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Heavy Metal Contamination in Drinking Water
and its Connection to Superfund Site Related Environmental Injustice

By

Emily Simmons Caruso

* * * * *

Submitted in partial fulfillment
of the requirements for
Honors in the Department of Environmental Science,
Policy, and Engineering

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ABSTRACT

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ADVISOR: Kurt Hollocher

Equal access to clean, potable drinking water is crucial for our society's health and advancement. In 2014, the infamous water crisis in Flint, Michigan, shed light on the widespread water quality issues impacting numerous communities in America. In response to the Flint water crisis, Union College established the Union College Water Initiative, providing free drinking water analyses to the public. This initiative aims to raise awareness and educate people by analyzing heavy metals commonly found in drinking water—specifically lead, copper, and zinc.

As a part of this initiative, I collected over 300 cold drinking water samples from residences, schools, and businesses across Eastern Massachusetts and beyond. Samples were analyzed by ICP-MS and compared with US-EPA drinking water limits. The EPA limits for copper, zinc, and lead in drinking water are 1300, 5000, and 15 ppb, respectively. Of the unfiltered samples, 2.1% exceeded the copper limit (2,125 to 7,155 ppb), 4.9% exceeded the zinc limit (5,382 to 42,444 ppb), and 6.3% exceeded the lead limit (15.9 to 889 ppb). Samples were also found above the EPA limits for uranium (to 63 ppb), arsenic (to 12.4 ppb), cadmium (to 49 ppb), and antimony (to 17.5 ppb). This study examines issues of water quality and its larger implications in the Environmental Justice Movement. Further research into distribution and sources of heavy metal contamination in particular areas will provide insight into health and equity issues, adding to our understanding of drinking water contamination across the United States.

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TABLE OF CONTENTS

Abstract	ii
Acknowledgments	iii
List of Figures	v
List of Tables	vi
Chapter 1 – Introduction	1
Background.....	1
Previous Work	3
Current Study.....	4
Chapter 2 – Methods	6
Chapter 3 – Results	10
EPA Regulations and Elements Analyzed	10
Zinc, Copper, and Lead	12
Other EPA Regulated Elements	19
Unregulated Elements	23
Lead and Copper in Different Sample Types	24
Private Wells	25
Water Sources Analyzed by Location	28
Chapter 4 – Discussion	34
Superfund Sites.....	34
W.R. Grace and Nuclear Metals Superfund Sites	37
Environmental Justice Implications of Superfund Proximity	41
EJSCREEN Mapping and Screening Tool	45
Essex County, New Jersey: An Example of Environmental Injustice	48
Diamond Alkali Co.....	52
White Chemical Corp	55
Orange Valley Regional Groundwater Contamination	57
Chapter 5 – Conclusions	61
References	64

LIST OF FIGURES

Figure 2.1	Sample locations	6
Figure 2.2	Schematic diagram of the ICP-MS instrument	8
Figure 3.1	Distribution of zinc (Zn) concentrations in samples	13
Figure 3.2	Distribution of copper (Cu) concentrations in samples	14
Figure 3.3	Distribution of lead (Pb) concentrations in samples	16
Figure 3.4	Distribution of arsenic (As) concentrations in samples	19
Figure 3.5	Distribution of uranium (U) concentrations in samples	19
Figure 3.6	Distribution of cadmium (Cd) concentrations in samples	21
Figure 3.7	Distribution of antimony (Sb) concentrations in samples	21
Figure 3.8	Distribution of selenium (Se) concentrations in samples	22
Figure 3.9	Distribution of barium (Ba) concentrations in samples	22
Figure 3.10	Distribution of the unregulated elements bismuth (Bi), rubidium (Rb), and strontium (Sr) concentrations in samples	23
Figure 3.11	Lead vs copper concentrations in different sample types	24
Figure 3.12	Rb/U ratio vs Sr/Ba ratio by location	28
Figure 3.13	Towns sampled in the state of Massachusetts	29
Figure 3.14	The Acton Water District	30
Figure 3.15	The Massachusetts Water Resource Authority Water System	32
Figure 4.1	Superfund sites in the United States	36
Figure 4.2	Acton Superfund proximity and water district	37
Figure 4.3	EJSCREEN national percentiles for Superfund proximity	47
Figure 4.4	Superfund sites in New Jersey	48
Figure 4.5	Superfund sites and EJ Index for Superfund proximity in Essex County, New Jersey	49
Figure 4.6	EJ Index for Superfund proximity at the Diamond Alkali Co. Superfund Site	55
Figure 4.7	EJ Index for Superfund proximity at the White Chemical Corp. Superfund Site	57
Figure 4.8	EJ Index for Superfund proximity at the ORGC Superfund Site	60

LIST OF TABLES

Table 2.1	Standards and internal standards used for analyses.....	9
Table 3.1	Samples from private wells	25
Table 4.1	Summary of treated water PFAS in the Acton Water District	39
Table 4.2	Contaminants at the W.R Grace and Nuclear Metals Superfund sites	41
Table 4.3	Demographic and Environmental indicators used in EJ Index analysis....	46
Table 4.4	Racial demographics for Newark City, the City of Orange, Essex County, and New Jersey	50
Table 4.5	EPA milestones for the Orange Valley Regional Groundwater Contamination Superfund Site	59

CHAPTER 1 – INTRODUCTION

Clean and potable water is essential to life. According to the United Nations (UN), universal access to clean water is considered a basic human right and is a fundamental step towards improving living standards worldwide (Butler et al., 2016). Even in the United States, which has among some of the safest drinking water supplies in the world, harmful contaminants that pose a risk to human health may still be found in public water supplies, as recently demonstrated by the Flint water crisis (Fedinick et al., 2019). Drinking water quality is regulated in the United States under the Safe Drinking Water Act (SDWA), which was established in 1974 with subsequent amendments in 1986 and 1996 (Weinmeyer, 2017). Under the SDWA, the Environmental Protection Agency (EPA) is charged with ensuring the public has safe drinking water (Weinmeyer, 2017). The SDWA establishes national monitoring and reporting requirements as well as national health standards known as maximum contaminant levels (MCLs) for nearly 90 drinking water contaminants (Schaider et al., 2019). Despite this, water contamination can and does still occur, and safe drinking water is still not guaranteed to everyone. Flint, Michigan, proved this in 2015 when their drinking water crisis made headlines all across the nation (Schaider et al., 2019).

Background

Flint was a flourishing city in the mid-20th century. As the home of General Motors, Flint's population grew alongside the developing automotive industry and, by the 1960s, had reached 200,000 people (Denchak, 2018). This changed in the 1980s and early '90s when General Motors relocated, leaving the city in a state of economic decline

and unemployment with a large percentage of the population fleeing Flint in search of jobs (Denchak, 2018). In a city that once boasted the highest median income in the state thanks to General Motors, nearly half of the people now live in poverty (Denchak, 2018). As Flint's economy and population fell into disrepair, the city's water system did too. The problem worsened when the city switched Flint's water supply from the Detroit water system to the Flint River (Campbell et al., 2016). In 2011, the Governor made the executive decision to appoint unelected emergency managers to run the city without any voter input (Denchak, 2018). In 2014, these state-appointed city managers switched to Flint River water as a cost-cutting measure, while they built a new pipeline to eventually take water from Lake Michigan; within a few weeks of the switch, residents started complaining about their water's taste, color, and odor (Denchak, 2018).

Not only is river water typically more complicated to treat than lake water, but, during Flint's industrial boom in the 20th century, the Flint River was heavily polluted by companies like General Motors (Denchak, 2018). When the switch to Flint River water was made in early 2014, the river water was not properly treated with an anti-corrosive agent, violating the EPA's Lead and Copper Rule (LCR), which calls for corrosion control if levels of lead or copper are discovered above EPA limits in over 10% of samples to stop the release of metals from water service lines (Butler et al., 2016). Consequently, the water caused both scale that had formed on the inside of pipes and the pipes themselves to corrode, leading to lead, iron, and rusty particulates leaching into the water (Masten et al., 2016). As a result of this corrosion, Flint's water was contaminated with extremely hazardous substances, including high levels of carcinogenic trihalomethanes and dangerous concentrations of lead (Masten et al., 2016). The people

of Flint faced serious health problems due to this toxic water; the city, however, denied there were any reasons to be concerned and insisted that the water was safe to drink (Campbell et al., 2016). In addition to the numerous severe, chronic medical conditions which developed in the citizens of Flint because of this water contamination, there were twelve fatalities resulting from Legionnaires' disease, which results from a failure of water supply bacteriological controls caused by water contamination (Denchak, 2018). According to more recent reports, however, it has been suggested that there were likely far more deaths related to the drinking water that are still unrecognized, including an estimated several hundred fetal fatalities (Binney et al., 2019). Flint's struggle is ongoing, as they continue to face poor water quality and, consequently, health and quality of life issues.

Flint, Michigan is not an isolated example of inadequate and unequal access to safe and potable drinking water. As a majority-Black city with 40% of its population living below the poverty line (Schaidt et al., 2019), this ongoing water crisis in Flint sparked a nationwide conversation about water quality and related implications of environmental injustice (Campbell et al., 2016). Flint helped to bring awareness to the subject of equal treatment and protection from environmental harm regardless of race, ethnicity, or income, and gave a glimpse into the drinking water crises that plague communities across the United States.

Previous Work

Inspired by Flint's water crisis, Union College started the "Union College Water Initiative" in 2017. This initiative seeks to increase water quality awareness and to

promote safe drinking water by providing free and accessible drinking water analyses to anyone who would like to participate.

Students started by collecting water samples from many of the buildings on the Union College campus, located in Schenectady, New York. These samples were analyzed for the heavy metal contaminants copper, lead, and zinc, as well as nine other elements. The initiative later grew to include samples from Union faculty members as well as other members from the Schenectady community, in order to gain a better understanding of what is in the local drinking water (Dolcimascolo et al., 2017). Overall, these samples from the Schenectady area generally had results below the EPA limits for lead, copper, and zinc. On campus, however, there was a case of high levels of both lead and copper in the water from a drinking fountain located in one of the fraternities, which has since been addressed as a result of these findings (Kruzshak, 2017). Since then, the initiative has expanded to include more locations and communities and, this year alone, hundreds of samples from New York City, the San Diego area, Eastern Massachusetts, and elsewhere have been collected.

Current Study

As a part of the Union College Water Initiative, this study focused on analyzing drinking water contamination and providing reports to participants, helping individuals learn of harmful heavy metal contaminants in their water that may be in violation of the Safe Drinking Water Act (SDWA). Health-based violations of the SDWA are the most severe, and they occur when systems have a problem that can directly affect human health, such as heavy metals levels that exceed EPA limits (Fedinick et al., 2019).

Nationally, the Environmental Protection Agency regulates the heavy metal contaminants lead, copper, and zinc, with limits set at 15 parts per billion (ppb) for lead, 1300 ppb for copper, and 5000 ppb for zinc (EPA, 2020A; EPA, 2020B). By testing drinking water samples for contaminants such as these, this study helped to identify potentially hazardous contamination and alert those involved so it can be addressed.

Health-based violations are not the only kinds of SDWA violations; there can also be monitoring and reporting violations, as well as public notification violations (Fedinick et al., 2019). The former occurs when systems do not regularly monitor or submit monitoring results to authorities, and the latter occurs when systems do not properly notify the public about drinking water quality (Fedinick et al., 2019). This project can help with these aspects of the SDWA as well. By providing free and accessible water analyses, this project allows individuals the resources to take matters into their own hands, rather than relying on administrative systems to properly monitor and report any issues. In addition, as studies have found that drinking water violations affect communities of color and communities of lower socioeconomic status more than other populations (Schaider et al., 2019), this project will examine the environmental justice (EJ) implications of water quality issues and their sources.

CHAPTER 2 – METHODS

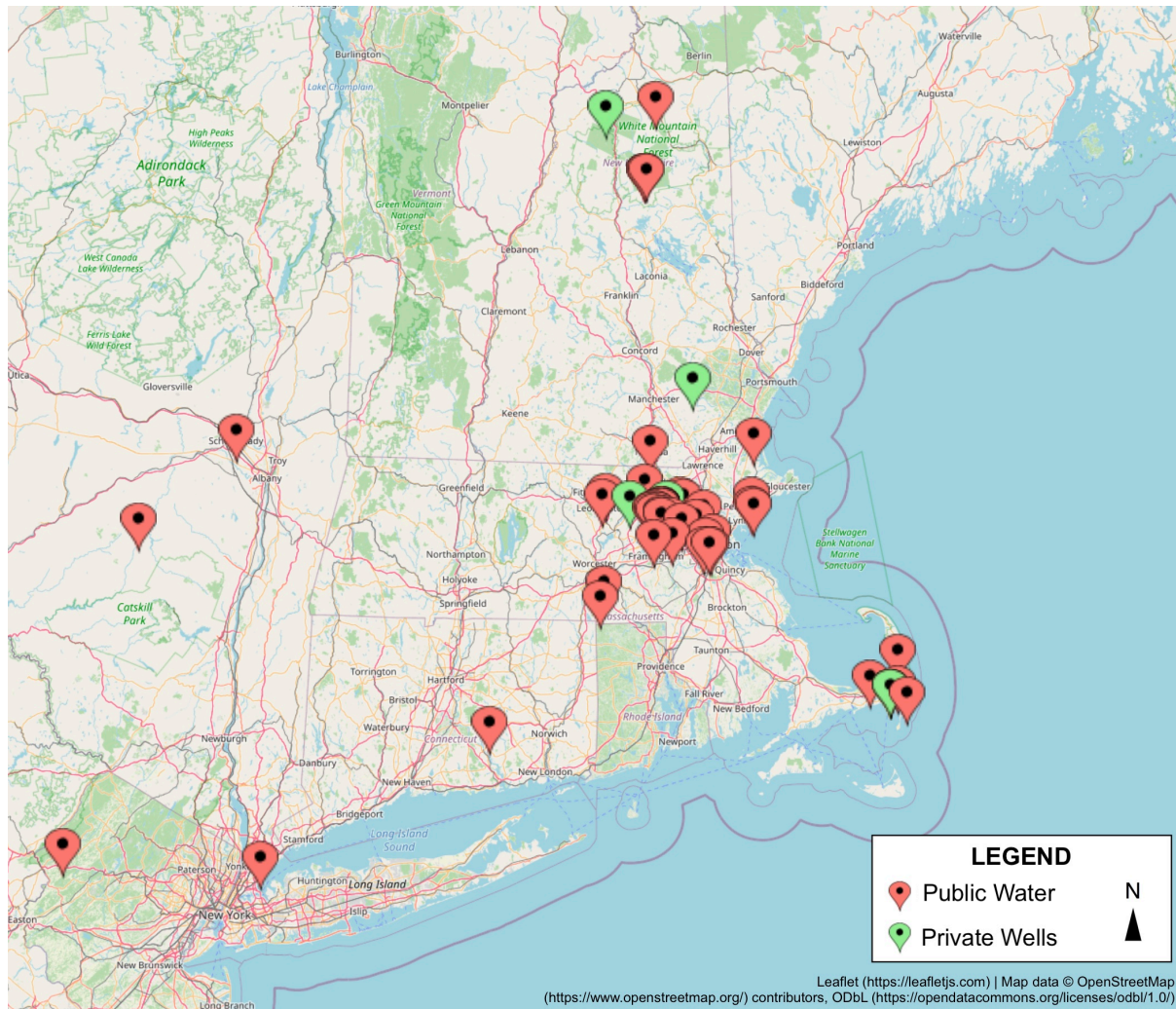


Figure 2.1: Map plotting all sample locations. Red pins indicate sample collection locations that use public water systems and green pins indicate sample locations that use private water wells.

Sample collection was focused in the Northeastern region of the United States. As seen in Figure 2.1, I collected 307 samples from thirty-five different towns and cities, twenty-five of which were located in Eastern Massachusetts (Acton, Beverly, Billerica, Boston, Brookline, Carlisle, Concord, Douglas, Groton, Leominster, Lexington, Lincoln, Marblehead, Newburyport, Somerville, Sudbury, Sutton, Watertown, Wayland, and Woburn, as well as four towns in located in Cape Cod: Harwich, Chatham, Dennis, and

Eastham). The other ten towns were located in New Hampshire (Bretton Woods, Franconia, Nashua, Raymond, and Waterville Valley), New York (New Rochelle, Schenectady, and Stamford), New Jersey (Blairstown), and Connecticut (Colchester). The samples were mostly collected from residences, but there were a few from businesses, and two public elementary schools were also tested. The samples collected include water drawn from public water supplies as well as from homes using private wells; as seen in Figure 2.1, locations using public water sources are marked in red, while locations that reportedly rely on private wells are marked in green.

People who chose to participate were given several new, 60 ml polyethylene plastic bottles in kits that had been prepared in advance and were asked to fill them with cold drinking water from any tap in their home or workplace. This typically included kitchen sinks, bathroom faucets, and filtered water dispensers in refrigerators, among others. Participants were asked to complete a form with information about the sampling location, time, and water source (e.g., kitchen tap, drinking fountain, filtered fountain, etc.). Information about the water sample type was also gathered, of which there were four different categories: “First Draw” specifies that the faucet had not been used in the past 8-18 hours, “Second Draw” specifies that the faucet had been left to run 1-2 minutes since taking the first draw, “Routine” indicates that the water source had been used regularly for some time prior to sampling, and “Unknown” indicates that the use of water source prior to sampling is not known. After collection, samples were kept in a cool and dark location until processing, to inhibit microbial activity, which might change the chemistry of the water or produce particulates that could interfere with analysis.

