

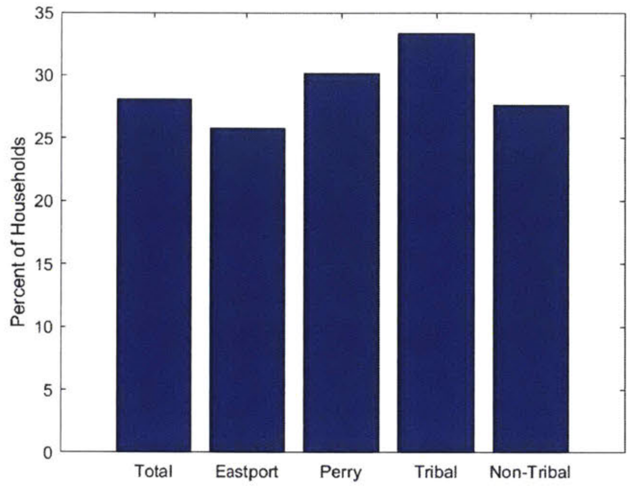

Fig 22: Percent of population exposed to arsenic concentrations above 5ppb in wells. Uncertainty is ±34%.

Treatment Plant Efficacy

Overall, the PWD treatment plant is effective in reducing concentrations of metals in the water.

Three water samples were collected that indicate the impact the treatment plant has on the PWD water quality. Fig 23a shows the concentrations at the impoundment, post-treatment, and at the rechlorination facility, while Fig 23b shows the concentrations for Fe separately as the concentrations are an order of magnitude larger. For Cr, Co, Ni, Cu, As, Cd, Pb, and Fe the concentrations decrease as they progress through the PWD distribution system. However, for Al and Mn the values increase post-treatment and then fall by the time the water reaches the chlorination plant, while for Se the value decreases and then increases. Except for Se, there is a net decrease of all metals after the re-chlorination plant, which is important because Eastport receives its water after the rechlorination facility, while Pleasant Point, receiving its water before the rechlorination facility, would have higher Al and Mn levels.

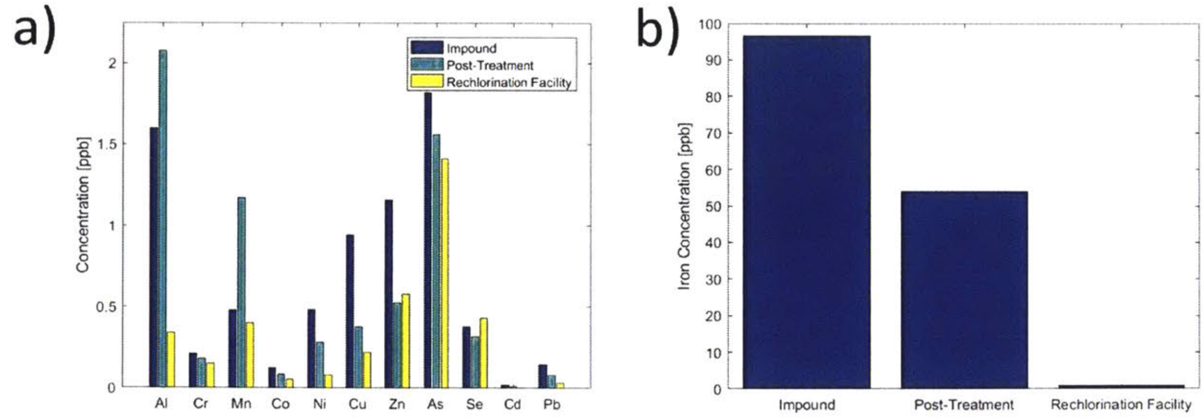

Fig 23: Concentrations of metals at the impoundment, post-treatment, and at the rechlorination facility. All values have uncertainties of 34%.

However, this contradicts how Pleasant Point samples have lower concentrations for most metals than Eastport, as discussed under the Statistical Differences in Concentration section. This indicates that metals are coming from somewhere between the rechlorination facility and Eastport homes. For a more detailed analysis of source analysis, refer to Abby Harvey's 2018 MIT thesis.

Filter Efficacy

Filters are installed to remove metals, however the data show filters may sometimes add to the metal concentrations depending on the filter and metal. It is important to replace filter cartridges as specified by manufacturers to ensure filters do not recontaminate the water.

Analyses of water samples taken at households with tap water filters installed indicate that filters may often remove, but in some cases appear to add to, metals in the water. Results are summarized below in Fig. 24. Fig 24a shows the absolute quantities of metal concentrations added or removed by filters, while Fig 24b shows percent change in concentration relative to the original concentration. Filters 2, 4, and 5 all were well water samples, while 1 and 3 were PWD samples. Samples submitted for filters 1-4 are running samples, while filter 5 compared standing samples. Certain filters added Mn, Ni, and Zn, while most of the other metals' concentrations changed little or decreased extensively.

Overall, the data indicate that the filters in themselves can in certain circumstances result in higher metal content in drinking water; for example, it is speculated that unmaintained filters could accumulate metals over time, especially during the initial flushing of drinking water taps, and at a later time, absent maintenance, leach such metals back into the water. However, it should be noted that water from only a very small number of filters was sampled in this study. Further, for the metals of primary concern (i.e. Pb and As) the overall effect of the filters was to reduce concentrations. Only two filters had concentrations of metals above EPA guidelines prior to filtration, and those were for arsenic. Filters 4 and 5 had As concentration at 14.6 ppb that was reduced to 2.0 ppb and 1.7 ppb, respectively. Furthermore, in filter 5 Pb was reduced from 3.8

ppb to 0.04 ppb (below the detection limit). The findings about filter efficacy would benefit from further study.

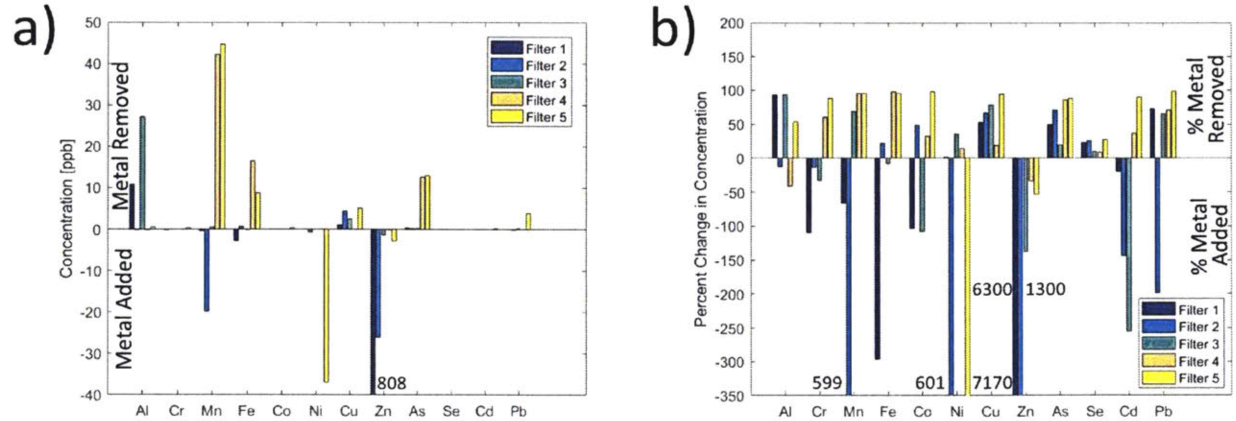

Fig 24: The impact of filters on metal concentrations. Fig 24a shows the absolute quantities of metal concentrations added or removed by filters, while Fig 24b shows percent change in concentration relative to the original concentration. Concentrations above the dividing line indicate metals removed by the filter to the water and concentrations below the dividing line indicate metals added by the filter.

Filtration Options

A study found ZeroWater® (model# ZD-013-D) pitchers effective in removing As to below EPA guidelines. The National Sanitation Foundation certifies filters and lists the filters by metal.

Filters added on to faucets that use anion exchange, adsorptive media, and reverse osmosis can be expensive, while relying on bottled water as an alternative water source is both costly and increases plastic waste. Barnaby et al. identified a tabletop water pitcher filter, ZeroWater® (model# ZD-013-D), that reduces As concentrations (both As^{3+} and As^{5+}) from 1000 ug/L to less than 3 ug/L, below the EPA MCL and below the 5 ppb threshold where cognitive effects in children are observed. Also, the concentrations of total dissolved solids and competing ions did not impede the filter from removing As to below the MCL guideline. The study also investigated the following models of tabletop filters: U.S., Pur® (model# PPT700W), Brita® (model# OB36/OB03), Great Value® (Wal-Mart-model# QP6-OS), and HDX® (Home Depot-model# QP8-07). When 100 ug/L As in soft water was filtered through them, ZeroWater® reduced the concentration to less than 1 ug/L, while the other filters did not reduce the concentration to below the MCL, and for 1000 ug/L, ZeroWater® reduced the concentration to less than 5 ug/L. Even with 100 ug/L As in hard water and well water from New Hampshire, the ZeroWater® filter removed As to below the 5 ug/L threshold (Barnaby, Liefeld, Jackson, Hampton, & Stanton, 2017).

It is important to note that filter effectiveness may vary with pH, chlorine content, concentrations of Mn and Fe, and other factors, which were not tested in this study. Also, ZeroWater® recommends replacing filter units every 15 gallons (Barnaby et al., 2017). However, the study did not measure the effectiveness of any of the filters over long term use and the frequency of cartridge replacement necessary for filtered water to remain in compliance with EPA guidelines.

The National Sanitation Foundation (NSF) list filters certified by their ability to treat a contaminant. A filter manufacturer can receive certification when the claims of the amount of contaminant reduction that can be achieved by the filter are verified by the NSF.[4] It is recommended to reference the NSF database when deciding to purchase a filter.

In addition to the options listed on the letter sent out to community members for actions they can take and resources they can refer to for advice (Appendix 3, Fig 9), the Dartmouth Arsenic and You website has many resources, including a section on treatment options.[5]

Lake Sediment Quality

Higher concentrations of metals are observed on the Southern and Eastern shores of Boyden Lake. As concentrations on the Southern shore of Boyden Lake had arsenic concentrations between the ISQG/TEL and the PEL, and concentrations of Pb were above the PEL for nearly all points sampled.

Appendix 4 contains figures depicting the sediment concentrations relative to the aquatic sediment quality guidelines for the metals that have such guidelines in Fig 25 while Fig 26 shows where metal concentrations are higher.