The next stage was analyzing the water samples for heavy metals. Analysis was conducted in the Geology Department at Union College through the use of inductively coupled plasma mass spectrometry, which is referred to as ICP-MS (Figure 2.2). The ICP-MS instrument is capable of analyzing most elements in the periodic table in any sample that can be put into an aqueous solution or ablated with a laser.

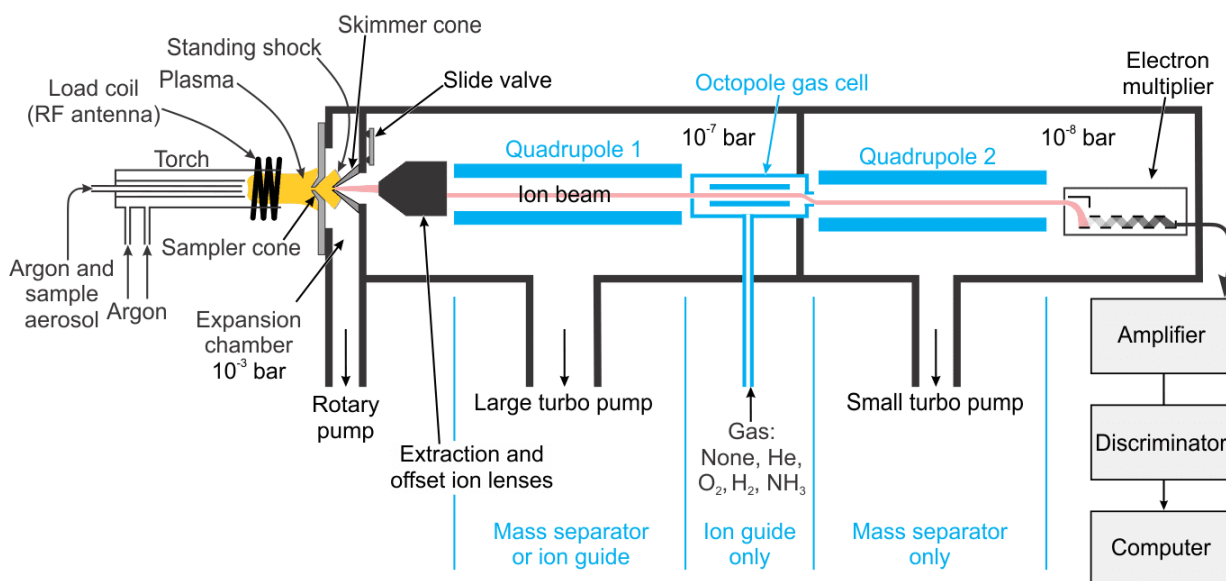


Figure 2.2: Schematic diagram of the inductively coupled plasma mass spectrometry (ICP-MS) instrument used to analyze water samples.

To prepare samples for analysis, they were weighed and sorted by contained water weight, before being acidified with high-purity HNO₃. About 14 ml of concentrated high-purity, 70% HNO₃ was added per kilogram of water in order to bring the samples to 1% acid. Samples were then transferred to autosampler tubes and standards were prepared (Table 2.1). Finally, the samples were run through the ICP-MS instrument to detect copper, lead, and zinc—the main heavy metal contaminants of concern in this project—as well as arsenic, selenium, rubidium, strontium, cadmium, antimony, barium,

bismuth, and uranium—used to aid in our understanding of what the analyses mean in terms of water and contamination sources.

Table 2.1: Standards and internal standards used for analyses, all concentrations in ppb.

	Standard concentrations				Analyzed isotope	Gas cell mode	Internal standard element	Precision*	DL**
	1	2	3	4					
Cu	100.5	50.2	20.1	10.0	65	He	Ga	1%	0.03
Zn	49.9	25.0	10.0	4.99	66	He	Ga	2%	0.07
As	10.0	5.00	2.00	1.00	75→91	O2 mass shift	Ru	1%	0.001
Se	10.0	5.01	2.01	1.00	80→96	O2 mass shift	Ru	2%	0.01
Rb	1.99	0.993	0.397	0.199	85	He	Ga	2%	0.001
Sr	299	149.4	59.8	29.9	86	He	Ga	1%	0.06
Cd	2.01	1.01	0.403	0.201	111	He	In	2%	0.0003
Sb	10.0	5.02	2.01	1.00	121→137	O2 mass shift	Ru	1%	0.0005
Ba	24.7	12.4	4.95	2.47	137	He	La	1%	0.004
Pb	49.8	24.9	10.0	4.98	206+207+208	No gas	Tl	1%	0.002
Bi	10.1	5.07	2.03	1.01	209	No gas	Tl	2%	0.000
U***	2.04	1.02	0.408	0.204	238*	No gas	Tl	1%	0.0001
Internal standard concentrations									
Ga				12.7	71	He			
Ru				39.4	99→115	O2 mass shift			
In				5.5	115	He			
La				5.0	139	He			
Tl				7.0	205	No gas			

* Typical analytical precision, standard 3 analyzed as unknowns: 2 relative standard deviations of the mean.

** Typical detection limits, blanks run as unknowns: 2 standard deviations of the mean + |average|.

***Corrected for depleted uranium 238/235 isotope ratio of 356.

CHAPTER 3 – RESULTS

EPA Regulations and Elements Analyzed

Of the twelve elements for which the samples were analyzed using inductively coupled plasma mass spectrometry, nine are monitored by the United States Environmental Protection Agency (EPA). Eight of those (lead, copper, arsenic, uranium, cadmium, antimony, selenium, and barium) have enforceable regulations, while the other element (zinc) has a non-enforceable guideline. The EPA has several different types of standards to regulate water quality, including maximum contaminant levels (MCLs), secondary maximum contaminant levels (SMCLs), maximum contaminant level goals (MCLGs), and action levels. As of 2020, the EPA's standards apply to over 100 drinking water contaminants on the basis of protecting human health and quality of life at the best level the water systems can reasonably be expected to achieve given available technology and cost (EPA, 2020A; EPA, 2020B).

A “maximum contaminant level” (MCL) is a federally enforceable drinking water quality standard set by the EPA. MCLs are a part of the National Primary Drinking Water Regulations (NPDWRs), which, as of 2020, set mandatory water quality standards for 88 drinking water contaminants (EPA, 2020A). The maximum contaminant level determines the highest allowable level of a contaminant in drinking water, based on effects on human health, while also taking into consideration the feasibility of implementing treatment given available technology and cost (EPA, 2020A). A “maximum contaminant level goal” (MCLG), on the other hand, is a non-enforceable standard set by the EPA based on human health risk only. The MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health (EPA, 2020A). In many cases, the

MCL and MCLG are the same; however, for some contaminants, such as lead, arsenic, and uranium, the MCL is higher than the MCLG (EPA, 2020A). In these cases, while any concentration of a contaminant over the maximum contaminant level goal is considered a health hazard, the EPA still allows concentrations above the MCLG level in drinking water as long as it is below the MCL. This means the concentration of a contaminant permissible in public water may be detrimental to human health. In addition, due to the Lead and Copper Rule, EPA limits for lead and copper are not called MCLs but rather are referred to as “action levels,” which only apply to the 90th percentile of the samples (Faherty, 2020). This means that, even if the EPA action level is exceeded, the Lead and Copper Rule states that no action is required unless the action levels for lead and copper are exceeded in more than 10% of samples (Faherty, 2020).

A “secondary maximum contaminant level” (SMCL) is another standard that is part of the EPA’s National Secondary Drinking Water Regulations (NSDWR). This sets noncompulsory, unenforced water quality standards for 15 contaminants (EPA, 2020B). There are three factors that may place a contaminant on the National Secondary Drinking Water Regulation list: aesthetic, cosmetic, and technical effects. Aesthetic effects are non-harmful but undesirable tastes, colors, and odors in the water (EPA, 2020B). Skin discoloration and tooth discoloration and/or pitting are both considered non-damaging cosmetic effects that may result from consuming water with certain secondary contaminants (EPA, 2020B). Technical effects of these contaminants with SMCLs may include possible reduced effectiveness of treatment for other contaminants and damage to water equipment, such as corrosion and staining related to corrosion, as well as scale formation and sedimentation, which may restrict water flow (EPA, 2020B). Aesthetic,

cosmetic, and technical effects caused by secondary contaminants over SMCLs are not considered a risk to human health; however, in addition to the undesirable nature of the water, these signs might indicate a larger problem with the quality of the water (EPA, 2020B).

In addition to the federal water quality regulations, states can have their own standards. In Massachusetts the standards are enforced by the Drinking Water Program (DWP) and are called the Massachusetts Maximum Contaminant Levels (MMCLs) (Smith, 2020). State regulations can be more stringent than those of the US-EPA, which are based on independent reviews of primary or secondary data, but in the case of the contaminants analyzed in this project, the MMCLs are the same as EPA MCLs (Smith, 2020).

Zinc, Copper, and Lead

Zinc, copper, and lead are the three heavy metal contaminants on which this study focused due to the high frequency that these contaminants appear in drinking water above EPA regulations, and our ability to analyze them. Zinc, copper, and lead contamination can all come from corrosion of household plumbing systems as well as erosion of natural deposits. I collected 307 samples from Eastern Massachusetts and surrounding areas in the summer of 2020, 285 of which were reportedly from unfiltered taps. Figures 3.1, 3.2, and 3.3 plot the distribution of zinc, copper, and lead concentrations, respectively, in these unfiltered water samples.

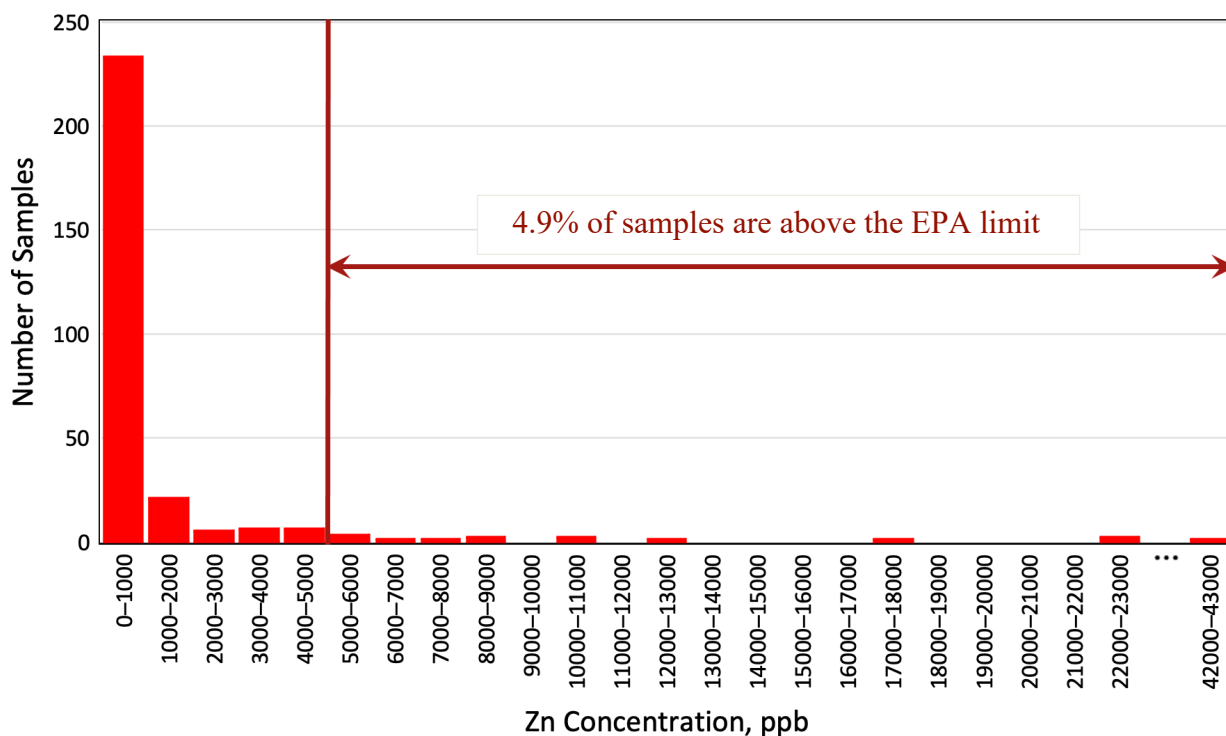


Figure 3.1: Distribution of zinc (Zn) concentrations in unfiltered samples. The arrow shows the range of samples that exceed the EPA’s secondary maximum contaminant level of 5000 ppb (5 mg/L).

Zinc has no enforceable MCL, but it does have a secondary MCL based on aesthetic and technical effects. As shown in Figure 3.1, of the 285 unfiltered water samples, approximately 4.9% had a concentration of zinc over the EPA SMCL of 5000 ppb (5 mg/L), ranging from 5,382 ppb to 42,444 ppb. A concentration of zinc above the EPA limit of 5000 ppb may give the water a metallic taste. According to the EPA, secondary limits based on aesthetic effects are set due to the undesirable nature of these effects rather than risk to human health (EPA, 2020B). Discolored or smelly water may cause people to stop using water from their public water system, even if the water is safe to drink. Furthermore, while aesthetic effects such as odor and taste are not dangerous to human health themselves, they may be a useful indicator of poor water quality (EPA,

2020B). In addition to aesthetic effects, zinc also causes undesirable technical effects such as damage to water equipment or reducing the effectiveness of a treatment for other contaminants. Zinc may increase corrosivity and staining related to corrosion. Both can affect the aesthetic quality of the water, reduce water flow, and cause damage to water pipes and plumbing (EPA, 2020B).

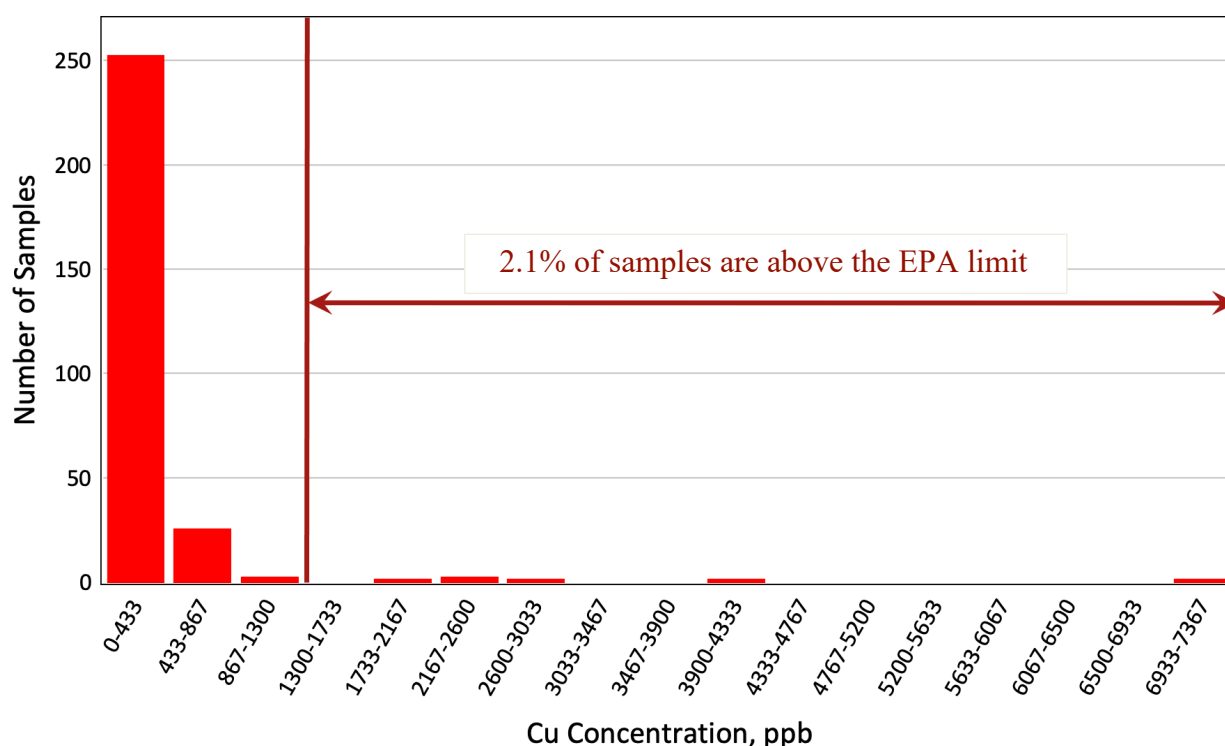


Figure 3.2: Distribution of copper (Cu) concentrations in unfiltered samples. The arrow shows the range of samples that exceed the EPA's action level of 1300 ppb (1.3 mg/L).

The EPA has two guidelines for the concentration of copper in drinking water. The primary and enforced limit, based off health effects, is the action level of 1300 ppb (1.3 mg/L). The secondary maximum contaminant level, which is not enforced, is set at 1000 ppb (1.0 mg/L) based on aesthetic and technical effects which are not considered a health risk. As illustrated in Figure 3.2, approximately 2.1% of the unfiltered samples had

a concentration of copper over the EPA action level of 1300 ppb, ranging from 2,125 ppb to 7,155 ppb. Furthermore, an additional 0.4% of samples exceeded the EPA SMCL of 1000 ppb.

Above the secondary limit of 1000 ppb, copper can alter the taste and color of water. Like zinc, copper can cause a metallic taste as well as causing blue-green staining (EPA, 2020B). Levels of copper exceeding the SMCL also may cause corrosion, which damages water pipes, reduces water flow, and causes corrosion-related staining which can impact the aesthetic quality of the water (EPA, 2020B).

Above the primary limit of 1300 ppb, copper can cause negative health effects in humans (EPA, 2020A). Short term exposure levels of copper over the EPA action level may cause gastrointestinal distress, while exposure for a longer time may cause liver or kidney damage (EPA, 2020A). In addition, both babies under one year of age and people with Wilson's Disease, an inherited disorder that causes excess copper to build up in the body, are particularly sensitive to higher levels of copper (EPA, 2020A). Despite the numerous health effects of copper contamination in drinking water, the Lead and Copper Rule only requires action be taken if concentrations over the action level are found in more than 10% of the taps sampled (Faherty, 2020). However, even this is rarely upheld due to a combination of non-compliance, underreporting, and lack of enforcement, and over 18 million Americans were served by a water system that violated the Lead and Copper Rule in 2015 (Faherty, 2020).

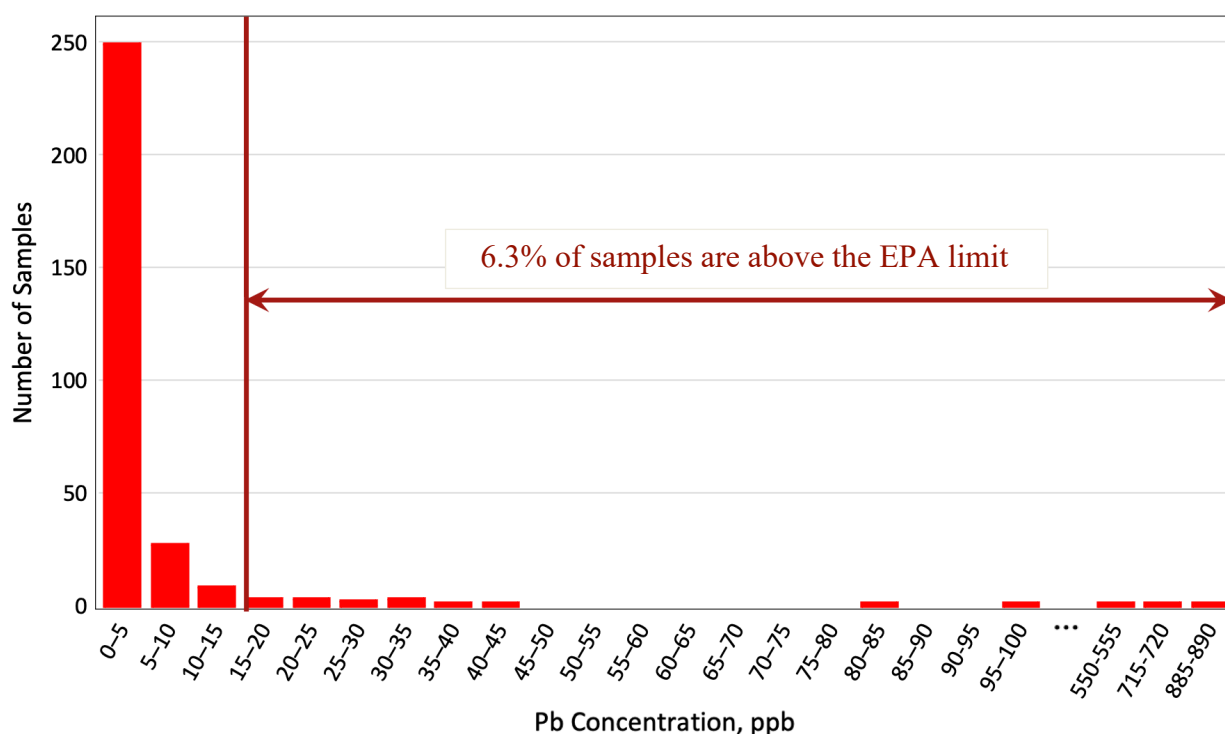


Figure 3.3: Distribution of lead (Pb) concentrations in unfiltered samples. The arrow shows the range of samples that exceed the EPA's action level of 15 ppb (0.015 mg/L).

As seen in Figure 3.3, approximately 6.3% of unfiltered samples had a concentration of lead over the EPA action level of 15 ppb (0.015 mg/L). The samples over the action level had concentrations of lead ranging from 15.9 ppb all the way up to 889 ppb which is approximately 60 times over the EPA limit. In addition to the action level, the EPA has also set a maximum contaminant level goal (MCLG) for lead at zero. Any level of lead above the MCLG is considered detrimental to human health; however, only lead concentrations that exceed the action level of 15 ppb are in violation of EPA regulations, and, due to the LCR, that is only if levels over the EPA action level are found in over 10% of samples (Faherty, 2020).

Lead is a very hazardous substance that can cause a great number of negative health effects. Exposure to very high levels of lead over a short period of time can result

in lead poisoning, anemia, weakness, stillbirths and miscarriages, kidney and brain damage, and in extreme cases death (Abadin et al., 2020). Prolonged exposure to lead causes high blood pressure, heart disease, kidney disease, and reduced fertility, and the EPA has determined that lead is a probable human carcinogen as well (Abadin et al., 2020). Lead is especially dangerous to children and infants, and they will show signs of severe lead toxicity at lower levels than adults (EPA, 2020A). Lead exposure in children causes damage to the brain and nervous system, slowed growth and development, learning and behavior problems, and hearing and speech problems (Abadin et al., 2020). Children can be exposed to unsafe levels of lead as early as development in the womb, as lead is able to cross the placental barrier; even at low levels, lead can damage a fetus's nervous system, affecting future behavior and intelligence (Abadin et al., 2020).

This is especially concerning considering that some of the highest levels of lead were discovered in samples collected from public elementary schools. Samples were collected from water fountains, classroom sinks, and bathrooms from two different elementary schools in Massachusetts, one located in Acton and one located in Leominster. Nearly 40% of all samples found to exceed the EPA action level for lead were from these schools. Of all the unfiltered samples from both schools combined, 27% were over the EPA action level of 15 ppb for lead (ranging from 19 ppb all the way up to 718 ppb), 31% were over the EPA SMCL of 5000 ppb for zinc (ranging from 5,381 ppb to 42,444 ppb), and 12% were over the EPA action level of 1300 ppb for copper (ranging from 2,125 ppb to 2,599 ppb). While both schools had significant levels of lead in their water, they had very different concentration patterns.

At the Leominster school, the levels of lead varied greatly depending on the location and sample type. A few samples had typical concentrations of lead (under 1 ppb), and a few were moderately high while still under the EPA limit (between 5-10 ppb); two samples, however, were exceptionally high (550 ppb and 718 ppb) and among some of the highest levels of lead discovered in this project. All the second draw samples, however, had more typical levels of lead (ranging from 0.3 ppb to 1.8 ppb). This may indicate that the lead problem at the Leominster school is likely due to the plumbing of the individual faucets rather than the school's main water system. The Acton school, on the other hand, had a more limited range of lead concentrations. Samples over the EPA action level of 15 ppb ranged from 19 ppb to 44 ppb and the only samples under 2.5 ppb of lead were from filtered fountains. Even the second draw samples were moderately high (between 5-10 ppb), and, surprisingly, fifty percent of the unfiltered second draw samples actually had higher levels of lead than the first draw samples. This may indicate that, at the Acton school, while the individual plumbing for the faucets likely contributed to their lead problem, the school's main water system is likely the source of the issue. This data suggests that the system that distributes water to the whole school may have lead concentrations ranging around 2-7 ppb (based on lead levels in second draw samples).

This study is a public outreach program for educational purposes only and, as we are not a certified lab, no action in response to our findings can be prescribed or followed up on beyond the extent to which the participant is willing. I did, however, learn from the participant that a new building for the public elementary school located in Acton, Massachusetts, is in the process of being built. The school is expected to move into the new building by the start of the 2022 school year and the old building will be demolished.

Other EPA Regulated Elements

In addition to lead, copper, and zinc, six of the other elements for which the samples were analyzed are also regulated by the EPA. Lead, copper, and zinc appear at levels above EPA regulations most frequently, and, in the past, the UCWI has not encountered any results near or above the EPA limit for any of the other substances.

Thus, it is noteworthy that several samples from my set had levels above EPA regulations for arsenic, uranium, cadmium, and antimony.

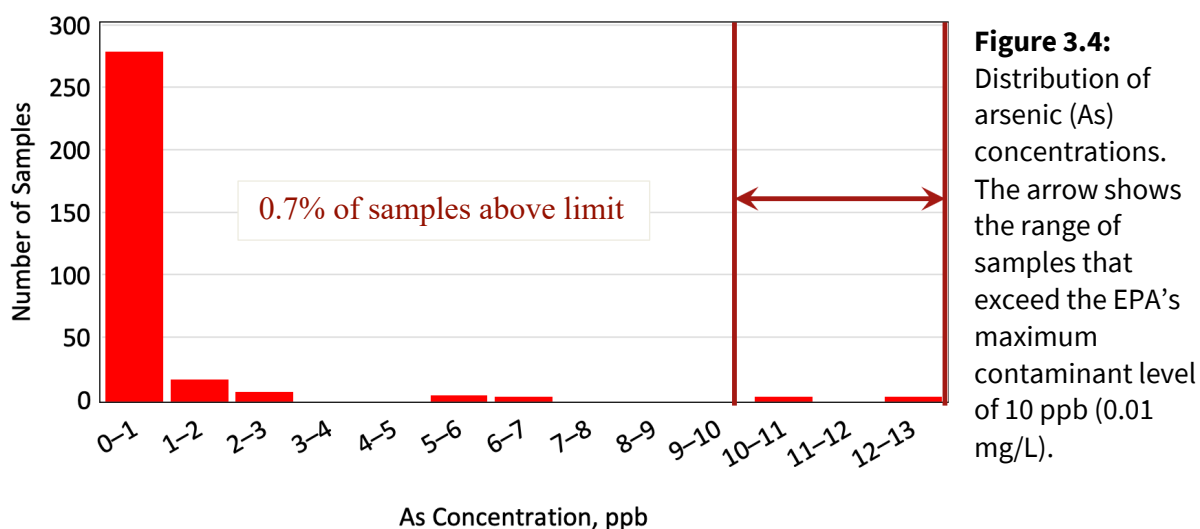
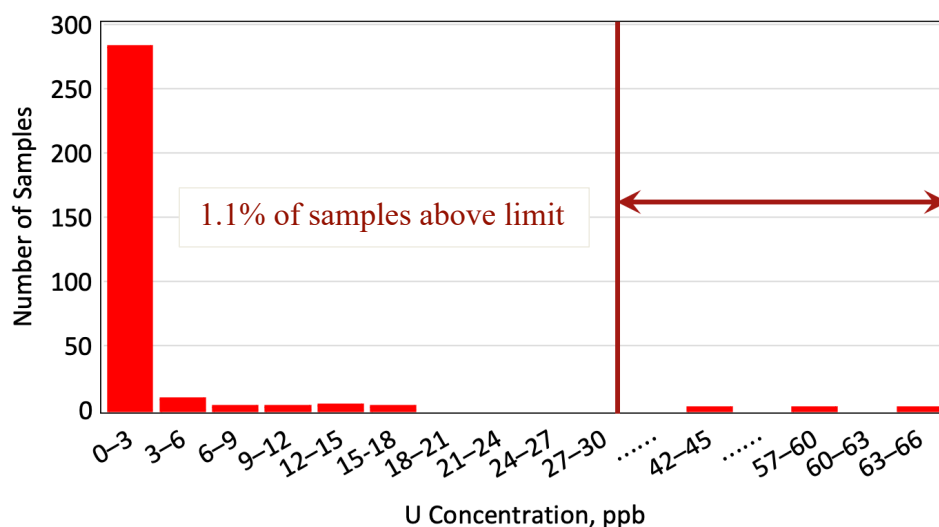


Figure 3.5: Distribution of uranium (U) concentrations. The arrow shows the range of samples that exceed the EPA's maximum contaminant level of 30 ppb (0.03 mg/L).



High concentrations of both arsenic (As) and uranium (U) were present in a number of the collected drinking water samples. As seen in Figure 3.4, arsenic was found above the EPA maximum contaminant level of 10 ppb (0.01 mg/L) in 0.7% of samples, ranging from 10.8 ppb to 12.4 ppb. This arsenic contamination can be the result of erosion of natural deposits or of human activity such as runoff from orchards and production wastes from glass and electronics (EPA, 2020A). As illustrated in Figure 3.5, uranium concentrations—which are usually the result of erosion of natural deposits (EPA, 2020A)—were found above the EPA MCL of 30 ppb (0.03 mg/L) in approximately 1.1% of the samples, ranging from 42.3 ppb to 63.3 ppb.

In addition to the maximum contaminant levels, the EPA has set maximum contaminant level goals (MCLGs) for both arsenic and uranium. In both cases, the MCLG is set at zero, meaning that any level of these contaminants puts human health at risk, but, due to available treatment and cost limitations, only concentrations over the MCL are addressed by the EPA (EPA, 2020A). Arsenic and uranium are both carcinogenic. Exposure to any concentration of arsenic is hazardous and can cause health issues such as problems with circulatory systems and skin damage, as well as an increased risk of skin, lung, bladder, and kidney cancers (EPA, 2020A). An increased risk of cancer is also caused by exposure to uranium, along with kidney toxicity (EPA, 2020A).

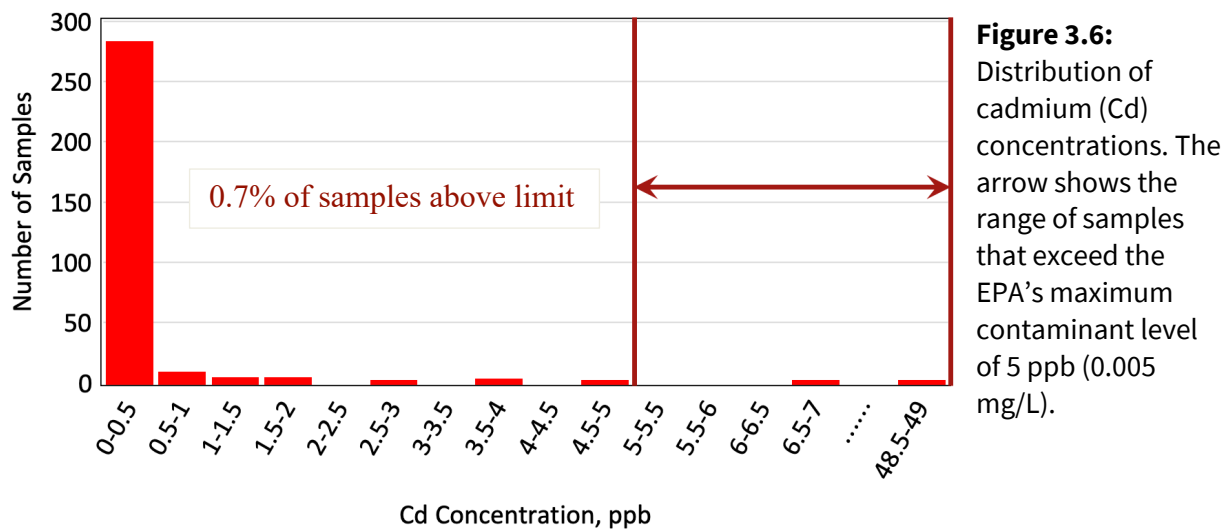
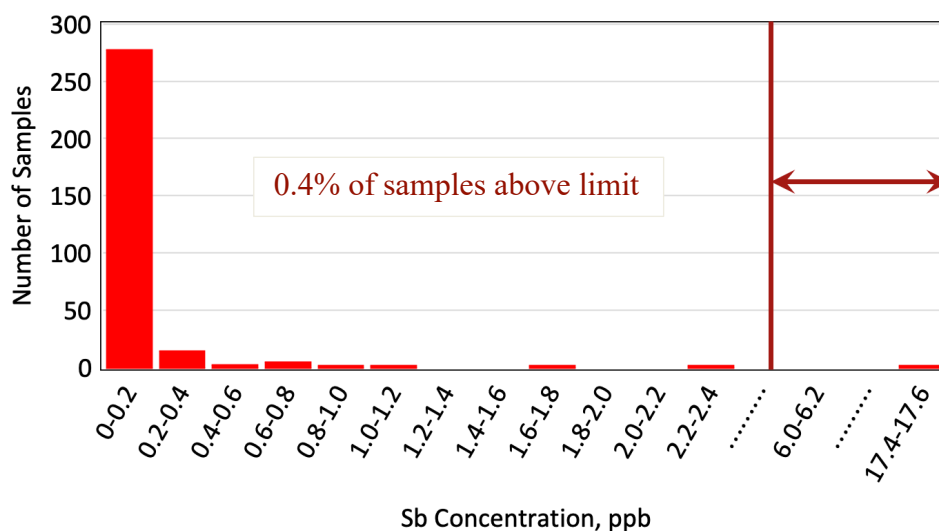


Figure 3.7: Distribution of antimony (Sb) concentrations. The arrow shows the range of samples that exceed the EPA's maximum contaminant level of 6 ppb (0.006 mg/L).