For Zn, Cr, Cu, and Cd, all of the sediment samples collected were below the ISQG/TEL level. Four points along the Southern shoreline of Boyden Lake had arsenic concentrations between the ISQG/TEL and the PEL, while all except one sediment sample had lead concentrations in exceedance of the PEL. Hence, the concentration of lead in the lake could result in probable ecological effects as defined by the Canadian guidelines, while the concentrations of As mean that ecological effects are possible and adverse effects sometimes occur.

The maps showing relative increases in concentrations consistently show higher concentrations on the Southern and Eastern shores of Boyden Lake. One hypothesis potentially explaining this phenomenon is that as the lake water flows downstream into the river and impoundment leading to the treatment plant, it is possible that over time the water pushes the contaminated sediment downstream with it. Since the outflow of Boyden Lake via Boyden Stream is situated in the Southeastern side of the lake (see Fig 1 in Chapter 1), this hypothesis aligns with lake morphometry.

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[4] The NSF website can be found at: http://www.nsf.org/consumer-resources/water-quality/water-filters-testing-treatment/contaminant-reduction-claims-guide

[5] The Arsenic and You website can be found at: https://www.dartmouth.edu/~arsenicandyou/water/treatment.html

Bioaccumulation of Arsenic in Fish

Bioaccumulation of As in fish requires further investigation into human exposure to As through fish consumption, as models indicate that non-carcinogenic adverse health effects may occur and that carcinogenic health risk is at 10^{-3}.

Bioaccumulation modeling indicates that human exposure to metals through fish consumption from Boyden Lake varies depending on BAF. Fig 27a indicates the hazard index associated with different BAF values (i.e. different fish found in Boyden Lake) and assuming two different intake rates: one is the EPA intake rate for Native American tribes in Maine, and the other the intake rate used by Maine DHHS prior to the EPA IR superseding it. The hazard index associated with fish consumption is the same order of magnitude as the hazard indices found for water. Since HI is greater than 1 for all intake rates and fish (i.e. the probability is greater than 1), this indicates that consumers of Boyden Lake fish may experience adverse health effects. Similarly, Fig 27b shows how risk due to fish consumption is an order of magnitude larger relative to water concerns. Hence, considering tribal intake rates of fish from Boyden Lake, it is possible that tribal members are exposed to arsenic through fish consumption.

Multiplying the tribal population by the minimum and maximum carcinogenic risk yields an excess arsenic related cancer incidence rate due to fish consumption between $6.18*10^{-4}$ and 2.25. Hence, depending on actual BAFs or species of fish and intake rates of fish, tribal cancer incidence rates increase differently.

However, it is important to note that the values of concentration of As found in fish tissue may differ from the model. Hence, it is important to conduct follow-up studies to investigate As concentrations in Boyden Lake fish. Additionally, this model focused on fish consumption by tribal members and did not account for intake rates of non-tribal members, which are likely lower as fishing for non-tribal members is less culturally significant.

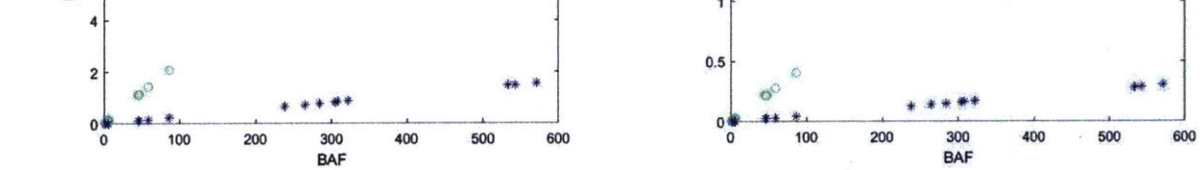

Fig 27: Bioaccumulation for different BAFs: a) hazard quotients and b) risk. HI and risk vary with different BAF and IR values (corresponding to different fish).

Springs

Metal concentrations in spring water meet EPA guidelines. However, microbial contamination may not be in compliance with EPA guidelines.

Spring water quality, from the spring water samples collected in this study, is in compliance with EPA guidelines for the metals analyzed, as seen in Table 16. (It is important to point out that what is colloquially referred to as spring water by the community is in fact surface water and/or well water, see the next section for more details). However, water samples collected from Pembroke Spring, a source of spring water that some community members use for drinking, were tested by the Sipayik Environmental Department for E. Coli, after a field test that indicates the presence or absence of E. Coli (but not the concentration) as part of this study came back positive, and those results came back positive, too. Hence, it is important to continue being cautious when using spring water for drinking, as it is neither treated nor monitored for water quality.

	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
Mean (ppb)	0.79	0.15	0.41	3.95	0.03	0.08	1.00	1.38	0.70	0.25	0.01	0.08
Stdev (ppb)	0.52	0.11	0.64	8.38	0.02	0.06	2.16	3.04	0.50	0.13	0.01	0.13

Table 16: Spring water mean and standard deviation across metals

Qualitative Results

Water quality concerns expressed by Eastport, Perry, and Pleasant Point residents are discussed below.

As previously discussed, there are both social and technical concerns surrounding drinking water quality in the Boyden Lake watershed. These include community, scientific, and government concerns summarized in an updated version of Table 1, in Table 17 below. Note 2 in Appendix 4 contains detailed information from the Eastport community meeting. While government and scientific concerns were known prior to the start of the study, the community meetings at Eastport, Perry, and Pleasant Point shed light on the water quality parameters concerning citizen scientists. PWD water consumers focused on metals, additives in the water treatment process, and contamination stemming from Boyden Lake, while well owners were concerned with arsenic contamination in the groundwater and dissolved radon. For all sources, community concerns included physical traits, health impacts of drinking water, and biological contamination, including color, developmental toxins, carcinogens, parasites, septic contamination, sulfur, smell, taste, pH, coliform, and discoloration.

The community meetings shed light on a third source of water that initially was not considered in the study: springs. There are two major springs that community members collect water from: a spring in Pembroke and a spring in Robbinston. However, neither are in fact springs but are colloquially referred by community members as springs. The 'spring' in Pembroke is surface water, while the 'spring' in Robbinston is either surface water or a Cartesian well. Community members did not have specific concerns associated with spring water and were in fact traveling 15-25 minutes to collect spring water to avoid drinking PWD or well water.

<table>
<tr><th>Water Source</th><th colspan="2">Community Concerns[1,2,3]</th><th colspan="2">Scientific Concerns[6]</th><th>Government Concerns[4,5]</th></tr>
<tr><td>PWD</td><td>F, Cl, As, Pb, Fe, boil orders, petroleum products</td><td rowspan="3">Color, contaminant affecting children development, carcinogens, parasites, septic contamination, sulfur, smell, taste, pH, coliform, discoloration</td><td>DBPs, Ba, Cr, Mn, Nitrate, Nitrite</td><td rowspan="3">Pb, Zn, Cu, Ag</td><td rowspan="3"><u>Primary Standards:</u> Microorganisms, disinfectants, DBPs, inorganic chemicals (Sb, As, Asbestos, Ba, Be, Cd, Cr, Cu, cyanide, F, Pb, Hg, nitrate, nitrite, Se, Th), organic chemicals, radionuclides <u>Secondary Standards</u>: Al, Cl, Cu, F, Fe, Mn, Ag, Zn, etc.</td></tr>
<tr><td>Well</td><td>As, Rn</td><td>Bacteria, As, F, U, Rn, Pb, Mn</td></tr>
<tr><td>Spring</td><td></td><td>Coliform</td></tr>
</table>

Table 17: Community, scientific, historical, and government concerns surrounding drinking water in the Boyden Watershed ("Eastport Community Meeting," 2017[1]; "Perry Community Meeting," 2017[2]; "Pleasant Point Community Meeting," 2017[3]; US EPA OW, 2015a,[4] 2015c[5]; USGS, 2002[6]).

Of the community concerns, some align with the data gathered in this study. Indeed, As was a major concern for well users and As levels in exceedance of EPA guidelines were observed in samples submitted. However, no As exceedances for PWD consumers were found, despite community concerns. Pb was a non-issue except in a number of households. While carcinogens in the form of As in well water and TTHM and HAA5 are present in PWD water, cumulatively across all three communities those three compounds together result in less than one incidence of cancer due to drinking water over the lifetime of the current population.

Lessons on Working with Communities

It was vital to this study to have a respected community partner in the area of study from the beginning, especially when working with a tribal community. The Sipayik Environmental Department was crucial in assisting with advertising community meetings, distributing kits, and collecting them. Although the tribal and Pleasant Point participation rates in the study were low, they would have been far lower without the community partner, as members of the Sipayik Environmental Department individually approached tribal members with requests to participate. It would have been culturally and ethically inappropriate for the researchers, as non-tribal members, to approach tribal members or do extensive marketing in Pleasant Point without a tribal partner.

Despite the close work with a community partner, there can still be challenges. While the first community meeting in Eastport had approximately 40 attendees, the following two meetings at Perry and Pleasant Point had fewer than 10. The community meeting at Pleasant Point was accidentally scheduled at the same time as a major tribal raffle event, while it is unclear why the Perry community meeting had such low turnout, although it was scheduled on a Sunday. It appears that tribal members are less likely to attend community meetings and require instead individual outreach to gain participation.

Although the instructions sheet attached with kits specifically said to only submit non-filtered samples, it is quite possible that filtered samples were submitted. In rented houses, citizen scientists may be unaware of the presence of a filter and renters or homeowners may simply be unable to take samples that bypass the filter. Regardless of the reason, future studies should specifically incorporate a line on the water collection bottle label asking the citizen scientists to indicate whether the water is filtered or not.

Furthermore, the literacy rate, especially among the elderly, was lower than expected. While the exact number is unknown, a number of anecdotes indicated challenges with reading the instructions sheet. For future studies, it may be beneficial to create pictorial instructions with minimal text.

To increase participation across the three communities, a flier was sent out to all mailboxes in Eastport, Perry, and Pleasant Point. The number of samples submitted then approximately doubled. This method of promoting community involvement is encouraged for future studies.

Furthermore, the existence of an email address and a Facebook page created for the study allowed citizen scientists to easily ask questions. This both decreased the errors associated with sample collection (when that type of question was asked) and increased the community focus of the project, as communication was two ways.

An important consideration when sending results to the community members was to avoid casting judgement on the results, as the research team is not composed of public health officials. Instead, citizen scientists were referred to a variety of resources, ranging from an online tool that can help with results interpretation, through a call line for well water arsenic concentration exceedances, to factsheets.

Chapter 5: Conclusion

The study demonstrated that there were isolated instances of exceedances of EPA guidelines in PWD water exclusive to Eastport. In wells, there were exceedances, especially of arsenic and manganese, in Eastport and Perry. Overall, results showed that well water had higher concentrations of Cu, Zn, As, Se, Cd, and Pb than did PWD water, at various levels of significance. Additionally, hypothesis testing demonstrated that Eastport PWD water had higher concentrations of Al, Cr, Mn, and Co than Pleasant Point water at different levels of significance. Furthermore, Eastport wells had higher concentration of Mn than Perry, while non-tribal PWD water had higher concentrations of Al, Cr, and Mn at differing levels of significance than tribal PWD water. When comparing tribal and non-tribal well water and comparing Perry vs. Pleasant Point and Eastport vs. Perry PWD water, no statistically different results were observed for any metal. The hazard index and carcinogenic risk values showed that flushing water would reduce both carcinogenic and non-carcinogenic risk. The hazard index analysis indicated that well water had a higher hazard index than PWD water, that non-tribal PWD water had a statistically significant larger HI than tribal PWD water, and that Eastport PWD water had a higher HI than Pleasant Point PWD water. The risk indicated the same as the hazard index, except that it showed that PWD water had a higher carcinogenic risk than well water when accounting for TTHM and HAA5, while the same was not true for the hazard index.

The health implications associated with drinking water quality accumulate to less than 1 incidence of cancer across the three communities, while 6.6±2.3 children in grades 3 to 5 are exposed to well water exceeding 5 ppb of arsenic, meaning a reduction in Full Scale IQ (6.09± 1.98 points), perceptual reasoning (4.97± 2.14), working memory (4.88± 2.24), and verbal comprehension (6.22± 2.49) may occur, as seen in the study by Wassermann et al. (Wasserman et al., 2014). Bioaccumulation of arsenic in fish warrants further investigation, as the model indicates that non-carcinogenic and carcinogenic risk from fish consumption is on the order of magnitude of or an order of magnitude larger than, respectively, the risk from drinking water. The quality of what the community refers to as spring water met EPA guidelines for metals, but further investigation of microbial contamination is warranted.

Analysis of the impact of the treatment plant on water quality indicated that overall metal concentrations in water decrease between the impoundment, treatment plant, and rechlorination facility, indicating that the increased metal concentrations in Eastport relative to Pleasant Point occur after the rechlorination facility. Furthermore, investigation of the filtration data indicated that filters can decrease concentrations of metals, including for As and Pb, but can also increase the concentrations.

While the scientific data is important, the community concerns gathered through this study, ranging from metals through biological concerns to radon and chlorine, are also important to contextualizing and presenting the results of this study, in addition to informing potential future studies in the region.

Chapter 6: References

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Chapter 7: Appendix

Appendix 1: Background

Meetings Notes from PWD treatment facility tour on 8/31 with Howard Johnson, PWD operator

- 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 standpipes 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 taste or odor issues
- Whenever there is heavy rain, it stirs up water, it is challenging to maintain water quality
- 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
    - 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

Notes 1: PWD treatment facility tour notes

Metal	Common Source	Health Risk	RfD (mg/kg-day)	CSF (per mg/kg-day)	MCLG (ppb)	MCL (ppb)
Pb	Corrosion of household plumbing, erosion of natural deposits	Delay in physical and mental development of infants and children; kidney problems and high blood pressure in adults		0.0085 (CA OEHHA, 2016)	0	TT: 15
As	Erosion of natural depositions, runoff from orchards, or glass & electronic productions waste	Skin damage, problems with circulatory systems, cancer	0.0003	1.5	0	10
Cu	Corrosion of household plumbing; erosion of natural deposits	Gastrointestinal distress, liver or kidney damage	0.019 (CA OEHHA, n.d.)		TT: 1300	1300
Al						50-200*
Cr	Steel and pulp mills; erosion of natural deposits	Dermatitis	1.5		100	100
Mn			0.14			50*
Fe			0.7			300*
Co					N/A	N/A
Ni			0.02		N/A	N/A
Zn			0.3			5000*
Se	Discharge from petroleum refineries and mines; erosion of natural deposits	Hair and fingernail loss; circulatory problems and numbness in extremities	0.005		50	50
Cd	Corrosion of pipes; erosion of natural deposits; discharge from refineries; waste batteries and paints	Kidney damage	0.0005		5	5

Table 3: MCL and MCLG EPA concentration limits and associated sources and health risks for metals of interest (US EPA OW, 2015b, 2015d). Carcinogenic slope factors and non-carcinogenic references doses are all from the EPA unless otherwise indicated (US EPA ORD, 2018)

Appendix 2: Method

MIT CEHS
Center for Environmental Health Sciences

Civil and Environmental Engineering

SIPAYIK ENVIRONMENTAL DEPT.

Drinking Water Quality Research in the Boyden Lake Watershed

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!

The Purpose

Provide independently tested drinking water quality information to Boyden Lake Reservoir communities

The Locations

Validate existing data and fill information gaps

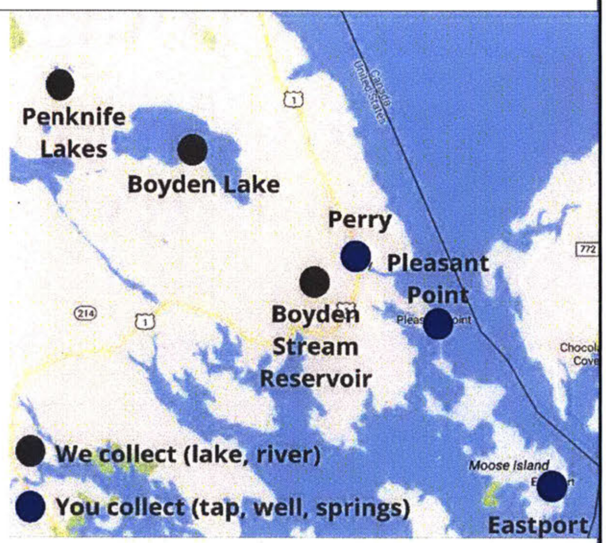
Lakes

Rivers

Tap water

Well water

Springs



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.

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

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

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

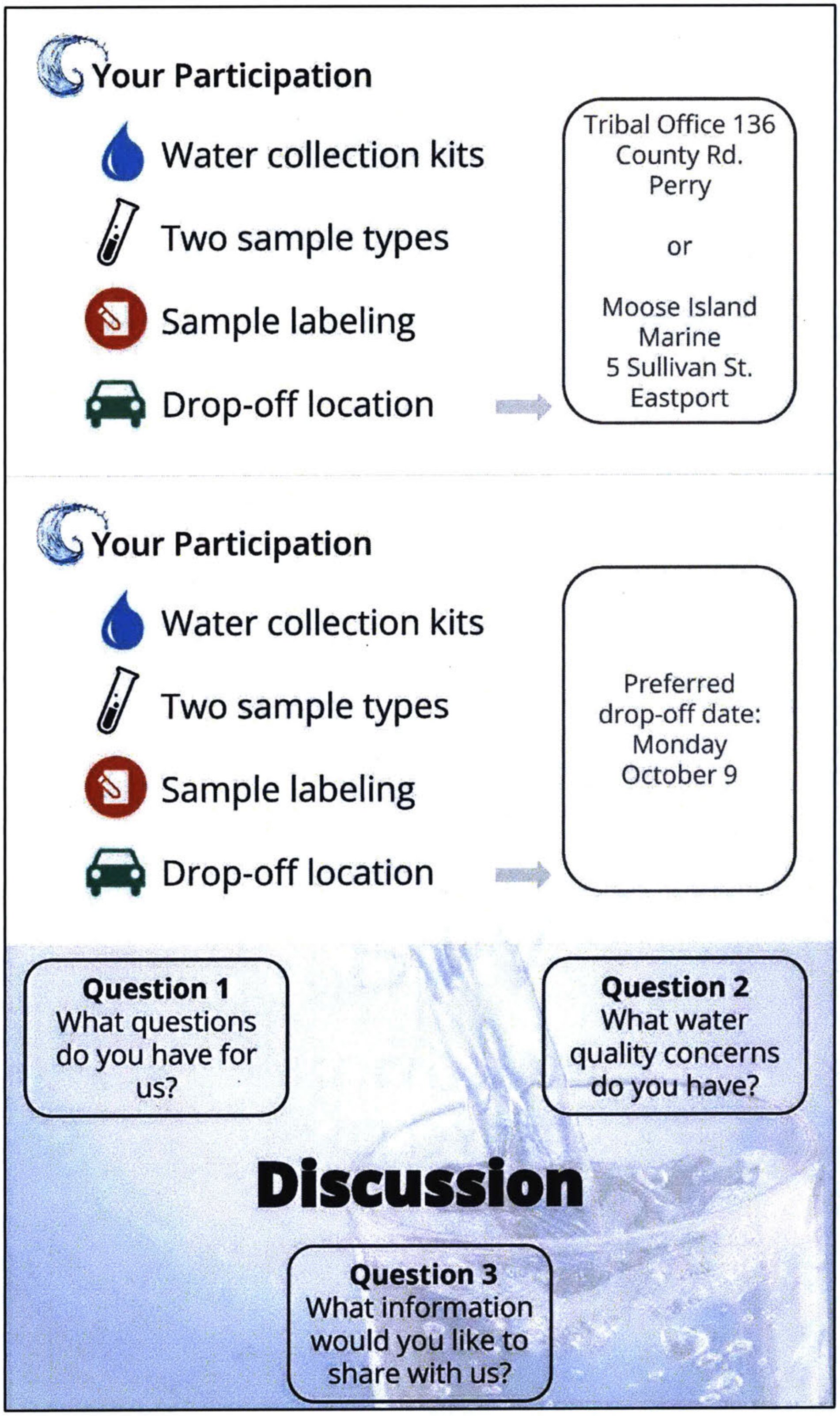


Fig 2. Presentation deck used for community meetings. Included is the one used in Perry.

Side 1

Community Meeting
Perry Elementary School
October 8, 2017

Water Quality Study of the Boyden Lake Watershed

Tchelet Segev & Abby Harvey
MIT Center for Environmental Health Sciences (CEHS)
MIT Civil and Environmental Engineering Dept.

Background Summary

- Boyden Lake supplies drinking water to the communities of Pleasant Point, Perry, and Eastport.
- Drinking water in Maine has been known to contain Arsenic, Lead, and Mercury.
- We are hoping to verify existing drinking water data and fill gaps, including analyzing water quality for wells and springs.