Both cadmium and antimony were found in levels exceeding EPA limits in one or two of the water samples. As shown in Figure 3.6, approximately 0.7% of the samples had a concentration of cadmium over the EPA MCL of 5 ppb, ranging from 6.6 ppb all the way up to 49 ppb. For antimony, on the other hand, only 0.4% of samples were found to have a concentration over the EPA limit of 6 ppb, ranging up to 17.6 ppb as seen in Figure 3.7. High concentrations of cadmium may result in kidney damage and can be caused by plumbing (specifically corrosion of galvanized pipes), as well as runoff from

waste batteries and paints, discharge from metal refineries, and erosion of natural deposits (EPA, 2020A). Antimony contamination of drinking water—which can cause health conditions such as a decrease in blood sugar and an increase in blood cholesterol—may be a result of discharge from petroleum refineries, ceramics, fire retardants, solder, and electronics (EPA, 2020A).

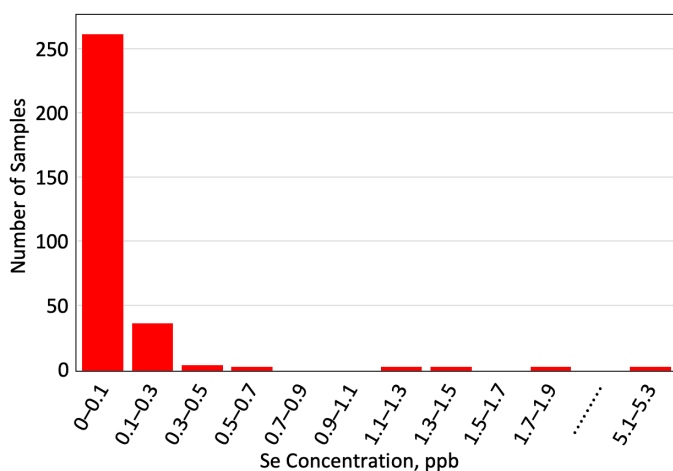


Figure 3.8: Distribution of selenium (Se) concentrations.

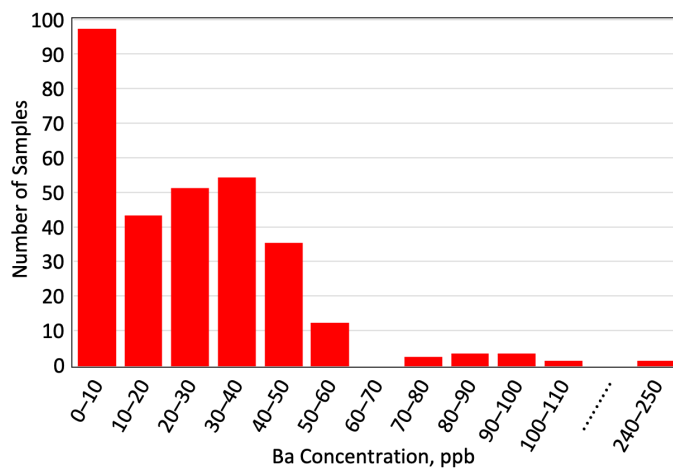


Figure 3.9: Distribution of barium (Ba) concentrations.

Selenium (Se) and barium (Ba) are both elements that are regulated by the EPA with MCLs of 50 ppb (0.05 mg/L) and 2,000 ppb (2 mg/L) respectively, but, as seen in Figures 3.8 and 3.9, no water samples were discovered to have concentrations over the EPA limits. At levels over the EPA MCL of 50 ppb, selenium can cause hair and fingernail loss, numbness in fingers and toes, and circulatory problems (EPA, 2020A). Selenium contamination in water may be caused by discharge from petroleum refineries, discharge from mines, or erosion of natural deposits (EPA, 2020A). Levels of barium in drinking water over the EPA limit of 2000 ppb can result in increased blood pressure and

can be caused by discharge from metal refineries, discharge of drilling wastes, or erosion of natural deposits (EPA, 2020A).

Unregulated Elements

Not all substances are regulated by the U.S. Environmental Protection Agency. Of the elements analyzed in the water samples using ICP-MS, three are unregulated: bismuth, rubidium, and strontium. Figure 3.10 illustrates the concentration distributions of these three unregulated elements.

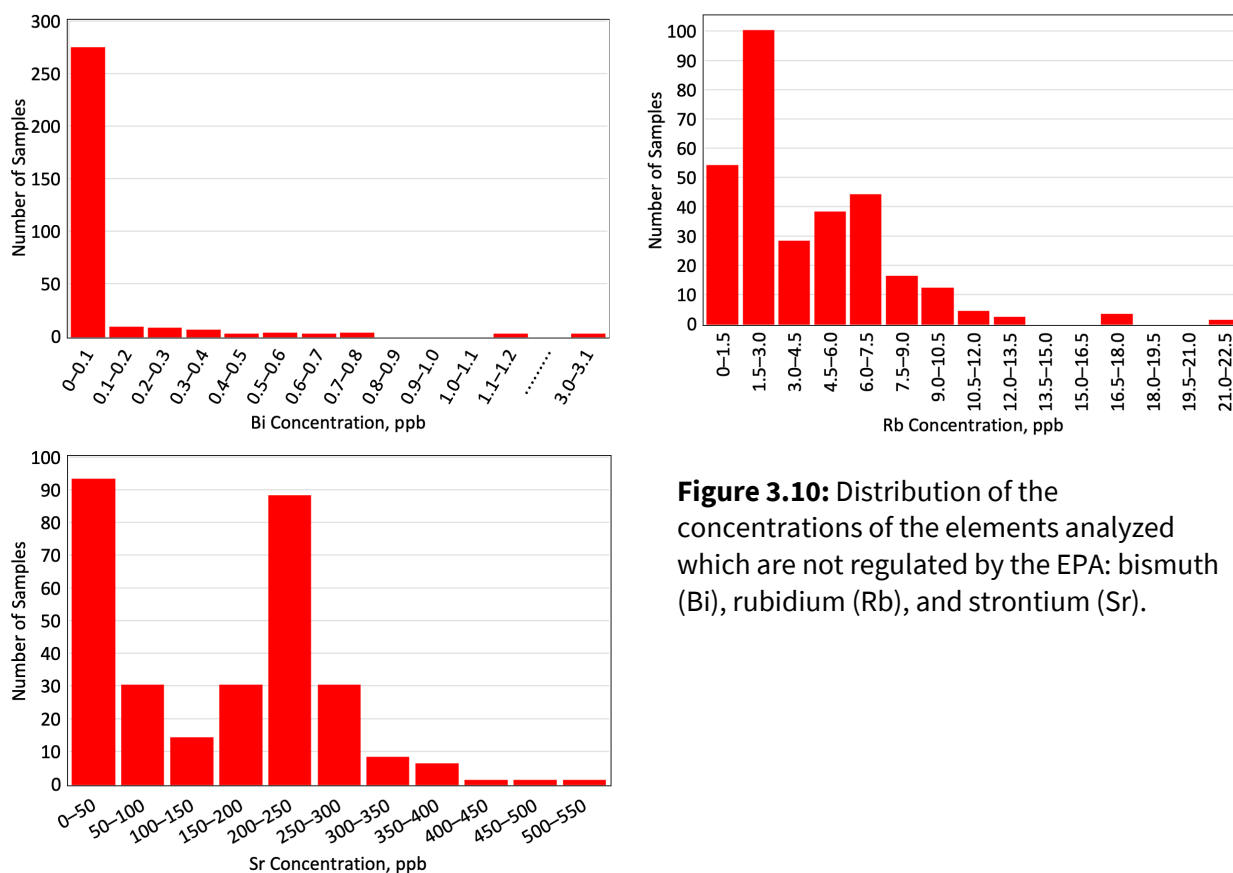


Figure 3.10: Distribution of the concentrations of the elements analyzed which are not regulated by the EPA: bismuth (Bi), rubidium (Rb), and strontium (Sr).

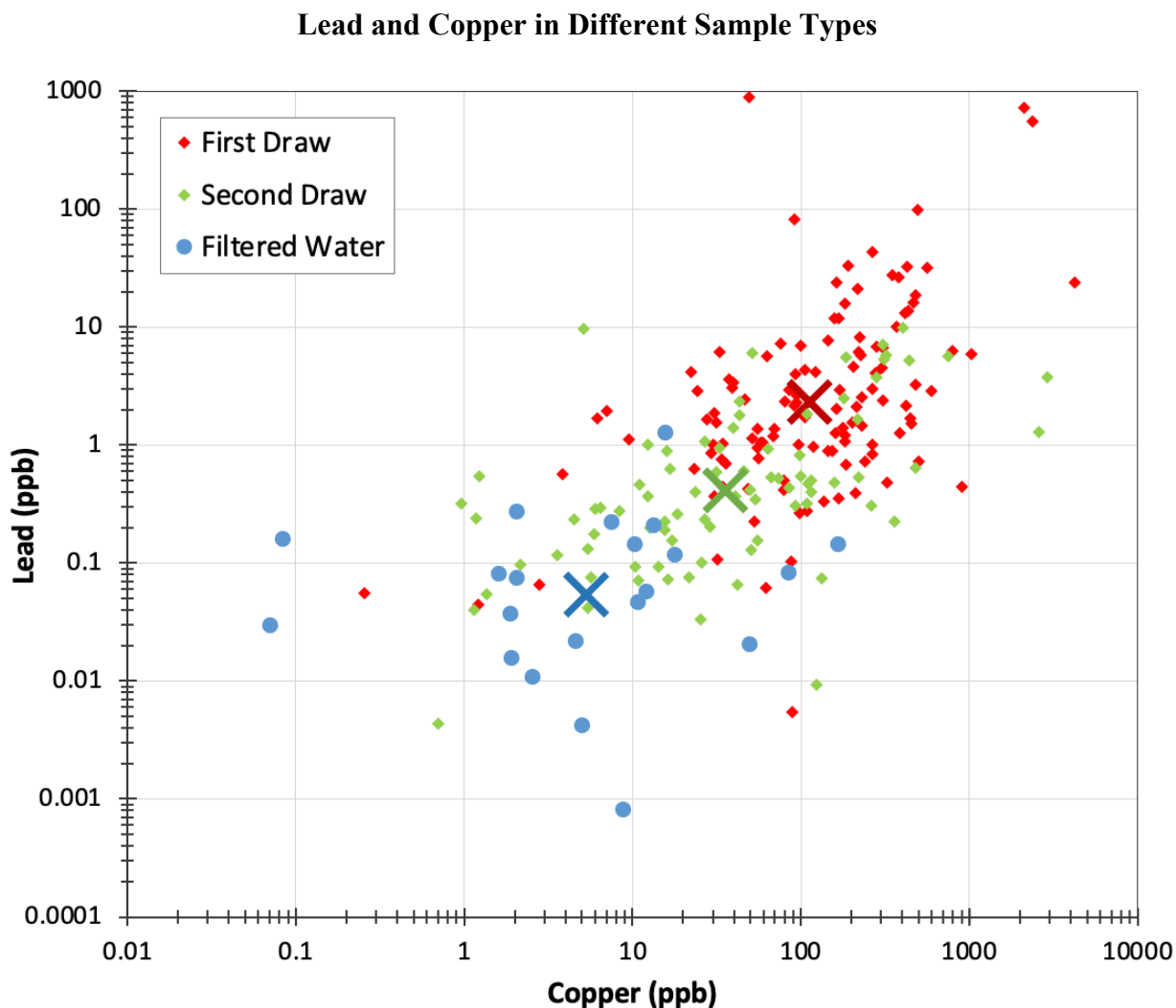


Figure 3.11: Lead (Pb) vs copper (Cu) concentrations in the different sample types: “first draw” samples (red), “second draw” samples (green), and filtered water samples (blue). The averages of each sample type are noted with an “X” in the corresponding color.

Figure 3.11 shows lead and copper concentrations of different sample types, including “first draw,” “second draw,” and “filtered water.” Some people noted that their water sample was “first draw,” which means that the sample was taken immediately after turning the tap on after it had not been used for 8 or more hours. Collecting first draw samples allows us to analyze water that has been sitting stagnant in the pipes. These first draw samples generally have the highest levels of both copper and lead overall, as seen in Figure 3.11. A “second draw” refers to a sample taken from the same faucet as a first

draw sample that has been left to run for a minute or two. Letting the water run before collecting the second draw sample allows us to compare the stagnant water from the first draw with fresher, flowing water. The graph clearly shows that, overall, the second draw samples had lower concentrations of copper and lead by about a factor of four. Though a comparatively simple solution, running the water before use appears to be a relatively effective option to improve water quality. The most effective option, however, is unsurprisingly using a working filter. As seen in Figure 3.11, we see the lowest overall concentrations of lead and copper in the samples that first passed through a filter. This water could be filtered in several different ways, such as with activated carbon, by reverse osmosis, etc. While letting the water run can help lower the concentrations of many heavy metals, using a working filter is the most reliable method to ensure water quality, reducing average lead and copper concentrations by about a factor of eight.

Private Wells

Table 3.1: Samples collected from residences with private wells, and the geologic formation on which it is located (U.S. Geological Survey, 2017).

Sample Numbers	Location	Source rock	Age
1665-1667 and 1671-1673	Harwich, Massachusetts	Granite, gneiss, and schist, undivided	Proterozoic Z
1725-1727	Carlisle, Massachusetts	Nashoba Formation	Ordovician or Proterozoic Z
1899-1900	Harvard, Massachusetts	Ayer Granite, Clinton facies	Lower Silurian
1905-1907	Raymond, New Hampshire	Massabesic Gneiss Complex	Late Proterozoic
1908-1910 and 1917-1919	Franconia, New Hampshire	Ammonoosuc Volcanics, Bimodal volcanic rocks and <i>Bethlehem Granodiorite</i>	Middle - Upper Ordovician and Early Devonian

Table 3.1 includes information on all the samples that were reported to have been collected from private wells (more samples may have been from private wells but were not noted as so by the participant). Privately owned wells are used by approximately 15% of the United States population, but the EPA regulations that protect public drinking water do not apply to these (DeSimone, 2019). States and towns may require sampling of privately owned water wells when installed, but this practice is not common, and it is even less common for states or towns to call for testing of private wells after their installation (DeSimone, 2019). All samples from private wells that were collected in this project were located in either Massachusetts or New Hampshire, neither of which have regulations on privately owned wells (MassDEP, 2021; NHDES, 2021). Thus, it is the responsibility of the homeowner to monitor the safety of their own water.

Out of the 25 unfiltered samples collected from private wells, 28% had levels of contaminants above EPA regulations. Harvard, Massachusetts—which sits on the Lower-Silurian-aged Ayer Granite, Clinton facies (Table 3.1)—was found to have high concentrations of uranium in its water. Uranium has an EPA maximum contaminant level of 30 ppb and a maximum contaminant level goal of zero. All unfiltered samples collected from private wells at this location had concentrations of uranium ranging from 9.2 ppb and up, with three samples exceeding the MCL. One such sample, collected from the kitchen sink at this location, had a uranium concentration of 57.8 ppb. Additionally, the water that was sampled directly from the private well at this location was over the EPA MCL for uranium in both the first and second draw (63.3 and 42.3 ppb respectively). The first draw sample also exceeded the EPA limit of 15 ppb for lead (27.6 ppb), and the SMCL of 5000 ppb for zinc (12,978 ppb). Overall, all unfiltered samples

taken from private wells in Harvard, Massachusetts, were found to have higher concentrations of uranium than anywhere else sampled.

High levels of heavy metal contaminants were also found in samples from private wells in Carlisle, Massachusetts and Raymond, New Hampshire. As seen in Table 3.1, Carlisle, Massachusetts sits on the Nashoba Formation, which is Ordovician or Proterozoic Z in age. A sample taken from the kitchen sink of a residence using a privately owned well had a level above the MCL of 10 ppb for arsenic (12.4 ppb). The other unfiltered sample from this location had a higher than typical level of arsenic (5.2 ppb) and a higher than typical level of barium (80.6 ppb); however, it did not exceed any EPA limits.

Nearly fifty percent of New Hampshire's population relies on private wells as their source of water (NHDES, 2021). Out of the five towns that were sampled in New Hampshire (Bretton Woods, Franconia, Nashua, Raymond, and Waterville Valley), samples from Raymond and Franconia were collected from residences using privately owned water wells. Raymond, New Hampshire, sits on the Massabesic Gneiss Complex which is Late Proterozoic in age (Table 3.1). A concentration of 6.6 ppb of cadmium was found in the first draw sample from a bathroom in Raymond, exceeding the EPA MCL of 5 ppb. This sample also had high concentrations of lead (23.7 ppb), copper (4,204 ppb), and zinc (10,509 ppb) that exceeded the EPA limits of 15 ppb, 1300 ppb, and 5000 ppb, respectively. Furthermore, copper concentrations exceeding the EPA action level were found in the other two samples from Raymond, which were taken from a regularly used kitchen sink and bathroom faucet (7,155.2 and 2,907.8 ppb of copper respectively), with a high level of lead (14.4 ppb) also found in the former.