Project Goals

Through this pilot project, we hope to collaborate with you to gain a better idea of the contaminants in the Boyden Lake Watershed, and to understand if improvements are needed in your drinking water quality. We plan to:

- Determine concentrations of Arsenic, Lead, Mercury, and other heavy metals in Boyden Lake, the Boyden Stream Reservoir, wells, springs, and in tap water throughout Pleasant Point, Perry, and Eastport.
- Perform a human health risk analysis based on contaminant levels.
- Pinpoint the potential sources of contaminant input.

How can you help?

You can have the quality of tap water in your home tested, whether you receive municipal water or use well or spring water. If you drink spring water, please take samples of both your spring and tap water. To participate in this project:

- Pick up a Tap Water Sample Kit from us at the Community Meeting. Be sure to pick up a kit for your neighbors and friends!
- Follow the directions on the sheet in the Sample Kit. Sign the Participation Form in the Sample Kit. Results will be emailed to you by May 2018 (if requested, results can be mailed by US Postal Service or distributed in person at the follow-up meeting in May 2018). These will include a brief summary of results from your tap water.
- Another community meeting will be held in late May or early June 2018 to share and discuss the results with you.

- *Additional Tap Water Sample Kits will be available at two local locations.*
- *To find Drop-Off and Pick-up Sites and Further Instructions* *PLEASE TURN THE PAGE OVER ….*

MIT Civil and Environmental Engineering

MIT CEHS Center for Environmental Health Sciences

Fig 3. Handout distributed at the community meetings, the back was equivalent to Fig 15.

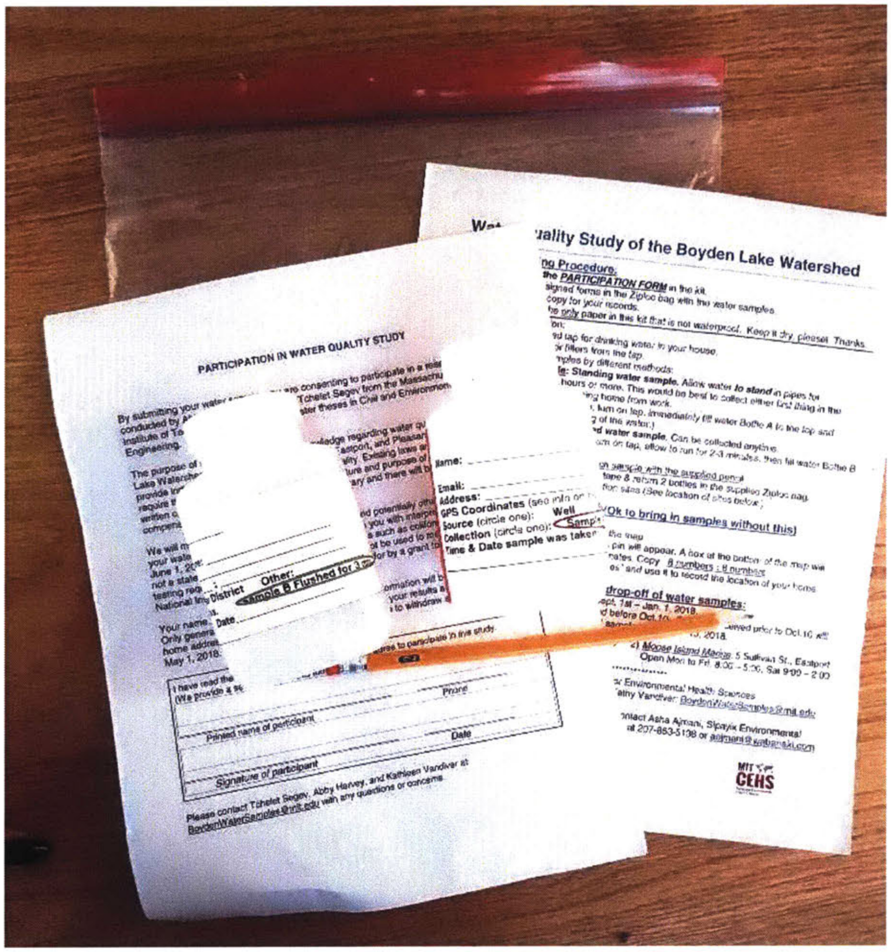


Fig 4. Disassembled kit contents: pencil, 2 participation forms, instructions sheet, and standing and running water bottles

Local
Postal Customer

PRSRT STD
ECRWSS
U.S. POSTAGE
PAID
EDDM RETAIL

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

Fig 5. Mailout sent to all households in Eastport, Perry, and Pleasant Point with mailboxes

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
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 Sept. 1st – Jan. 1, 2018.
Preferred drop-off dates are before Sept. 1 and before Oct.10. Samples received prior to Oct.10 will receive first priority. Drop-off for the completed samples ends Jan. 15, 2018.

Two Sites: 1) *Tribal Office:* 136 County Rd., Perry
Open Mon to Fri, 8:00 - 4:30

2) *Moose Island Marine:* 5 Sullivan St., Eastport
Open Mon to Fri, 8:00 – 5:00; Sat 9:00 – 2:00

****

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

Fig 6. Instructions included with kits

Name: ____

Email: _________________________________ **Phone:** ______________________

Address: ____

GPS Coordinates (see info on how): ________________ : ______________________

Source (circle one): **Well** **Passamaquoddy Water District** **Other:**____________

Collection (circle one): **Sample A Standing for 6 hrs.** **Sample B Flushed for 3 mins.**

Time & Date sample was taken: Time___________ **Date**___________________

Name: ____

Email: _________________________________ **Phone:** ______________________

Address: ____

GPS Coordinates (see info on how): ________________ : ______________________

Source (circle one): **Well** **Passamaquoddy Water District** **Other:**____________

Collection (circle one): **Sample A Standing for 6 hrs.** **Sample B Flushed for 3 mins.**

Time & Date sample was taken: Time___________ **Date**___________________

Fig 7. Water bottle labels for standing (Sample A, red) and running (Sample B, green) samples

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 to provide individuals information on their water quality. Existing laws and good practice require that all participants be informed of the nature and purpose of the 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. (We provide a second copy of this form 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.

Fig 8. Consent form included with most samples

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

Date
Dear _____(insert 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 __(insert water source)___ water sample you submitted for __(insert address)___ in a data 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/

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

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

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

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)			15	None
Arsenic (As)			10	None
Copper (Cu)			1300	1000
Manganese (Mn)			None	50
Iron (Fe)			None	300
Cadmium (Cd)			5	None
Zinc (Zn)			None	5000
Aluminum (Al)			None	50-200
Selenium (Se)			50	None
Cobalt (Co)			None	None
Nickel (Ni)			None	None

3

Fig 9. Stock results letter sent to community members

Appendix 3: Data Analysis

Fish	BAF (L/kg)	Location	Source
Landlocked salmon	4.9 (Masu)	Hayakawa River hot springs, Japan	(Kaise et al., 1997)
Brook trout	570 (small)	Blacklick	(US EPA OW, 2003)*
	310 (small)	Haarrington	(US EPA OW, 2003)*
	300 (large)	Blacklick	(US EPA OW, 2003)*
	240 (large)	Haarrington Creek	(US EPA OW, 2003)*
Rainbow smelt			
Smallmouth bass	550	Queen Lake	(Chen et al., 2000)
	530	Queen Lake	(Chen et al., 2000)
Hornpout (Bullhead)	280 (Brown)	Herrington Creek	(US EPA OW,
Banded killifish	85.8 (killifish)	Upper Mystic Lake	(Chen & Folt, 2000)
	1.8	Moira Lake	(Azcue & Dixon, 1994)
Pumpkinseed Sunfish	6.1	Moira Lake	(Azcue & Dixon, 1994)
	270	Chaffin Pond	(Chen et al., 2000)
American eel			
Chain pickerel			
Largemouth bass	46	Upper Mystic Lake	(Chen & Folt, 2000)
	1.5	Moira Lake	(Azcue & Dixon, 1994)
	46	Mirror Lake	(Chen et al., 2000)
White perch	1.4	Moira Lake	(Azcue & Dixon, 1994)
	320	Community lake	(Chen et al., 2000)
Yellow perch	59	Upper Mystic Lake	(Chen & Folt, 2000)
Lake trout			
Brown trout			

Table 6: Bioaccumulation factors for various fish found in Boyden Lake

*From Mason et al. 2002. Archives of Environmental Contamination and Toxicology 38:283-297 via (US EPA OW, 2003).

Sample Group (Running)	Sample Size
Well	146
PWD	118
Non-tribal Well	134
Tribal well	12
Non-tribal PWD	94
Tribal PWD	24
Eastport PWD	94
Perry PWD	6
Pleasant Point PWD	18
Eastport Well	62
Perry Well	83

Table 7: Sample sizes of sample groups analyzed in the study by water source, town, and tribal affiliation

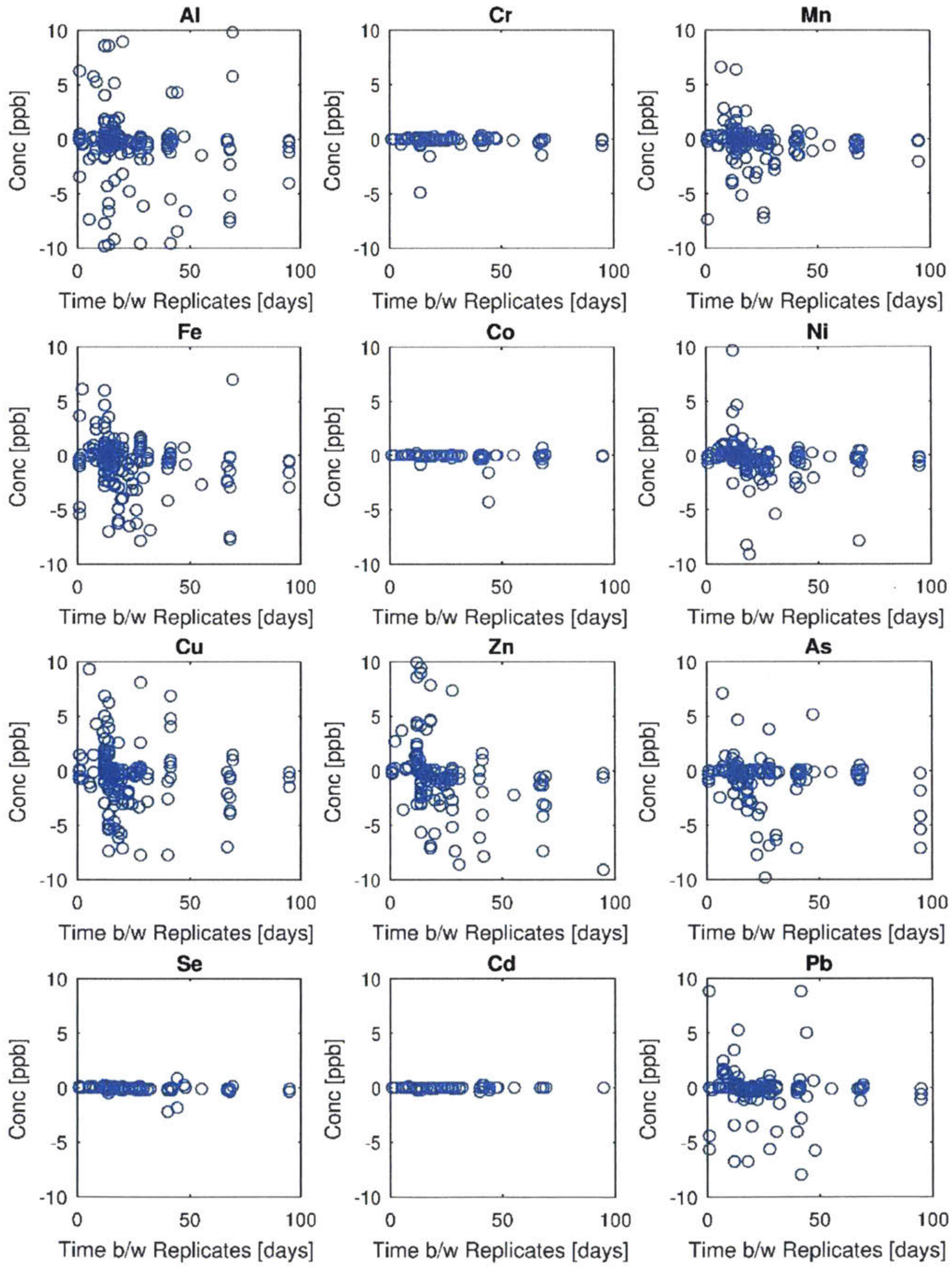


Fig 11. Consistency in concentration delta between samples. The figure shows how time between when replicates were measured had varying effect on the concentrations of metals, but overall was symmetrical about the zero axis.

Table 8: Comparison of state lab and MIT lab results for As and Pb

Metal	Sample No	20	34	48	170	189	198	199	203	235	237	254	255	272	287	333	344	373	538	544	569
As	State Lab [ppb]	<1	4.2	48	<1	2.7	11	11	32	<1	<1	<1	<1	<1	<1	<1	41	13	<1	28	15
	MIT Lab [ppb]	0.7	3.5	61	0.3	2.7	11	11	31	0.7	0.2	0.3	0.2	0.2	0.2	0.2	44	7	0.2	28	14
	MIT Uncertainty [ppb]	0.25	1.23	21.4	0.11	0.95	3.85	3.85	10.9	0.25	0.1	0.11	0.07	0.1	0.1	0.1	15	2.5	0.1	9.8	4.9
	Percent Error	V	17	27	V	0	0	0	3.1	V	V	V	V	V	V	V	7.3	46	V	0	6.7
Pb	State Lab [ppb]	<0.5	240	<0.5	21	<0.5	<0.5	<0.5	<0.5	5.6	13	2	<0.5	<0.5	21	<0.5	<0.5	<0.5	12	1.1	1
	MIT Lab [ppb]	0	238	0.4	30	0	0.3	0.3	0	3.7	10	5	0.5	0.2	19	0	0.2	0.2	12	1.4	1
	MIT Uncertainty [ppb]	0	83.3	0.14	10.5	0	0.11	0.11	0	1.3	3.5	1.75	0.18	0.1	6.7	0	0.1	0.1	4.2	0.5	0.4
	Percent Error	V	0.83	V	43	V	V	V	V	34	23	150	V-	V	9.5	V	V	V	0	27	0

Appendix 4: Results and Discussion

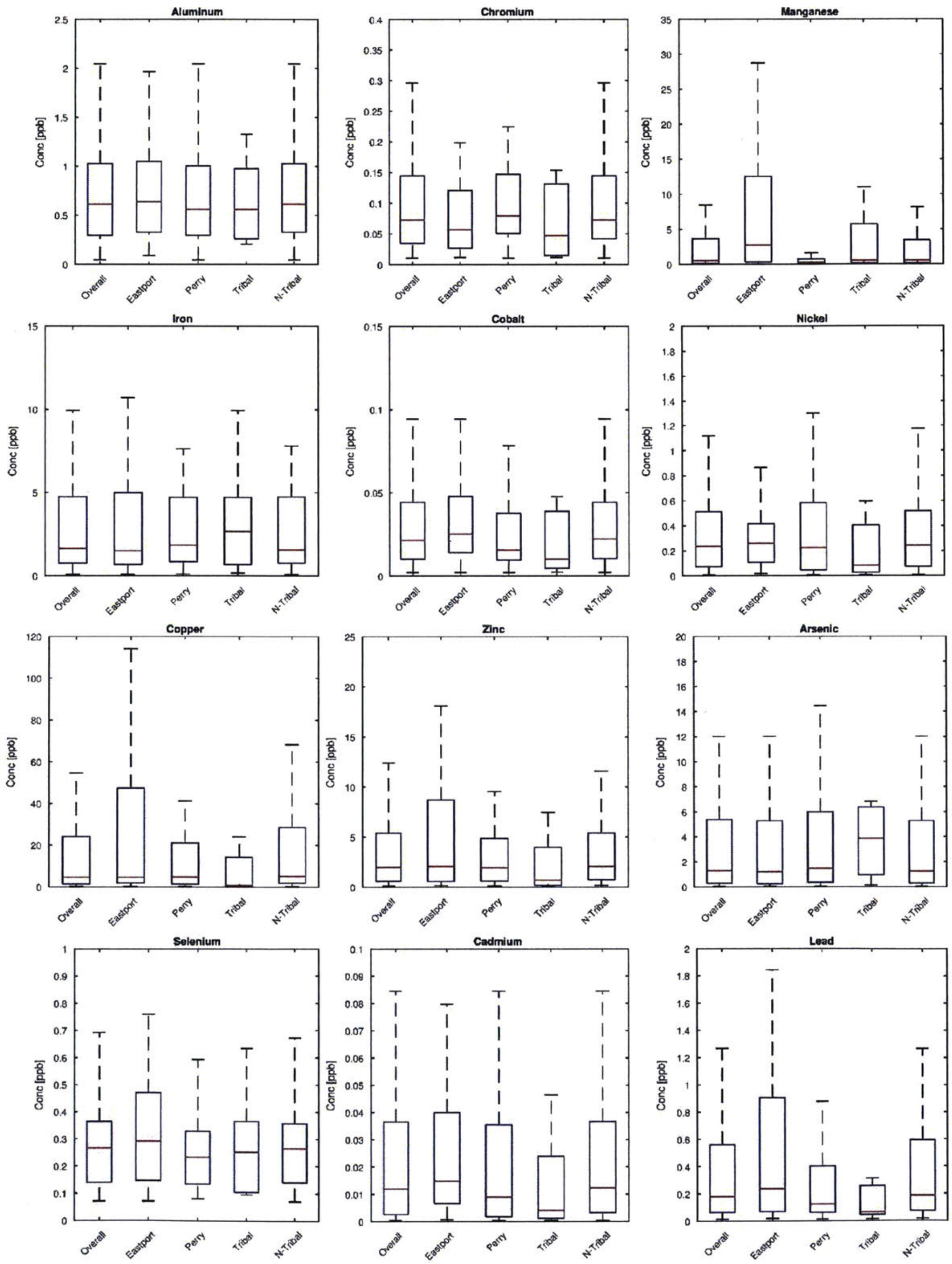


Fig 14. Distributions of well water concentrations across metals, communities, and tribal affiliation. All concentrations have average uncertainties of 34% (see Chapter 3 Sample Uncertainty section).

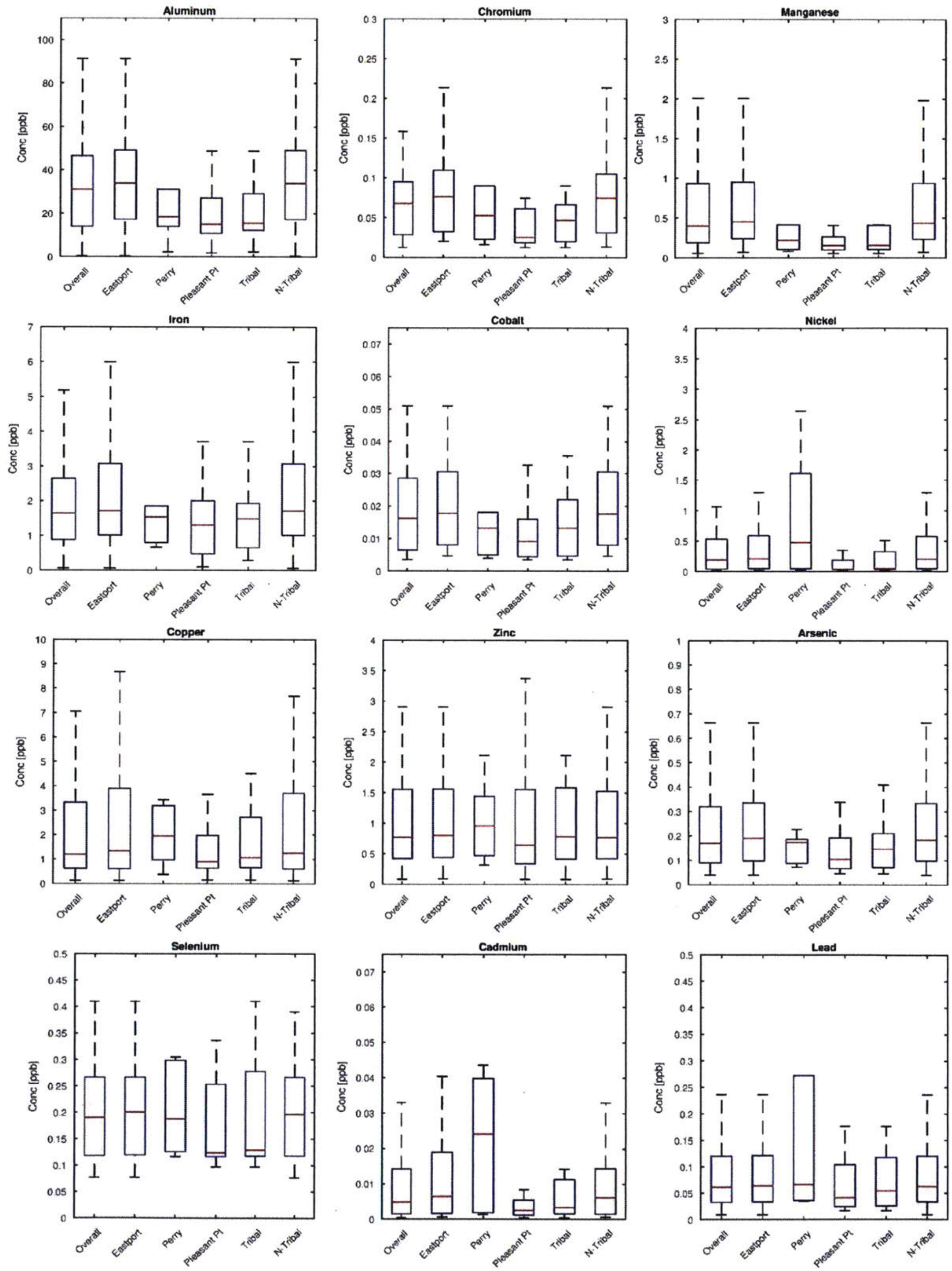


Fig 15. Distributions of PWD water concentrations across metals, communities, and tribal affiliation. All concentrations have average uncertainties of 34% (see Chapter 3 Sample Uncertainty section).