Water Sources Analyzed by Location

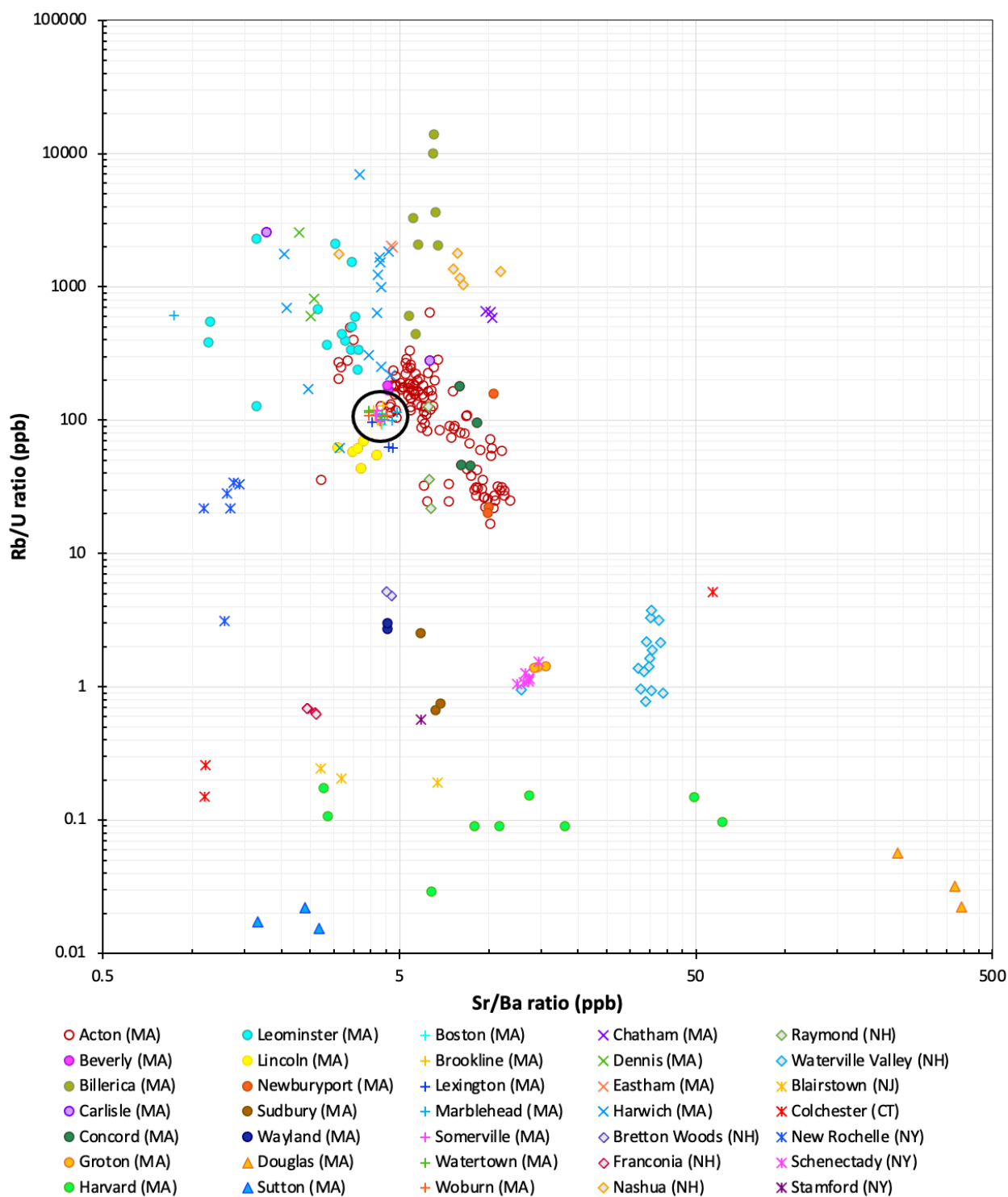


Figure 3.12: Graph plotting Rb/U ratio vs Sr/Ba ratio of all unfiltered samples by location.

*MWRA samples are circled in black.

Figure 3.12 plots the rubidium/uranium ratio against the strontium/barium ratio in order to differentiate water sources by location. Samples taken from filtered water were excluded from this graph, as filters can change relative element concentrations. The 285 unfiltered drinking water samples were collected from 35 different towns or cities in the Northeastern United States (see Figure 3.12). Twenty-five of these cities or towns are located in Massachusetts, five in New Hampshire, three in New York, one in New Jersey, and one in Connecticut. The locations of all twenty-five Massachusetts towns and cities sampled are highlighted in Figure 3.13.

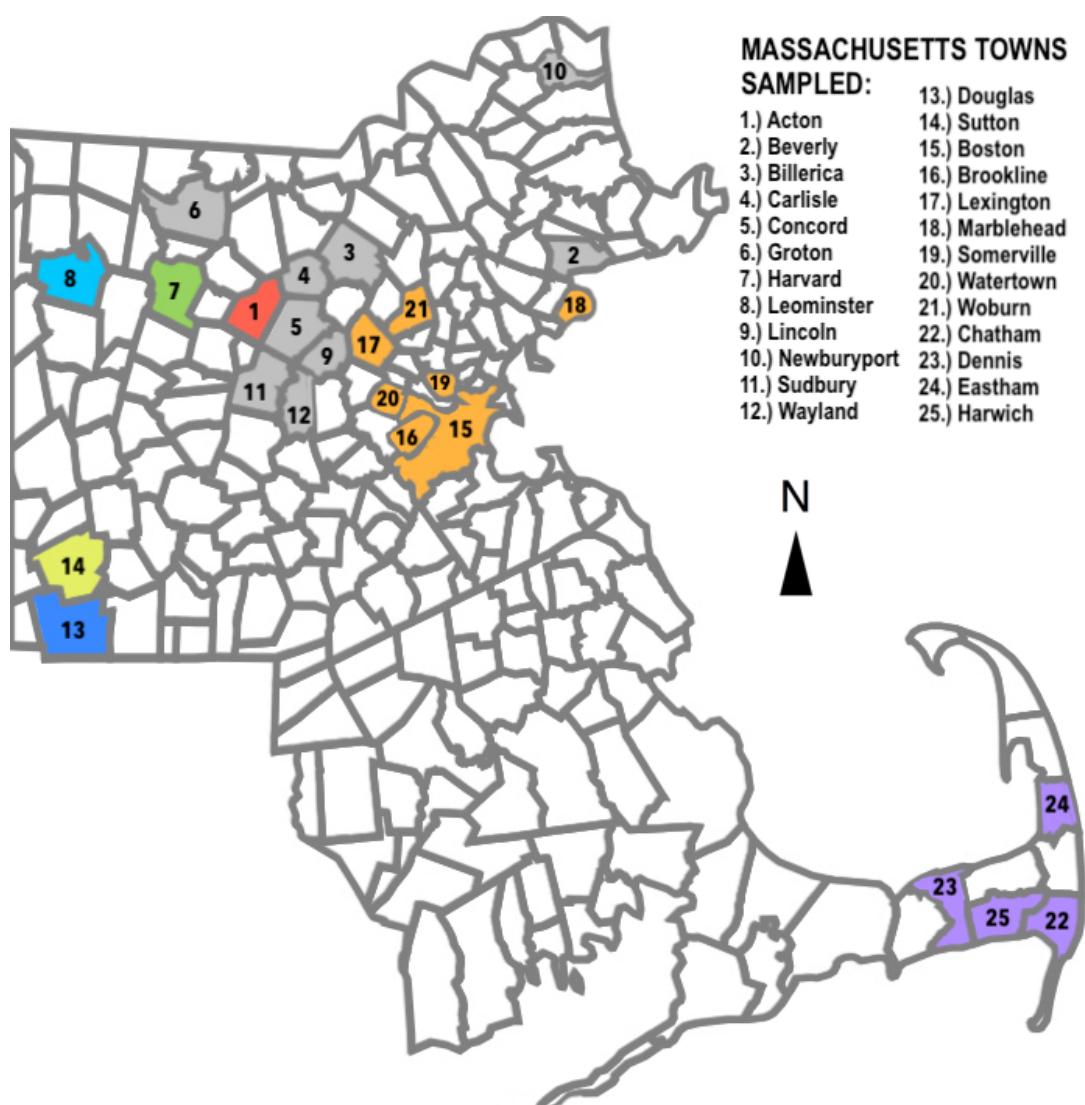


Figure 3.13: Map of all 25 towns and cities sampled in the state of Massachusetts.

Approximately 40-45% of the samples collected were from Acton, Massachusetts, which is highlighted in red in Figure 3.13. In Figure 3.12, the datapoints from Acton (marked with red circles) plot as one larger cluster above a second, smaller cluster to the lower right. The Acton Water District draws its water from an underlying aquifer through seven wellfields in five different wellfield zones (called Zone II's, Fig. 3.14), all located within the town (Allen et al., 2020). The water is processed through two different treatment plants: the South Acton Treatment Plant and the North Acton Treatment Plant, with a third one currently in the process of being built in Central Acton (Allen et al., 2020). The two operating treatment plants, collecting their water from different wellfields, may be responsible for the pattern of the two clusters of samples from Acton.

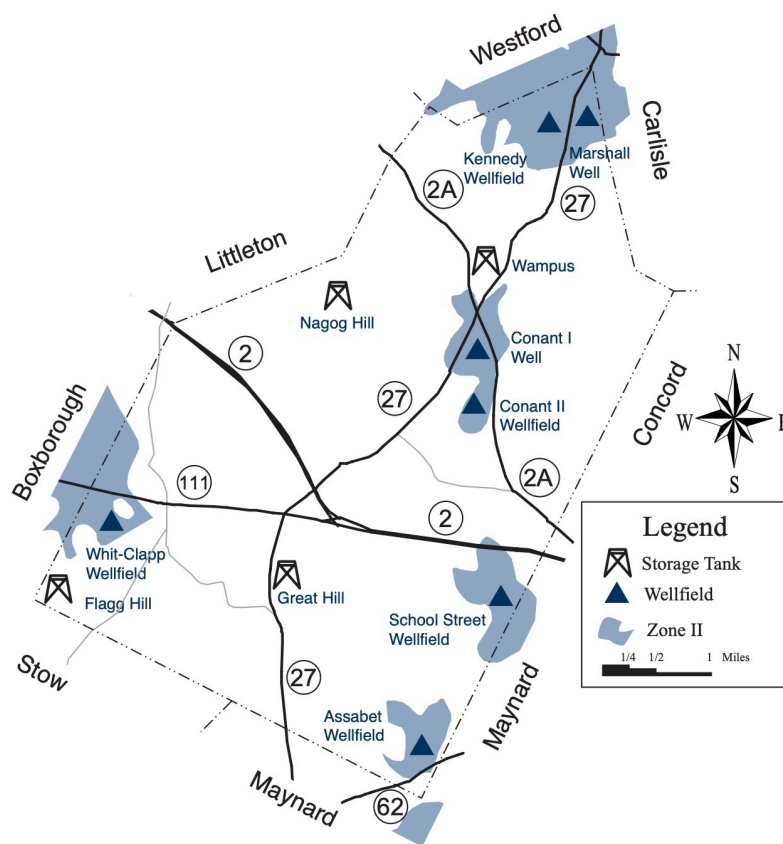


Figure 3.14: Map of the Acton Water District, showing the different wellfields, wellfield zones (called zone II's), and storage tanks (Allen et al., 2020).

All the unfiltered samples from Cape Cod, Massachusetts (purple in Figure 3.13) are marked in Figure 3.12 with an “X” symbol. The datapoints from Cape Cod are in the upper-left quadrant of the graph. The samples from Harwich are from two different types of water sources (i.e., private vs. public wells). About half of the samples from Harwich were collected from residences that used water from Harwich’s public town water, while the other half were collected from two different residences with private wells. In Figure 3.12, the public water datapoints plot at or above 1000 Rb/U while the datapoints from samples collected from private wells are below 1000 Rb/U due to lower levels of rubidium.

Samples from Boston, Brookline, Lexington, Marblehead, Somerville, Watertown, and Woburn, Massachusetts (orange in Figure 3.13), are represented with the “+” symbol in Figure 3.12. These datapoints form a very tight cluster at approximately the intersection of 100 Rb/U and 5 Sr/Ba (circled in black in Figure 3.12). This is because all these locations are part of the Massachusetts Water Resources Authority (MWRA) water system. The MWRA’s water is supplied from the Quabbin Reservoir, which is located about 105 kilometers west of Boston, as well as the Wachusett Reservoir, which is located about 55 kilometers west of Boston (Figure 3.15) (MWRA, 2021). These two reservoirs combined provide water to 2.5 million people and 5,500 industrial users, supplying approximately 200 million gallons a day to Eastern Massachusetts. According to the MWRA, the Quabbin and Wachusett Reservoirs are among the most abundant and high-quality water supplies in the world (MWRA, 2021). Samples from public water sources are expected to form clusters, but the MWRA sample cluster is an extreme example. The cluster of samples supplied by the MWRA is so small because, the larger

the source of water, the more slowly changes will occur, thus resulting in a tighter cluster. As the Quabbin Reservoir is so large—large enough to hold a five-year supply of water (MWRA, 2021)—changes are reflected especially slowly, which causes this uniquely tight cluster of MWRA samples. Figure 3.15 shows the extent of the MWRA; all cities and towns sampled in this study that rely solely on the MWRA water system are highlighted in orange. Woburn (highlighted in yellow in Figure 3.15), on the other hand, is only partially supplied by the MWRA. Nevertheless, as the data points from Woburn fall in the MWRA cluster in Figure 3.12, it is likely that the water sampled came from the MWRA system (MWRA, 2021).

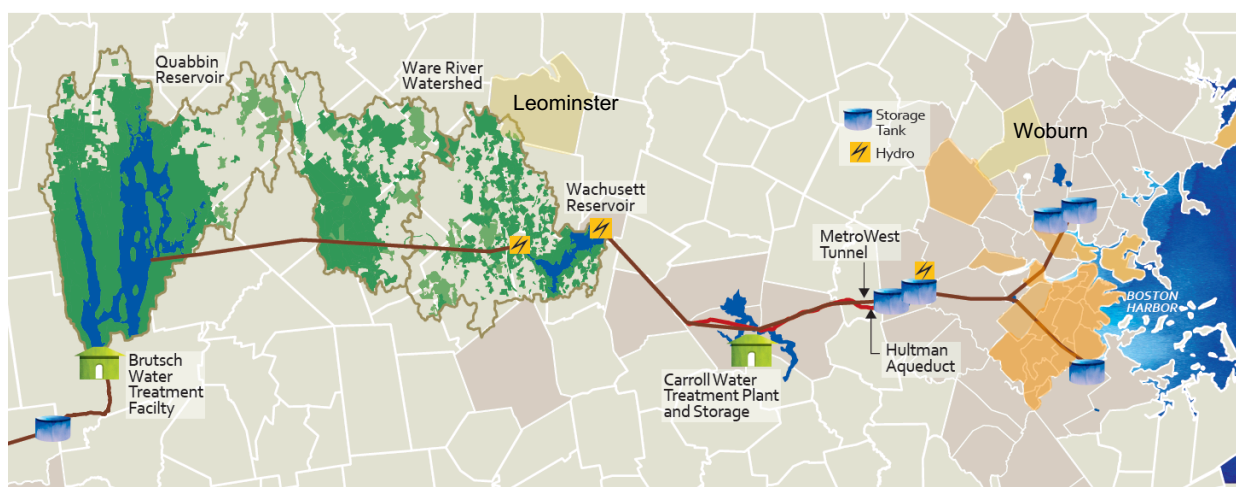


Figure 3.15: Map of the Massachusetts Water Resource Authority Water System. All towns and cities from which water samples were collected in this study are highlighted. Those highlighted in orange are fully supplied by the MWRA. Highlighted in yellow, Woburn receives part of its water from the MWRA, and Leominster receives MWRA only on an emergency basis (e.g., drought, well field pump failure) (MWRA, 2021).

The other town highlighted in yellow in Figure 3.15 is Leominster, Massachusetts (light blue in Figure 3.13). Leominster is included in the map of the MWRA system (Figure 3.15), but is not grouped with the other MWRA sample locations in Figure 3.12 because, while it is a part of the MWRA, it only uses MWRA water as backup on an emergency basis (e.g., drought, well field pump failure) (MWRA, 2021). Seen in Figure

3.12, datapoints from Leominster (marked with light blue circles) form an interesting pattern. There were two main sampling locations in Leominster: an apartment complex and an elementary school; as seen in Figure 3.12, the results from the apartment complex form a tighter cluster, while the results from the school are significantly more spread out.

Some of the outliers in the Massachusetts data plotted in Figure 3.12 are Harvard (highlighted in green in Figure 3.13), Sutton (yellow), and Douglas (dark blue). The samples from Harvard, Massachusetts, are distinct from the other areas, as illustrated in Figure 3.12. The Harvard samples plot very low on the Rb/U axis (between 0.02 and 0.2), the result of relatively high levels of uranium, and they are widely dispersed along the Sr/Ba axis (scattered between 2.5 and 100) (Figure 3.12). Geographically, Harvard is located between Acton, Groton, and Leominster (Figure 3.13), but unlike the nearby towns, samples from Harvard were from private wells drilled into aquifers above the Ayer Granite, rather than public water systems. The samples from Harvard, Massachusetts, clearly have a distinct water chemistry that differs greatly from the towns that surround it.