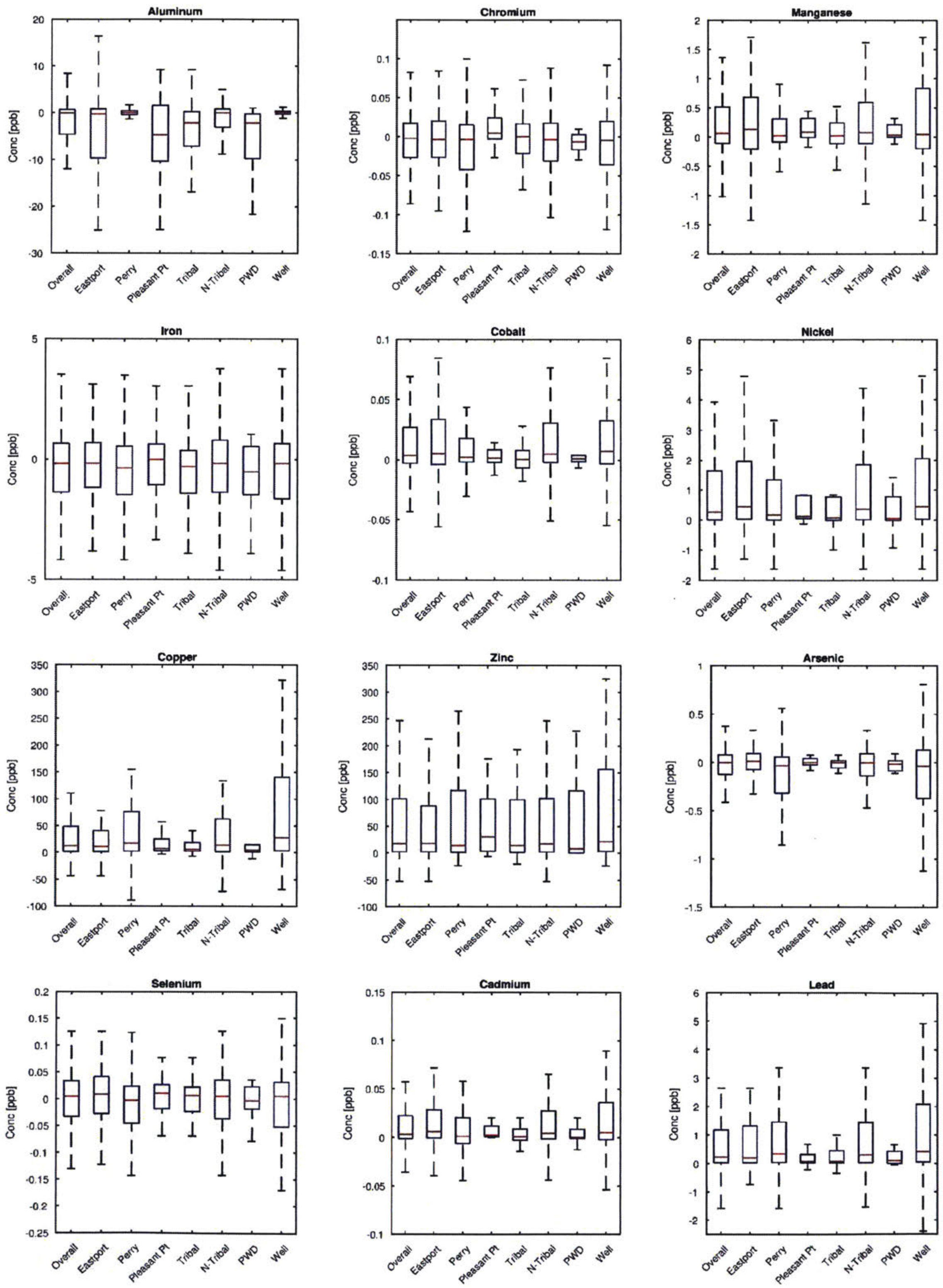


Fig 16. Distributions of differences between standing and running water concentrations across metals, communities, and tribal affiliation. All concentrations have average uncertainties of 34% (see Chapter 3 Sample Uncertainty section).

PWD: Eastport>Pleasant Pt		PWD: Eastport>Perry			PWD: N-Tribal>Tribal			Well: N-Tribal>Tribal			Well> PWD		
Z Value	p	Rank Sum	Z Value	p	Rank Sum	Z Value	p	Rank Sum	Z Value	p	Rank Sum	Z Value	p
2.73	0.00317*	4.82E+03	1.07	0.143	6.00E+03	2.68	0.00363*	9915	0.467	0.320	1.11E+04	-13.3	1.00E+00
4.07	0.0000237***	4.82E+03	0.980	0.164	6.06E+03	3.14	0.00085**	10053	1.45	0.074	2.01E+04	1.26	0.103
3.54	0.000202***	4.87E+03	1.73	0.0414	6.10E+03	3.39	0.000354**	9855	0.0392	0.484	2.03E+04	1.60	0.054
2.25	0.0124	4.80E+03	0.718	0.236	5.88E+03	1.89	0.0295	9854	0.0321	0.487	1.97E+04	0.583	0.280
2.33	0.0100	4.82E+03	1.08	0.140	5.89E+03	1.96	0.0249	10069	1.56	0.059	2.09E+04	2.46	0.007
2.82	0.00243*	4.73E+03	-0.312	0.623	5.86E+03	1.78	0.0374	10083	1.66	0.0481	1.98E+04	0.709	0.239
0.883	0.189	4.72E+03	-0.472	0.681	5.62E+03	0.184	0.427	10194	2.45	0.0071	2.35E+04	6.66	1.38E-11****
0.725	0.234	4.75E+03	-0.036	0.514	5.59E+03	-0.0501	0.520	10108	1.84	0.0328	2.22E+04	4.71	1.27E-06****
2.31	0.0105	4.82E+03	0.980	0.164	5.88E+03	1.94	0.0265	9674	-1.25	0.894	2.52E+04	9.54	7.35E-22****
1.27	0.102	4.73E+03	-0.239	0.595	5.64E+03	0.277	0.391	9959	0.780	0.218	2.18E+04	3.98	3.39E-05***
2.17	0.0151	4.65E+03	-1.42	0.921	5.66E+03	0.451	0.326	10067	1.55	0.061	2.16E+04	3.62	0.00014855***
1.24	0.108	4.71E+03	-0.617	0.731	5.65E+03	0.391	0.348	10086	1.69	0.0460	2.29E+04	5.75	4.47E-09****

Table 9: Results of hypothesis testing of average concentrations

Metal	Well: Eastport>Perry			PWD: Perry>Pleasant Pt			
	Rank Sum	Z Value	p	Rank Sum	Z Value	p	Rank Sum
Al	4.61E+03	0.334	0.369	84	0.567	0.285	5.66E+03
Cr	4.08E+03	-1.79	0.963	92	1.10	0.136	5.83E+03
Mn	5.80E+03	5.11	0.000000165****	85	0.633	0.263	5.76E+03
Fe	4.29E+03	-0.933	0.825	89	0.900	0.184	5.60E+03
Co	5.04E+03	2.04	0.0205	80	0.300	0.382	5.61E+03
Ni	4.72E+03	0.785	0.216	97	1.43	0.076	5.67E+03
Cu	4.66E+03	0.514	0.304	94	1.23	0.109	5.42E+03
Zn	4.62E+03	0.382	0.351	82	0.433	0.332	5.40E+03
As	4.28E+03	-1.00	0.842	88	0.833	0.202	5.60E+03
Se	4.99E+03	1.83	0.0334	91	1.03	0.151	5.47E+03
Cd	5.13E+03	2.40	0.0083	104	1.90	0.0287	5.59E+03
Pb	4.90E+03	1.51	0.066	96	1.37	0.086	5.47E+03

Eastport Well	PWD Run								Well Run							
Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean
1.9	113.6	0.3	46.4	31.0	13.9	11	26.1	35.5	31.7	0.0	1.0	0.6	0.3	1	3.6	1.5
0.2	1.0	0.0	0.1	0.1	0.0	0	0.1	0.1	2.9	0.0	0.1	0.1	0.0	0	0.3	0.1
32.8	5177.6	0.1	0.9	0.4	0.2	0	474.5	44.5	737.7	0.0	3.6	0.5	0.2	0	70.4	16.7
4.2	6105.1	0.1	2.6	1.6	0.9	1	559.4	55.2	5092.1	0.1	4.7	1.6	0.8	1	419.9	41.2
0.0	7.3	0.0	0.0	0.0	0.0	0	0.7	0.1	5.2	0.0	0.0	0.0	0.0	0	0.4	0.1
0.8	23.4	0.0	0.5	0.2	0.0	0	2.2	0.7	144.7	0.0	0.5	0.2	0.1	0	12.0	1.6
50.4	121.0	0.1	3.3	1.2	0.6	1	12.0	3.8	8662.5	0.1	24.1	4.6	1.4	1	943.2	144.8
23.5	53.8	0.1	1.6	0.8	0.4	1	8.4	3.2	1726.5	0.1	5.4	2.0	0.6	0	209.1	39.4
4.3	1.8	0.0	0.3	0.2	0.1	0	0.2	0.2	54.6	0.0	5.4	1.3	0.3	0	7.4	4.4
0.4	3.1	0.1	0.3	0.2	0.1	0	0.3	0.2	3.0	0.1	0.4	0.3	0.1	0	0.3	0.3
0.0	0.5	0.0	0.0	0.0	0.0	0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0	0.0	0.0
1.2	7.8	0.0	0.1	0.1	0.0	0	0.8	0.2	28.3	0.0	0.6	0.2	0.1	0	3.2	1.0