The towns of Sutton (highlighted in yellow in Figure 3.13) and Douglas (highlighted in dark blue), are geographically located at or near the southern Massachusetts state border. Samples from these two towns are marked with the “Δ” symbol in Figure 3.12. Each town forms a small cluster between 0.01 and 0.1 on the Rb/U axis, but they are on opposite ends of the Sr/Ba axis (Figure 3.12). Sutton samples plot between 1.5 and 3.0 on the Rb/U axis, whereas Douglas samples plot between 200 and 400 (Figure 3.12), which is interesting given their geographic proximity; the two towns are right next to each other, yet they differ considerably.

CHAPTER 4 – DISCUSSION

The Superfund Program

Superfund Sites are areas of human-influenced contamination that the U.S. Environmental Protection Agency (EPA) has deemed to be the most serious and urgent in the country. In 1980, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) was enacted into law by Congress and became known as the Superfund program (Smollin and Lubitow, 2019). This program was created to investigate and clean up environmental contamination at sites that pose a significant threat to human and ecological health. The funding for the Superfund program is based on the “polluter pays” principle, which assumes those responsible for creating the pollution should be held financially liable for cleaning it up; unfortunately, it doesn’t always work that way (Smollin and Lubitow, 2019). Hazardous waste sites become “Superfund sites” through an evaluation process called the hazardous ranking system (HRS). The HRS determines a location’s hazard level (HRS score), scored between 0 and 100, based on the “likelihood that a site has released or has the potential to release hazardous substances into the environment; characteristics of the waste (e.g., toxicity and waste quantity); and people or sensitive environments (targets) affected by the release” (EPA, 2021E). Sites that receive HRS scores of 28.50 or greater are considered for placement onto the Superfund National Priority List (NPL) (EPA, 2021E), the EPA’s official list of contaminated sites that are eligible for extensive, long-term cleanup action under the Superfund program (EPA, 2021E). As of February 2021, there have been 1,765 Superfund sites officially added to the NPL (as seen in Figure 4.1).

Superfund sites require long-term clean-up of toxic materials that can often cause dangerous contamination of the surrounding environment, including groundwater resources (Smollin and Lubitow, 2019). According to the EPA, groundwater contamination is a common issue at Superfund sites, and over 80 percent of such sites have adversely impacted the quality of nearby groundwater (EPA, 2019). The Superfund program was designed to try to mitigate such contamination; however, this cleanup process can take anywhere from years to decades, and, in some cases, the groundwater cannot be restored at all (EPA, 1996). Out of all 1,765 Superfund sites that have been so designated since the program was created 41 years ago, only 438 have been deleted from the NPL after the EPA determined that “no further response is required” (Figure 4.1) (EPA, 2021E). Sites can be deleted from the NPL if the EPA determines the criteria for any one of the following is met: if it no longer poses a significant environmental or health risk; if responsible or other parties have implemented all appropriate response action required; or if all appropriate Superfund-financed responses under CERCLA have been implemented and that no further response by responsible parties is appropriate (EPA, 2021E). It is important to note that, because only one of the above criteria must be met, sites can be deleted from the NPL and no longer receive federal assistance even if the threat to human and environmental health has not been resolved. The other 1,327 NPL sites are still classified as “active,” the majority of which have been active for decades (Figure 4.1). In addition, 48 new sites have been proposed and are awaiting further review for a final site designation (Figure 4.1) (EPA, 2021E).

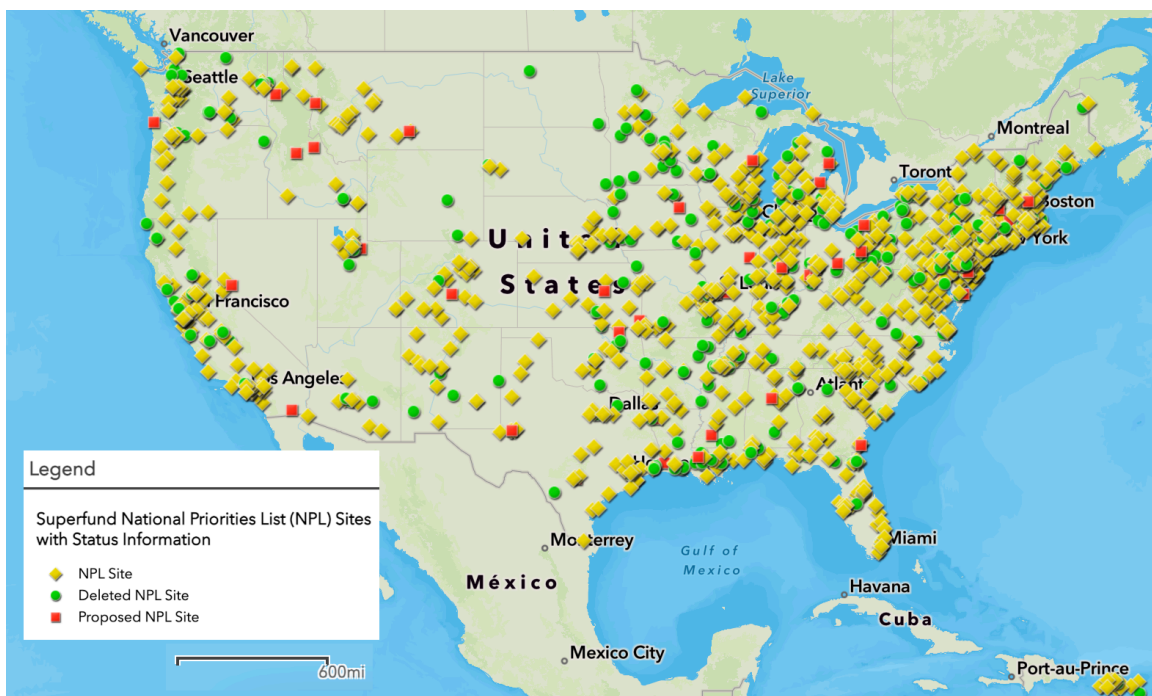


Figure 4.1: Map of all Superfund sites located in the United States. The yellow diamonds are active NPL sites, the green circles are sites that have been deleted from the NPL, and the red squares are proposed NPL sites that have not yet been added to the NPL as they are still under review (EPA, 2021E).

It is not surprising that when the hazardous materials from these sites leach into drinking water, there can be serious negative effects on the health and safety of the surrounding community (Canter and Sabatini, 1994). More than half of the most common hazardous substances found at Superfund sites are human carcinogens, and virtually all are connected to adverse kidney, liver, and/or reproductive system conditions (Smollin and Lubitow, 2019). High rates of miscarriage, genital malformations, heart disease, and even increased death rates have all been linked to Superfund contamination (Smollin and Lubitow, 2019). Research has also revealed a pattern between contaminants from Superfund sites and significantly increased health issues in children. This includes skin disorders, reduced weight, learning disabilities, attention-deficit/hyperactivity disorder, central nervous system damage, cardiac abnormalities, kidney-urinary tract infections,

seizures, leukemia, and Hodgkin's lymphoma (Smollin and Lubitow, 2019).

Unfortunately, low-income, marginalized communities often bear the brunt of these negative effects.

W.R. Grace and Nuclear Metals Superfund Sites

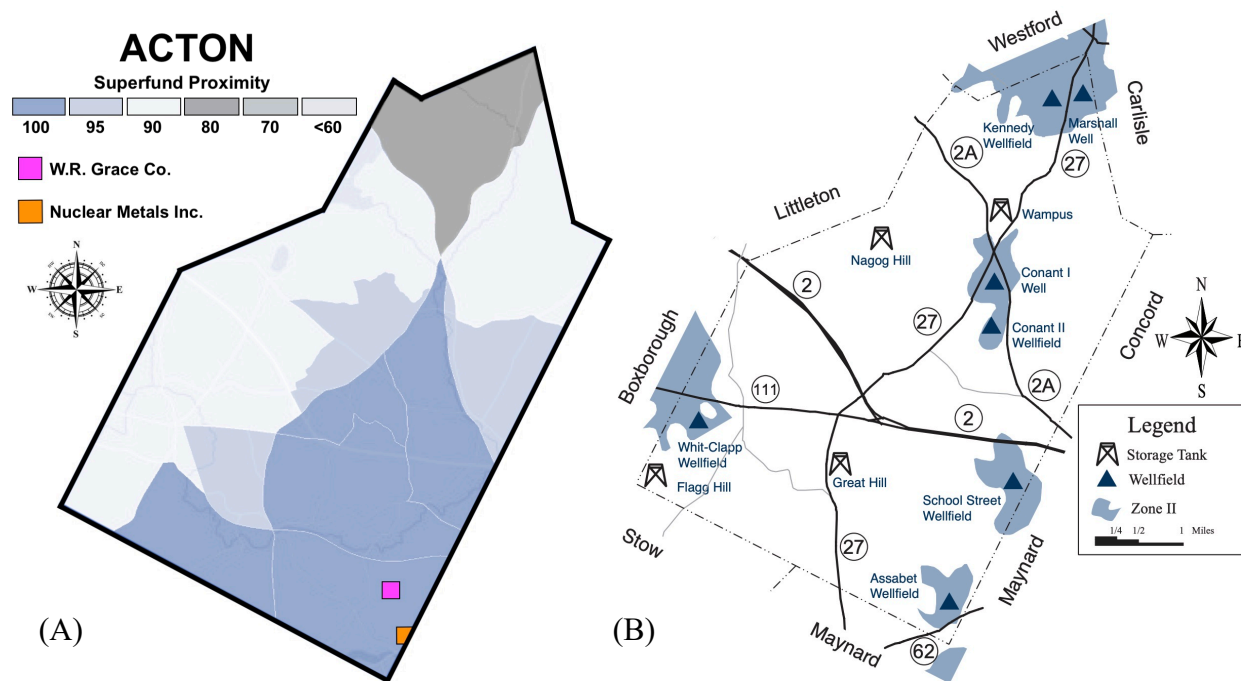


Figure 4.2: Maps of Acton, Massachusetts. (A) The two Superfund sites are located in the southeast corner of Acton (the approximate location of the W.R. Grace site is marked in blue, and the approximate location of the Nuclear Metals site is marked in green) (modified from EPA, 2021A). (B) There are seven different wellfields in five different zones that supply water to Acton, Massachusetts (retrieved from Allen et al., 2020). *The most productive of the District's sources is the "Assabet Wellfield."

There are two Superfund sites located in Acton, Massachusetts, the location of ~40-45% of the samples collected: the W.R. Grace & Co. and Nuclear Metals Inc. Superfund sites (Figure 4.2). On two separate occasions during the period of sample collection, the Acton Water District sent out a public notice to all town residents to

inform them of contamination of the public water supply (Allen, 2020; Allen and Mostoller, 2020).

In June of 2020, the first of the two notices was sent out to the residents of Acton, which included important information regarding town drinking water and the contaminants known as Per- and Polyfluoroalkyl Substances (or PFAS) (Allen, 2020). PFAS are known to be highly hazardous to human health; however, despite the potentially harmful nature of the compounds, there are no enforced regulations for PFAS set by the EPA. The EPA's non-enforceable health advisory level for PFOA and PFOS (the two most-studied PFAS compounds) is currently set at 70 ppt (parts per trillion) (Naidenko and Andrews, 2019). Not only is this guideline not enforced, but research has demonstrated that 70 ppt is far too high to be protective of human health and the environment (Naidenko and Andrews, 2019). The Massachusetts Department of Environmental Protection has a guideline of 20 ppt (Allen, 2020), yet even this has been shown to still be too high (Naidenko and Andrews, 2019). The European Food Safety Authority sets a so-called tolerable intake value that, translated to a drinking water limit, equals 6.5 ppt, and the EWG (Environmental Working Group), an independent research organization, set a health guideline of only 1 ppt, due to the reduced effectiveness of vaccines and impact on mammary gland development which result from PFAS contamination (Naidenko and Andrews, 2019).

Sampling done by the town of Acton from January 13, 2020, to April 28, 2020, showed a range of 0.0 to 48.33 ppt of the combined total of six PFAS compounds (see Table 4.1) (Allen et al., 2020). PFAS are not naturally occurring, and therefore this contamination must be the result of anthropogenic activities (Naidenko and Andrews,

2019). The notice sent to the public said that they had not identified a source of the contamination as of yet; however, it did acknowledge that the two Superfund sites that are located in Acton, MA, are linked to the presence of PFAS compounds (Allen, 2020). Given the proximity of over half of Acton's wellfields to the Superfund sites (Figure 4.2), and that PFAS are known contaminants at both Superfund sites located in Acton, we can reasonably conclude that the W.R. Grace and Nuclear Metals Superfund sites are a likely origin of the 2020 Acton water contamination.

Table 4.1: Summary of Treated Water Per- and Polyfluoroalkyl Substances (PFAS) in the Acton Water District from January to November. The locations correspond with the wellfields in the Acton Water District as shown in Figure 4.1. The North Acton WTP remains off and was sampled on September 10 and November 20, 2020, with the water not being served to customers (retrieved from Allen, 2020).

Sample Date	Sample Location				
	Clapp/ Whitcomb	Conant 1	Conant 2	North Acton WTP	South Acton WTP
January 13, 2020	--	--	--	--	20.85
March 2, 2020	--	--	--	--	21.03
March 26, 2020	--	7.72	10.84	--	--
April 2, 2020	ND	--	--	47.24	--
April 27, 2020	ND	9.89	--	--	--
April 28, 2020	--	--	7.86	40.36	--
June 2, 2020	--	--	--	--	22.5
July 10, 2020	--	17.99	25.61	--	--
July 13, 2020	ND	--	--	--	18.78
August 31, 2020	--	22.6	26.4	--	19.4
September 10, 2020	--	--	--	14.04	--
October 26, 2020	ND	--	--	--	--
November 2, 2020	--	25.7	--	--	18.08
November 18, 2020	--	--	25.13	--	--
November 30, 2020	--	--	--	16.33	--

*WTP = Water Treatment Plant. Units are in parts per trillion (ppt) or ng/L.

**ND = below method detection limit.

***Results provided are the sum of 6 PFAS Compounds: PFOA, PFOS, PFNA, PFHxS, PFHpA, and PFDA.

****Samples exceeding the Massachusetts Department of Environmental Protection Guideline of 20 ppt (ng/L) are in bold.

On August 3rd of 2020 the Acton Water District released a second public notice, this time informing the public that arsenic had been detected above the EPA Drinking Water Standard (10 ppb) (Allen and Mostoller, 2020). Arsenic is one of the twelve elements for which my samples were analyzed using ICP-MS. The notification of possible arsenic contamination may explain some of the higher-than-typical results for arsenic detected in my samples (seen in Figure 3.4). This public notice did not identify a source of the spread, only noting that arsenic is a naturally occurring contaminant in some regions and it also may be a by-product of some agricultural and industrial activities (Allen and Mostoller, 2020). It is reasonable to hypothesize, however, that the contamination came from one or both of the nearby Superfund sites. Arsenic is a known contaminant at both the W.R. Grace and Nuclear Metals Superfund sites: according to the EPA's list of contaminants provided for each Superfund site (Table 4.2), arsenic contaminated the groundwater and soil at Nuclear Metals (EPA, 2021C) and the groundwater, soil, and sediment at W.R. Grace (EPA, 2021G). In addition, more than half of Acton's wellfields are located in areas of close proximity to the Superfund sites (Figure 4.2). One of which, the Assabet Wellfield, is the most productive of the District's sources. The Assabet Wellfield can deliver 700 gallons of water per minute and is located in the southern corner of Acton, right between the W.R. Grace and the Nuclear Metals Superfund sites (Figure 4.2). Given the proximity of Acton's wellfields and presence of arsenic at these sites, as well as the likelihood that the PFAS contamination stemmed from these sites, it is probable that these Superfund sites caused the 2020 arsenic contamination of Acton's water supply.

Table 4.2: Contaminants at W.R Grace and Nuclear Metals Superfund sites (retrieved from EPA, 2021C; EPA, 2021G).

W.R. Grace Co.		Nuclear Metals Inc.	
Contaminant Name	Contaminated Media	Contaminant Name	Contaminated Media
ANTIMONY	Groundwater	ARSENIC	Groundwater
ARSENIC	Groundwater	ARSENIC	Soil
ARSENIC	Sediment	BARIUM	Groundwater
ARSENIC	Soil	COPPER	Groundwater
CADMIUM	Groundwater	COPPER	Sediment
CADMIUM	Soil	LEAD	Sediment
COPPER	Groundwater	URANIUM	Groundwater
LEAD	Groundwater	URANIUM	Soil
ZINC	Groundwater		

*This table only lists the contaminants that were sampled in this study.

**W.R. Grace has 36 other contaminants recorded by the EPA that are not listed here.

***Nuclear Metals has 26 other contaminants recorded by the EPA that are not listed here.

Environmental Justice Implications of Superfund Proximity

A clean environment is something that is easily taken for granted, but it is not guaranteed to everyone. This section will look at the relationships between environmental issues, quality of life, and the socio-economic and racial makeup of communities. Low-income communities, people of color, and indigenous peoples have extensively suffered higher rates of the adverse effects associated with exposure to environmental toxins. In 1982, a protest over a hazardous PCB landfill in a small, predominately Black community in Warren County, North Carolina, led to the formation of the Environmental Justice Movement (Bullard, 2001). Environmental justice is defined as the “fair treatment and meaningful involvement of all people regardless of race, color, national origin, or

income with respect to the development, implementation and enforcement of environmental laws, regulations and policies” (Smollin and Lubitow, 2019). This means that no population should bear a disproportionate share of negative environmental consequences. The Environmental Justice Movement works to address environmental injustice, which refers to the unequal burdens experienced by communities of color, low-income, and indigenous populations in regard to environmental, health, housing, energy, transportation, land-use, and civil rights laws and regulations (Bullard et al., 2007). Under the umbrella of environmental injustice falls environmental racism, which describes the disproportionate impact of pollution specifically on communities of color, the racial biases in government regulations, and the lack of attention to racial issues in established environmental advocacy organizations (Smollin and Lubitow, 2019). While the Flint water crisis is one of the best-known examples of social and environmental injustice related to drinking water quality and safety in the recent past in the U.S. (Campbell et al., 2016), problems like this are not limited to Flint, Michigan. Issues of environmental justice are seen all across the nation and the world.

Superfund sites are common locations of environmental injustice. Superfund sites pose a high risk to human health, yet nearly fifty percent of the U.S. population reside within a ten-mile radius of at least one Superfund site—a disproportionate percentage of whom belong to historically marginalized communities (Smollin and Lubitow, 2019). According to the prominent 1987 study by the UCC Commission for Racial Justice, “Toxic Wastes and Race in the United States,” the population of people belonging to marginalized groups was three times higher in communities with two or more active hazardous waste sites or major landfills than in communities without such facilities.

Discriminatory laws and policies have placed environmental hazards directly in the path of Black and Brown communities; approximately seventy percent of Superfund sites are found within a mile of federally assisted housing, which is located disproportionately in low-income communities of color (Coffey et al., 2020).

A higher frequency of superfund sites end up in historically marginalized communities both directly and indirectly, from intentionally selecting communities of color for waste-disposal sites and polluting industrial facilities, to lowering penalties for polluting in those areas, consequently condemning their residents to contamination. Fines and regulations tend to vary from place to place, often being the lowest in areas of low-income and marginalized communities. According to a widely acclaimed study by Marianne Lavelle and Marcia Coyle, the average fine in the areas with the greatest population of marginalized groups was approximately 1/5 that in areas with the greatest white population (Lavelle and Coyle, 1992). Polluting industries are driven to communities of color because the penalties for polluting there are so low that they can simply be dismissed as a cost of doing business (Bullard et al., 2007). Facilities will build those fines into their budget because it is cheaper to pay the fine than it is to implement strategies that would prevent the violation in the first place, suggesting how little value these companies place on the lives of people of color (Bullard et al., 2007). The almost complete lack of retribution and consequences allows companies in marginalized communities to operate with impunity, generating numerous hazardous waste sites as a result.

Despite the fact hazardous waste sites are more likely to be found in low-income areas and communities of color, these communities are not as likely to receive the

advantages of Superfund program funding as their white counterparts are. The Superfund program is both disproportionately ineffective and discriminatorily implemented (Coffey et al., 2020). Sites in areas with large populations of historically marginalized peoples are more often given lower hazardous ranking scores, are less likely to be added to the National Priority List, and the process for a site in a marginalized community to be added to the NPL takes about twenty percent longer than it does for those located in white communities (Lavelle and Coyle, 1992). Those that *are* listed on the NPL, typically are cleaned up with lower frequency and urgency than those in wealthier, white communities (Smollin and Lubitow, 2019). According to Marianne Lavelle and Marcia Coyle, communities of color have to wait about four years longer than white communities to get a Superfund site cleaned up (Lavelle and Coyle, 1992). The tactics implemented to clean up these sites also differ. Permanent treatment of Superfund site contamination is undoubtedly preferable to simply containing it. However, containment technologies were selected more frequently than permanent treatment by an average of seven percent in communities of color. Conversely, sites located in white communities received permanent treatment twenty-two percent more frequently than containment technologies (Lavelle and Coyle, 1992). This demonstrates that, not only are people of color more frequently exposed to hazardous waste pollution, but they can also expect discriminatory treatment from federal institutions in response to said hazard.

As marginalized communities tend to live in closer proximity to Superfund sites, they are more vulnerable to the negative impacts on both human health and quality of life resulting from Superfund site pollution (Banzhaf et al., 2019). The implications of this are immense. The direct health and environmental impacts from hazardous waste sites are

bad enough, but they also exasperate other crises such as the COVID-19 pandemic and climate change, among countless others. Contaminants from Superfund sites cause many medical conditions that can put an individual at higher risk for COVID-19 complications, resulting in Black and Brown communities having significantly higher rates of COVID-19 infection and death (Coffey et al., 2020). Another major cause for concern is the societal implications of Superfund sites' effect on the cognitive health of children. Exposure to some contaminants from Superfund sites, such as lead, have been shown to substantially impact students' academic performance. Thus, this increases the disparity between the academic outcomes of disadvantaged students and other students and contributes to perpetuating the cycle of poverty and oppression (Banzhaf et al., 2019). Unfortunately, many residents are not even informed of the health risks in their communities, let alone have the means or opportunity to move to escape them (Bullard, 2001).

EJSCREEN Mapping and Screening Tool

In response to the growing Environmental Justice Movement, in 2015 the EPA created a free online program called EJSCREEN that uses nationally consistent data to map and screen environmental justice-related variables in the United States (EPA, 2021A). Through the use of maps and reports, EJSCREEN is able to display three different kinds of information: environmental indicators, demographic indicators, and Environmental Justice Indexes (EJ Indexes) (EPA, 2021A). An EJ Index summarizes how environmental indicators and demographics come together in the same location (EPA, 2021A). The screening tool includes eleven environmental factors and six

demographic factors to calculate a variety of EJ indexes, including the proximity to National Priorities List Superfund sites (Table 4.3) (EPA, 2021A).

Table 4.3: Demographic and Environmental indicators used in Environmental Justice Index analysis (EPA, 2021A).

Demographic Indicators	Environmental Indicators
Percent low-income	NATA air toxics cancer risk
Percent People of Color	NATA respiratory hazard index
Less than high school education	NATA diesel PM (DPM)
Linguistic isolation	Particulate matter (PM2.5)
Individuals under the age of 5	Ozone
Individuals over the age of 64	Traffic proximity and volume
--	Lead paint indicator
--	Proximity to Risk Management Plan (RMP) sites
--	Proximity to Hazardous Waste Facilities
--	Proximity to National Priorities List (NPL) sites
--	Wastewater Discharge Indicator (Stream Proximity and Toxic Concentration)

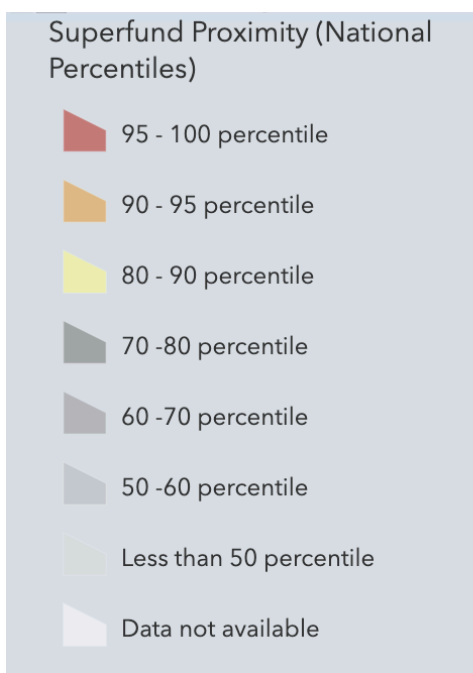
*NATA = National-Scale Air Toxics Assessment

This study utilizes the EPA’s EJSCREEN program to assess the Environmental Justice Index for Superfund proximity in various regions. For each environmental factor, the EJ Index color codes the areas that contribute the most toward the nationwide disparity in that environmental factor, which, in this case, is Superfund site proximity (EPA, 2021A). “Disparity” in this case means the difference between the environmental indicator’s average value among these demographic groups and the average in the U.S. population. The EJ Index for Superfund proximity is estimated using the environmental indicator, population, and demographic indexes (EPA, 2021A). A Demographic Index is based on the average of two demographic indicators: percent low-income and percent minority (EPA, 2021A). EJ Index is calculated by multiplying the environmental

indicator (in this case Superfund proximity) by the population for the given “block groups” (a geographic area defined by the Census Bureau that usually has 600-3,000 people living in it) (EPA, 2021A). This is then multiplied by the difference between the Demographic Index for the given block group and the Demographic Index for the whole United States, as shown in the equation below (EPA, 2021A).

$$EJ\ Index = \left(\frac{Environmental\ Indicator}{Pop\ count\ for\ Block\ Group} \right) * \left(\frac{Demographic\ Index\ for\ Block\ Group}{Demographic\ Index\ for\ U.S.} - 1 \right)$$

On EJSCREEN maps, the EJ Index results in areas which are color-coded based on their national percentile, shown in Figure 4.3 (EPA, 2021A). The national percentile shows what “percent of the U.S. population has an equal or lower value,” in order to assess how local residents compare to everyone else in the United States (EPA, 2021A). Based on



these calculations, areas that fall in the highest percentile of 95-100 (highlighted in red) experience the greatest amount of environmental injustice stemming from the proximity of Superfund sites (EPA, 2021A).

Figure 4.3: National percentiles for Superfund proximity with the corresponding colors. All EJSCREEN figures in this study (Figures 4.5, 4.6, 4.7, and 4.8) correspond to this legend (EPA, 2021A).

Essex County, New Jersey: An Example of Environmental Injustice

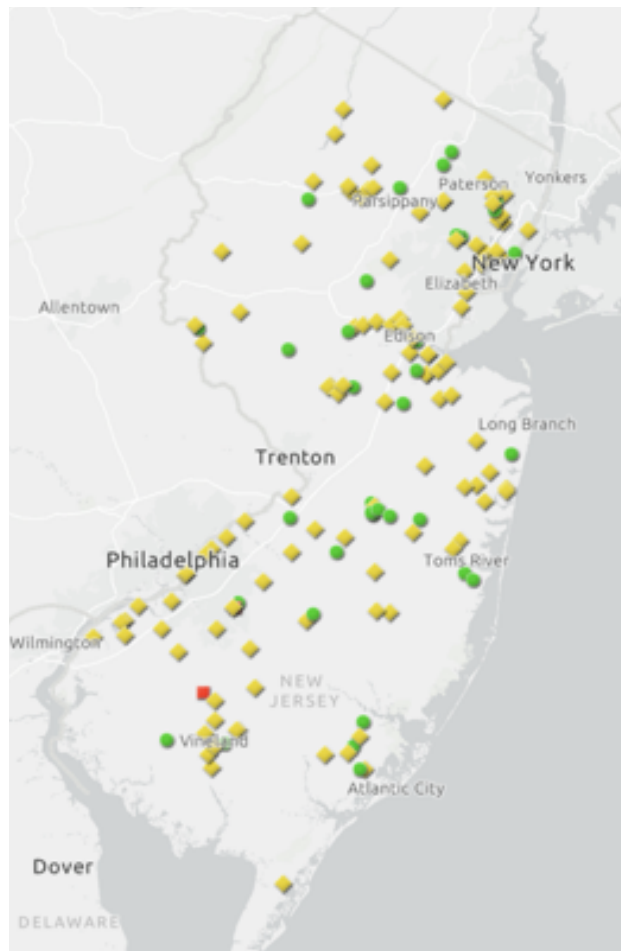


Figure 4.4: Map of all the Superfund sites located in New Jersey. The yellow diamonds are currently active National Priorities List sites (NPL sites), the green circles are sites that have been deleted from the NPL, and the red squares are proposed NPL sites that have not been added to the NPL yet as they are still under review.

Legend

Superfund National Priorities List (NPL) Sites with Status Information

- ◆ NPL Site
- Deleted NPL Site
- Proposed NPL Site

An intersectional look at inequality in America will reveal that environmental injustice stemming from Superfund sites is occurring frequently across the country. One poignant example is the current experience of the community in Essex County, New Jersey. As seen in Figure 4.4, New Jersey has 115 Superfund sites currently listed as “Active” on the National Priority List, more than any other state in the United States (EPA, 2021E). New Jersey accounts for approximately 2% of the U.S. population and only 0.2% of the land area of the country (World Population Review, 2021), yet it makes up ~8.7% of the nation’s 1,327 active Superfund sites (EPA, 2021E).

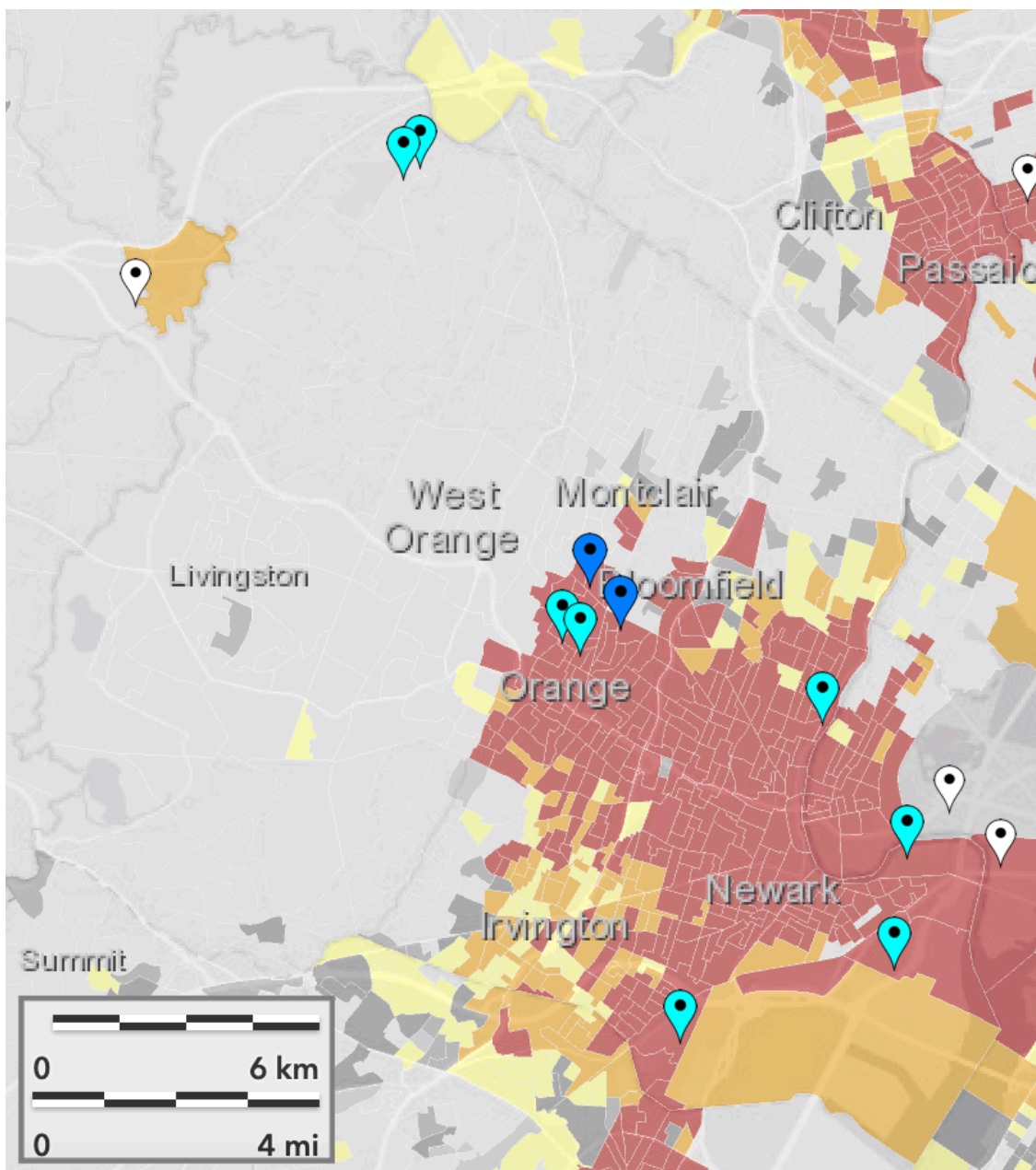


Figure 4.5: Map of Environmental Justice Index (EJ Index) for Superfund proximity in Essex County, New Jersey (corresponding to the national percentiles in Figure 4.3). NPL Superfund sites are marked: the light blue pins mark current active NPL sites located in Essex County, the dark blue pins mark sites that have been deleted from the NPL, and the white pins mark active Superfund sites located outside the borders of Essex County (EPA, 2021A).

As seen in Figure 4.5, a large portion of Essex County is a hot spot of Superfund-related environmental racism. This is unsurprising, as Essex County is home to New Jersey's largest city, Newark (World Population Review, 2021), and, because industry

and waste tend to follow people, Superfund sites often are more concentrated in highly populated areas. Critically, however, Newark is also a majority Black city. According to the 2019 U.S. Census, Newark's population is 11% White (not Hispanic or Latinx), while approximately 50% of its population is Black (see Table 4.4). Given the large percentage of people of color in this area, the high number of hazardous waste sites seems unlikely to be attributable to city population alone, but rather is a clear example of Superfund related environmental racism, as shown in Figure 4.5. Due to race and income, residents of Newark, New Jersey, have been subjected to a disproportionate amount of environmental harm stemming from toxic waste sites.