Eastport PWD Run		Perry Well Run														
Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev
26.3	38.4	13.2	0.0	1.0	0.6	0.3	0	2.1	1.2	31.7	0.1	1.1	0.6	0.3	1	5.0
0.1	0.1	1.7	0.0	0.1	0.1	0.1	0	0.2	0.1	2.9	0.0	0.1	0.1	0.0	0	0.4
531.1	55.8	148.6	0.0	0.7	0.3	0.1	0	18.5	4.8	737.7	0.0	12.5	2.7	0.3	0	103.7
626.0	68.9	5092.1	0.1	4.7	1.8	0.8	1	555.2	69.3	34.7	0.1	5.0	1.5	0.7	1	6.2
0.7	0.1	0.5	0.0	0.0	0.0	0.0	0	0.1	0.0	0.8	0.0	0.0	0.0	0.0	0	0.1
2.5	0.7	144.7	0.0	0.6	0.2	0.0	0	15.8	2.2	12.4	0.0	0.4	0.3	0.1	0	2.1
13.3	4.3	8662.5	0.2	21.0	4.8	1.4	1	1237.8	217.1	1229.3	0.1	47.3	4.7	1.9	1	165.9
8.1	3.2	1726.5	0.1	4.9	1.9	0.6	1	254.0	51.7	1009.5	0.1	8.7	2.1	0.6	0	126.8
0.3	0.3	31.9	0.0	6.0	1.5	0.4	0	6.3	4.5	54.6	0.1	5.3	1.2	0.3	0	8.8
0.3	0.2	0.9	0.1	0.3	0.2	0.1	0	0.2	0.3	3.0	0.1	0.5	0.3	0.1	0	0.4
0.1	0.0	0.2	0.0	0.0	0.0	0.0	0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0	0.0
0.9	0.3	28.3	0.0	0.4	0.1	0.1	0	3.5	0.9	18.8	0.0	0.9	0.2	0.1	0	2.8

Pleasant Point PWD Run			Perry PWD Run														
Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode
10	16.1	21.7	100.5	2.3	31.1	18.3	13.9	2	32.3	30.7	113.6	0.3	49.1	33.8	17.3	13
0	0.0	0.0	0.2	0.0	0.1	0.1	0.0	0	0.1	0.1	1.0	0.0	0.1	0.1	0.0	0
0	0.4	0.3	1.0	0.1	0.4	0.2	0.1	0	0.3	0.3	5177.6	0.1	1.0	0.5	0.2	0
0	1.0	1.3	4.1	0.7	1.8	1.5	0.8	1	1.1	1.7	6105.1	0.1	3.1	1.7	1.0	1
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0
0	0.1	0.1	2.6	0.0	1.6	0.5	0.0	0	1.0	0.9	23.4	0.0	0.6	0.2	0.0	0
1	1.2	1.4	3.4	0.4	3.2	1.9	1.0	2	1.1	2.0	121.0	0.1	3.9	1.3	0.6	1
0	10.8	3.8	2.1	0.3	1.4	1.0	0.5	1	0.6	1.0	53.8	0.1	1.6	0.8	0.4	1
0	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0	0.1	0.2	1.8	0.0	0.3	0.2	0.1	0
0	0.1	0.2	0.3	0.1	0.3	0.2	0.1	0	0.1	0.2	3.1	0.1	0.3	0.2	0.1	0
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0
0	0.1	0.1	0.8	0.0	0.3	0.1	0.0	0	0.3	0.2	7.8	0.0	0.1	0.1	0.0	0

Tribal Well Run				Tribal PWD Run												
Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1
0.3	1	0.4	0.6	100.5	2.3	29.1	15.5	12.3	10	21.3	24.4	63.6	1.8	27.1	15.0	10.8
0.0	0	0.1	0.1	0.4	0.0	0.1	0.0	0.0	0	0.1	0.1	0.1	0.0	0.1	0.0	0.0
0.1	0	7.3	4.3	1.7	0.1	0.4	0.2	0.1	0	0.4	0.4	1.7	0.1	0.3	0.2	0.1
0.7	1	3.0	3.3	4.1	0.3	1.9	1.5	0.7	1	1.0	1.5	3.7	0.1	2.0	1.3	0.5
0.0	0	1.4	0.4	0.3	0.0	0.0	0.0	0.0	0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0	0.4	0.3	2.6	0.0	0.3	0.0	0.0	0	0.6	0.4	0.5	0.0	0.2	0.0	0.0
0.2	0	26.3	12.8	6.2	0.2	2.7	1.1	0.6	1	1.5	1.8	4.5	0.2	2.0	0.9	0.6
0.2	0	5.7	3.4	47.8	0.1	1.6	0.8	0.4	0	9.4	3.3	47.8	0.1	1.6	0.6	0.3
1.0	4	4.4	4.4	1.2	0.0	0.2	0.1	0.1	0	0.2	0.2	0.4	0.0	0.2	0.1	0.1
0.1	0	0.2	0.3	0.4	0.1	0.3	0.1	0.1	0	0.1	0.2	0.3	0.1	0.3	0.1	0.1
0.0	0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0	0.4	0.3	0.8	0.0	0.1	0.1	0.0	0	0.2	0.1	0.3	0.0	0.1	0.0	0.0

Non-Tribal Well Run					Non-Tribal PWD Run											
Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median	Q1	Mode	Stdev	Mean	Max	Min	Q3	Median
0.6	0.3	0	3.8	1.5	113.6	0.3	49.1	33.8	17.3	34	26.5	38.3	1.3	0.2	1.0	0.6
0.1	0.0	0	0.3	0.1	1.0	0.0	0.1	0.1	0.0	0	0.1	0.1	0.6	0.0	0.1	0.0
0.5	0.2	0	73.3	17.8	5177.6	0.1	0.9	0.4	0.2	0	531.1	55.8	25.9	0.1	5.7	0.5
1.6	0.8	1	438.1	44.6	6105.1	0.1	3.1	1.7	1.0	1	626.0	68.9	9.9	0.2	4.7	2.7
0.0	0.0	0	0.1	0.0	7.3	0.0	0.0	0.0	0.0	0	0.7	0.1	5.2	0.0	0.0	0.0
0.2	0.1	0	12.5	1.7	23.4	0.0	0.6	0.2	0.0	0	2.5	0.7	1.3	0.0	0.4	0.1
5.1	1.9	1	983.6	156.7	121.0	0.1	3.7	1.2	0.6	1	13.3	4.3	95.9	0.2	14.3	0.7
2.0	0.7	1	218.0	42.6	53.8	0.1	1.5	0.8	0.4	1	8.1	3.2	20.8	0.1	4.0	0.7
1.2	0.3	0	7.6	4.4	1.8	0.0	0.3	0.2	0.1	0	0.2	0.2	16.9	0.2	6.3	3.9
0.3	0.1	0	0.3	0.3	3.1	0.1	0.3	0.2	0.1	0	0.3	0.2	0.6	0.1	0.4	0.3
0.0	0.0	0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0	0.1	0.0	0.0	0.0	0.0	0.0
0.2	0.1	0	3.3	1.1	7.8	0.0	0.1	0.1	0.0	0	0.9	0.3	1.6	0.0	0.3	0.1

Group			
Statistic	Max	Min	Q3
Al	31.7	0.0	1.0
Cr	2.9	0.0	0.1
Mn	737.7	0.0	3.4
Fe	5092.1	0.1	4.7
Co	0.8	0.0	0.0
Ni	144.7	0.0	0.5
Cu	8662.5	0.1	28.6
Zn	1726.5	0.2	5.4
As	54.6	0.0	5.3
Se	3.0	0.1	0.4
Cd	0.2	0.0	0.0
Pb	28.3	0.0	0.6

Table 11: Statistics by metal and groups. All units are in ppb.

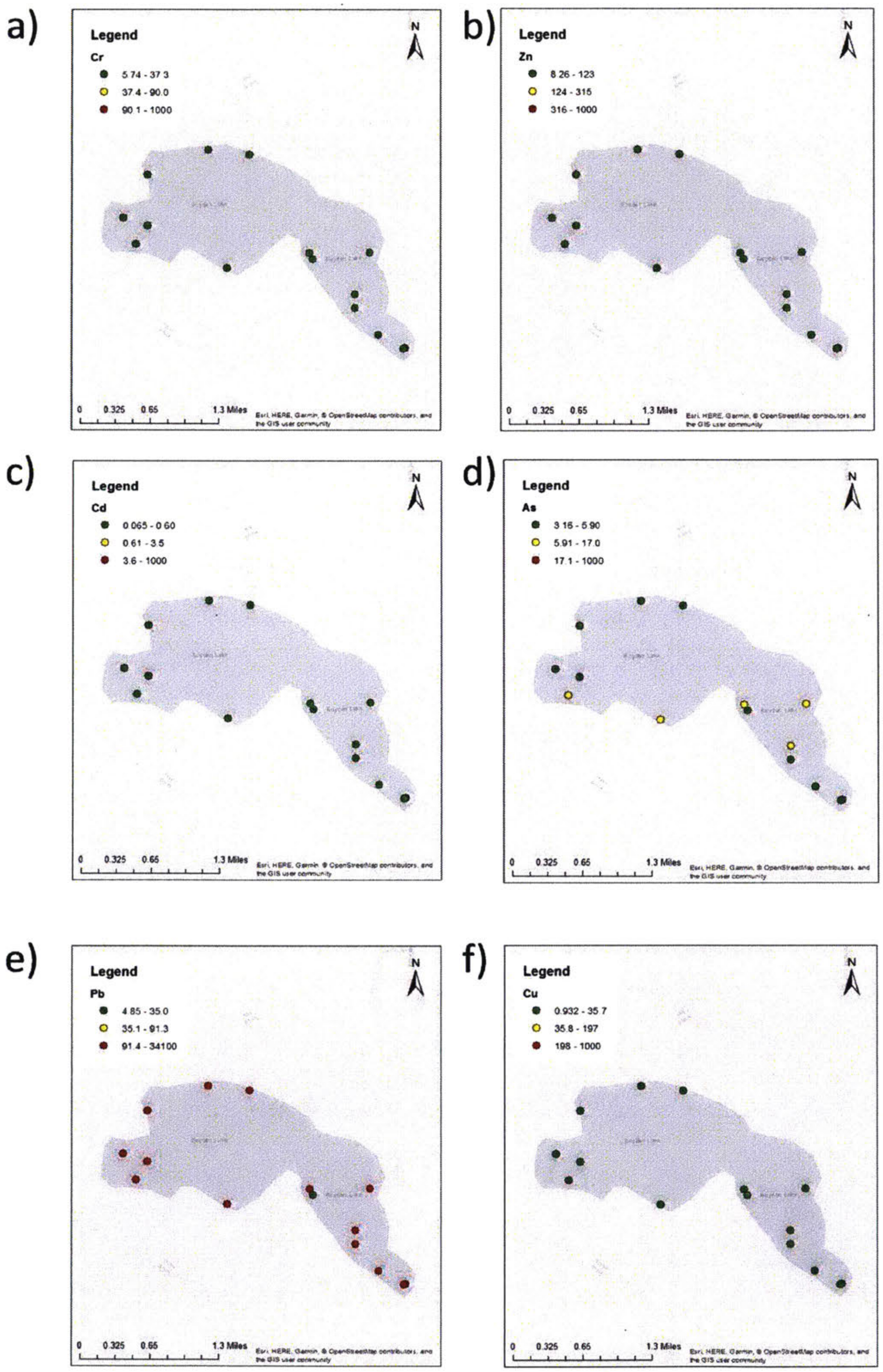
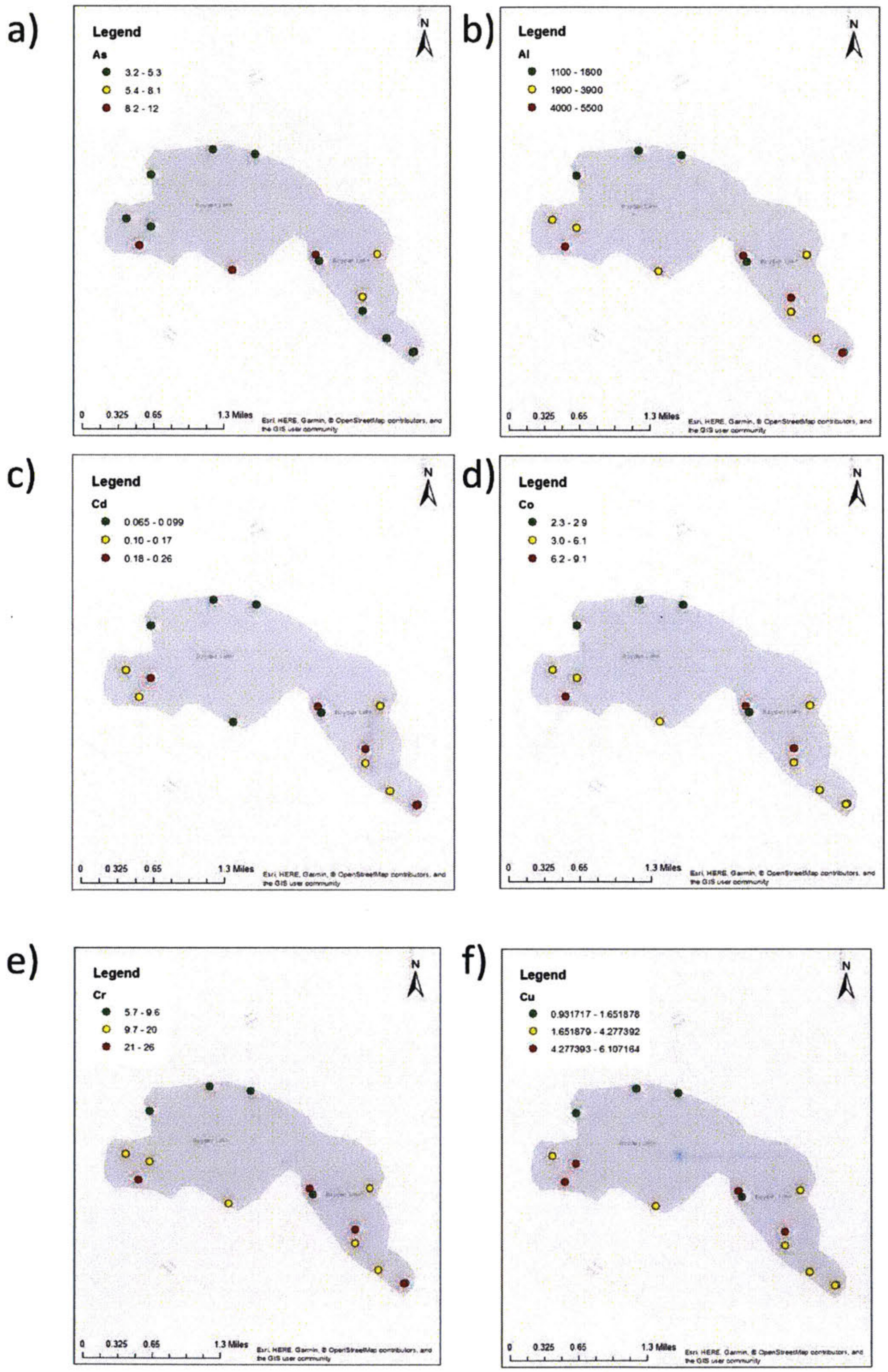


Fig 25: Sediment concentrations relative to sediment freshwater aquatic guidelines for: a) Pb, b), Zn, c) As, d) Cr, e) Cd, and f) Cu.


a)
Legend
As
3.2 - 5.3
5.4 - 8.1
8.2 - 12
b)
Legend
Al
1100 - 1800
1900 - 3900
4000 - 5500
c)
Legend
Cd
0.065 - 0.099
0.10 - 0.17
0.18 - 0.26
d)
Legend
Co
2.3 - 2.9
3.0 - 6.1
6.2 - 9.1
e)
Legend
Cr
5.7 - 9.6
9.7 - 20
21 - 26
f)
Legend
Cu
0.931717 - 1.651878
1.651879 - 4.277392
4.277393 - 6.107164
N
0 0.325 0.65 1.3 Miles

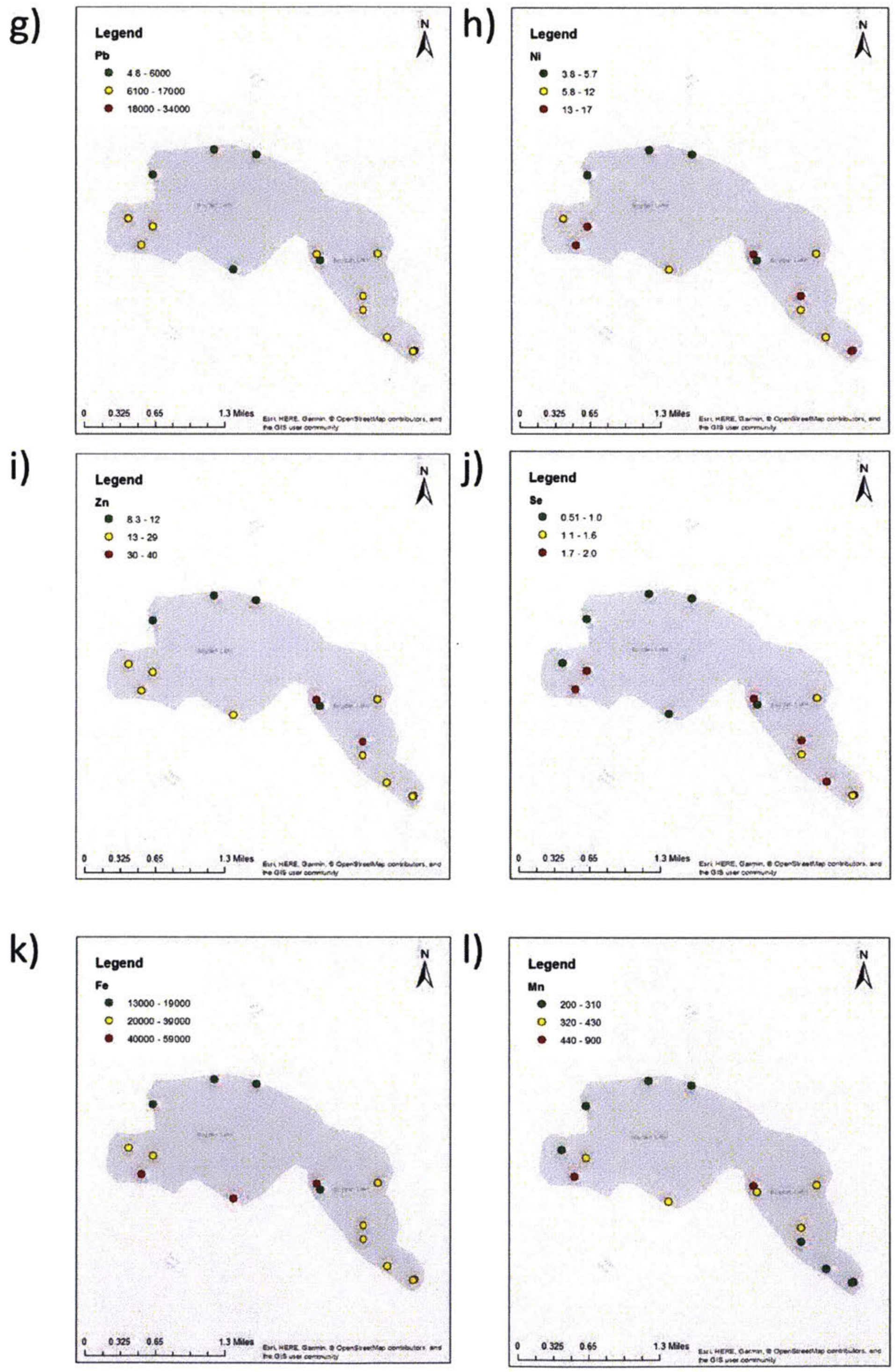


Fig 26: Sediment concentration gradients for: a) As, b) Al, c) Cd, d) Co, e) Cr, f) Cu, g) Pb, h) Ni, i) Zn, j) Se, k) Fe, and l) Mn.

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
- Radon
- Boyden Lake dam: how to maintain healthy water level
- Ground water/ wells: leakage of ground water into wells
- Fluoride? What concentration?
- Chlorination?
- Carcinogens? Manmade of naturally occurring?

- Petroleum products from recreational boating on the Boyden Lake (inadequate sanitation systems surround Boyden Lake? Up to date?)

3) <u>What information would like to share with us?</u>

- 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

Notes 2: Qualitative data gathered from the discussion at the Eastport community meeting