Table 4.4: Racial and economic demographics for Newark City, the City of Orange township, Essex County, and New Jersey as a whole (modified from United States Census Bureau, 2019).

	Newark City	City of Orange	Essex County	New Jersey
<i>Population estimates (July 1, 2019)</i>	282,011	30,551	798,975	8,882,190
Race and Hispanic Origin				
White	28.6%	13.5%	48.9%	71.9%
Black or African American	50.1%	69.7%	41.9%	15.1%
American Indian and Alaska Native	0.3%	0.0%	0.8%	0.6%
Asian	1.9%	1.7%	5.9%	10.0%
Native Hawaiian and Other Pacific Islander	0.0%	0.0%	0.1%	0.1%
Two or More Races	2.4%	1.5%	2.4%	2.3%
Hispanic or Latino	36.3%	25.0%	23.8%	20.9%
White, not Hispanic or Latino	11.0%	2.9%	30.2%	54.6%
Income & Poverty				
Median household income (2015-2019)	\$35,199	\$42,966	\$61,510	\$82,545
Per capita income in past 12 months (2015-2019)	\$20,163	\$22,745	\$38,722	\$42,745
Persons in poverty	27.4%	21.4%	13.8%	9.2%

*Newark City and the City of Orange township are both located within Essex County, New Jersey

Newark has faced numerous environmental problems, especially involving water quality and industrial pollution. Similar to Flint, Michigan, there is a major drinking water crisis in Newark, New Jersey that predominantly affects those in historically marginalized and low-income communities. In 2016, the first signs of a new problem appeared when elevated levels of lead were discovered in the drinking water in thirty Newark public schools (Faherty, 2020). The New Jersey Department of Environmental Protection (NJDEP) required a new drinking water sampling regime in Newark which revealed rapidly increasing lead levels (Faherty, 2020). The problem continued to worsen, and by 2018, the level of lead in Newark's water was among the highest of any major city in the country (NDRC, 2021). This drinking water contamination resulted in high rates of lead poisoning, especially in children (NDRC, 2021). Furthermore, as low-income and historically marginalized communities are more likely to live in older housing with lead pipes, they were exposed to the highest rates of lead contamination (Faherty, 2020). Despite the multiple notices of noncompliance sent to the city by the NJDEP, Newark city officials continued to falsely assure the public that there wasn't a problem and that the water was safe to drink with statements like: "[t]he truth is that the water supplied by the City is safe to drink...the City's water is not contaminated with lead...our water is safe" and "our water is some of the safest water in New Jersey" (Faherty, 2020). After the EPA finally acknowledged Newark's water crisis in mid-2019, the city released a plan to replace 18,000 lead service lines (Faherty, 2020). Now, recent reports show that while the lead levels in Newark remain dangerously high, they are beginning to drop (NDRC, 2021).

Newark's water crisis is unfortunately just one of many environmental hazards threatening the area. The large industrial presence in Newark has produced high levels of long-term pollution from centuries of loose environmental regulations, mismanagement of pollutants, and illegal dumping of hazardous waste, once again demonstrating the little value placed on the lives of people of color. Pollution from industrial waste can cause a multitude of negative health conditions such as chronic diseases, including hypertension and diabetes (Ortiz et al., 2020). In addition, approximately one-fourth of all the children in Newark have asthma, three times the national average (Ortiz et al., 2020). Among the many hazardous waste sites located in Newark, four have been placed on the National Priority List as active Superfund sites. These sites include the Riverside Industrial Park, Diamond Alkali Co., White Chemical Corp., and Pierson's Creek Superfund sites (as seen in Figure 4.5) (EPA, 2021E). Other sites in Essex County include the Unimatic Manufacturing Corporation, U.S. Radium Corp., Orange Valley Regional Groundwater Contamination, Montclair/West Orange Radium site, Glen Ridge Radium site, and Caldwell Trucking Co Superfund sites (Figure 4.5) (EPA, 2021E). The following sections will look closer at three of these sites and the environmental justice implications of each.

Diamond Alkali Co.

The Diamond Alkali Co. Superfund Site, located in Newark City, Essex County, New Jersey (Figure 4.4), has received some media attention in recent years. The Diamond Alkali Company owned and operated an herbicide and pesticide manufacturing plant from 1951 to 1969, but the production of chemical products such as DDT and phenoxy herbicides began at this site as early as the mid-1940s. The Diamond Alkali Company produced agricultural chemicals including "Agent Orange" (EPA, 2021B), a

notoriously hazardous herbicide containing equal parts of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), as well as traces of the contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), that was used by U.S. military forces during the Vietnam War to kill dense vegetation and wipe out crops. 2,3,7,8-TCDD, one of the byproducts of producing Agent Orange, is extremely toxic and is one of the many compounds commonly referred to as dioxin (EPA, 2021B). According to reports from a New Jersey Superior Court case about this location, the Diamond Alkali Company would dump dioxin into trenches that flowed into the Passaic River nearly every other week. This hazardous substance was also supposedly tracked through the streets of Newark by trucks traveling to and from their dumping site (Ortiz et al., 2020).

This location was added to the National Priorities List as an official Superfund site in 1984, after sampling revealed high levels of a large number of hazardous substances at and around the site as well as in the Lower Passaic River. These included dioxins, semi-volatile and volatile organic compounds, herbicides, pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), mercury, and other heavy metals (EPA, 2021B). This contamination has affected groundwater, surface water, air, soil, and even building structures. The uncontrolled spread of these hazardous materials leached into the river and made its way all the way into Newark Bay and the ocean. As a result, the Diamond Alkali Co. Superfund Site is one of the farthest reaching and widespread Superfund sites identified to date, in terms of affected area (Ortiz et al., 2020).

The EPA reports that contamination from the site poses a significant threat to both the health of the people in that area, as well as the health of the wildlife near the site and

along the river and bay. The waters of the Passaic River are covered with toxic contaminants; additionally, the heavy metals have also become embedded in the sediment of the river and bay and are reportedly a major health concern for communities all along the river (EPA, 2021B). As a result, the consumption of all fish and shellfish from the Passaic River is prohibited by the state of New Jersey. The cost of cleaning this site up will be immense, making it one of the most expensive cleanup projects in the history of the Superfund program (Ortiz et al., 2020). Initial clean up actions were taken when the site was first added to the NPL, but further investigation and planning for long-term cleanup are still ongoing and there is no target date to complete the cleanup. The EPA selected a remedy for the lower 8.3 miles of the Lower Passaic River in 2016 (EPA, 2021B), but as each day passes, remediation grows more and more urgent and the area's residents suffer from health and quality of life issues resulting from the pollution (Ortiz et al., 2020).

Figure 4.6 illustrates the environmental justice ranking based on Superfund proximity for the Diamond Alkali Co. Superfund Site. This site is clearly centered in a large region in the 95-100th percentile (highlighted in red in Figure 4.6). Areas in the 95-100th percentile are those that contribute the most toward the nationwide disparity in that environmental factor, in this case Superfund proximity. Of Newark's 282,270 residents, approximately 11% are White (not Hispanic or Latinx), 50% are Black, 2% are Asian, and 36% are Hispanic or Latinx (Table 4.4) (United States Census Bureau, 2019). The area surrounding the site is heavily industrialized and is located in one of Newark's most densely populated neighborhoods. Targeted due to race and income level, the residents of this area have unjustly suffered the consequences of the extensive pollution radiating

from this site. In addition, extreme weather events and other climate change-related environmental impacts are exasperating these effects, as they can “stir up” the toxins, further putting this community at risk (Ortiz et al., 2020).

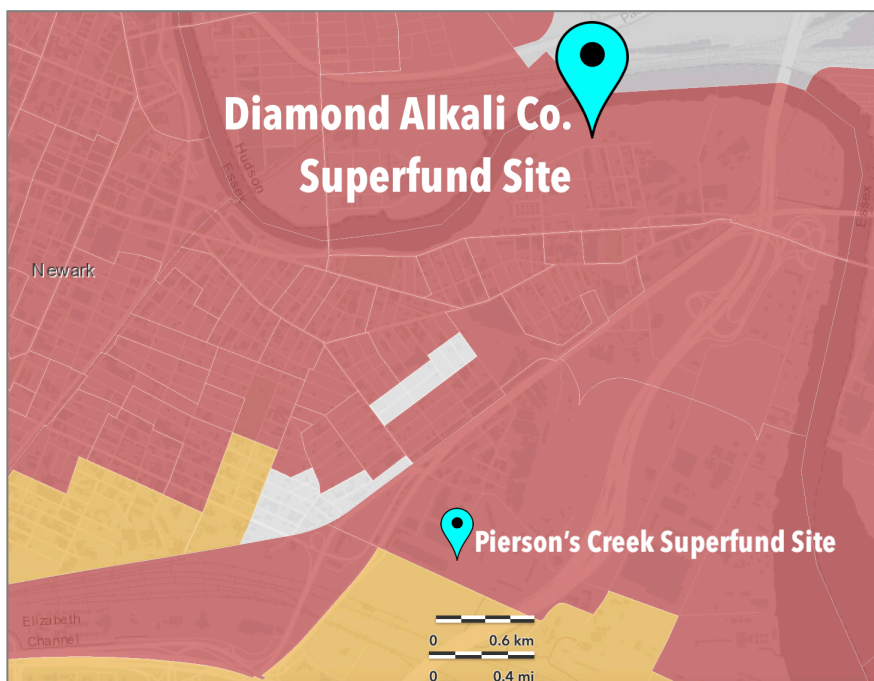


Figure 4.6: Map of Environmental Justice Index (EJ Index) for Superfund proximity at the Diamond Alkali Co. Superfund Site. *Colors correspond to national percentiles in Figure 4.3 (EPA, 2021A).

White Chemical Corp.

Newark, New Jersey is also home to the White Chemical Corp. Superfund Site (Figure 4.4). This location was owned by the Union Carbide Corporation until 1970, the Central Services Corporation until 1975, and the Lancaster Chemical Company until 1983, when it was then leased to the White Chemical Corporation. This site was run by the White Chemical Corp. from 1983 through 1990 before being officially added to the National Priorities List as a Superfund site in 1991. Fire retardant compounds, acid chlorides, brominated organics, and mineral acids (most notably hydriodic acid) were manufactured at this site and, during its operation, the White Chemical Corp. received

many citations for facility violations. The improper handling of these toxic materials led to them leaching into the soil and groundwater, contaminating the surrounding area with dangerous chemicals including volatile organic compounds (VOCs) (EPA, 2021F). The main contaminants of concern identified at the site include the carcinogenic Trichloroethylene and 1,2-Dichloroethane (EPA, 2021F).

Not only is Newark a Black-majority city, but the residents living closest to the White Chemical Corp. site are predominantly Black and Brown. According to the most recent data available, there are approximately 16,734 residents living within a one-mile radius of the White Chemical Superfund Site, of which 70% are Black and 20% are White (Singer et al., 2013). Figure 4.7 shows the projected environmental injustice value in relation to Superfund proximity for the region surrounding the White Chemical Corp. Superfund Site. As clearly illustrated, this site is the source of significant environmental inequality due to the close proximity of a hazardous waste site, combined with the high percentage of historically marginalized groups in the surrounding community.

While the more immediate threats (i.e., deteriorating drums of hazardous waste) have been cleaned up, the contaminated groundwater still needs to be addressed. Yet, the White Chemical Corp. Superfund Site was one of the 5 out of 115 sites in New Jersey that did not receive any funding in 2019 (Warren, 2020). Due to budget cuts, cleanup efforts were stalled for 34 Superfund sites in the U.S., two of which are located in Essex County, New Jersey (Warren, 2020). The paused cleanup for the White Chemical Corp. Superfund Site is an example of how communities of color experience a higher frequency of hazardous sites in their area, as well as of how these communities receive poorer treatment within the Superfund program. Reduced funding is just one of the many

reasons that Superfund sites located in communities of color can take several years longer to be cleaned up than sites in white communities (Lavelle and Coyle, 1992). Despite being on the National Priority List, the White Chemical site, and health and well-being of the community surrounding it, are not being made a priority.

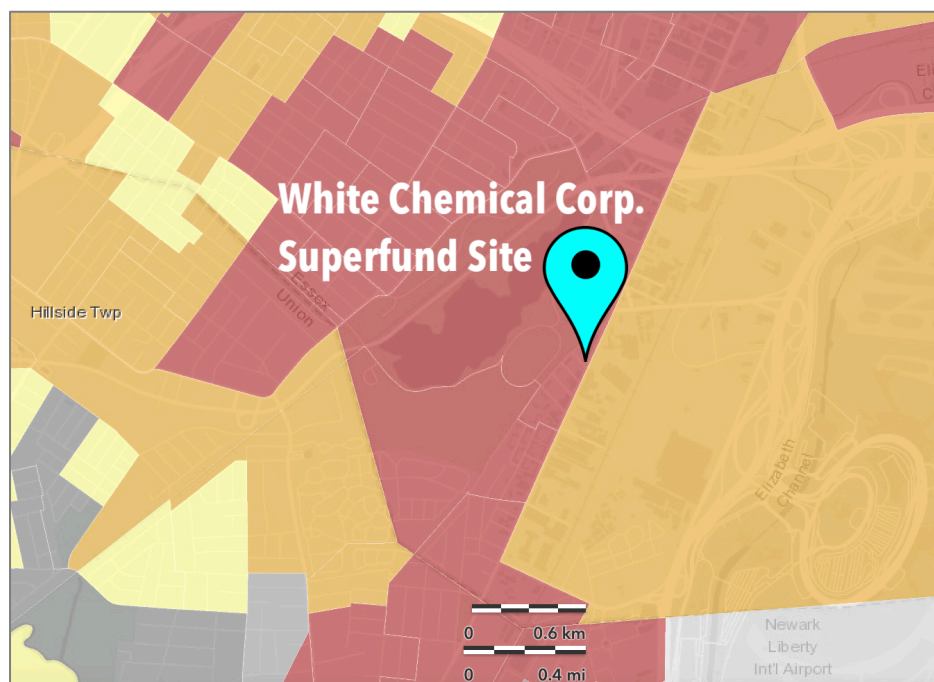


Figure 4.7: Map of Environmental Justice Index (EJ Index) for Superfund proximity at the White Chemical Corp. Superfund Site. *Colors correspond to national percentiles in Figure 4.3 (EPA, 2021A).

Orange Valley Regional Groundwater Contamination

The city of Newark is not an isolated example of environmental racism stemming from Superfund proximity; other parts of Essex County also have an abundance of Superfund sites. The Orange Valley Regional Groundwater Contamination Superfund Site (OGRC site) is located in the City of Orange township, Essex County (Figure 4.4), and stretches all the way into the neighboring municipalities (Aluwalia, 2015).

Despite being discovered nearly 30 years ago in 1992, the Orange Valley Regional Groundwater Contamination Superfund Site is one of the more recently

designated sites, only added to the National Priorities List in 2012 (EPA, 2021D). With a hazardous ranking score of 50, the OGRC Superfund Site is a large groundwater plume contaminated with a variety of common commercial and industrial chemicals including: tetrachloroethylene (PCE), trichloroethylene (TCE) and cis-1,2-dichloroethylene (cis-1,2-DCE). The levels of both PCE and TCE tested at the public water supply wells have been found to exceed the EPA's maximum contaminant levels (Aluwalia, 2015). According to the EPA, there are several possible sources of contamination, but investigations are still ongoing, and the EPA has not officially identified a responsible party as of 2020 (EPA, 2021D). Some sources, however, list Selecto Flash Inc. as the company that may have been responsible for the toxic leak (Singer et al., 2013).

Immediate measures to protect the health of the community were taken, as the main contaminated public water wells were shut off and are no longer in use (Aluwalia, 2015). In addition, the EPA claims that they have a treatment system in place that removes site-related contaminants in order to provide the community with safe drinking water (EPA, 2021D). However, details on the implementation or progress of this initiative are uncertain as no milestones have been publicly recorded since 2012 when it was first placed on the Superfund program's National Priorities List (Table 4.5) (EPA, 2021D). It appears that there have not yet been any measures taken towards the containment of the ORGC spread or treatment of the plume. Beyond some additional resampling in 2019, no information regarding progress towards removing site-related contaminants has been made available to the public. According to the EPA's "Cleanup Progress" page, remedy selection is estimated for September to November 2023, and remedy implementation currently has no estimated date (Table 4.5) (EPA, 2021D).

Table 4.5: List of milestones on the EPA’s Cleanup Progress page for the Orange Valley Regional Groundwater Contamination Superfund Site (retrieved from EPA, 2021D).

Milestone	Date(s)
Initial Assessment Completed	09/30/1992
Proposed to the National Priorities List	03/15/2012
Finalized on the National Priorities List	09/18/2012
Remedial Investigation Started	09/17/2012
Remedy Selected	Estimated Sep – Nov 2023
Remedial Action Started	Not Yet Achieved
Construction Completed	Not Yet Achieved
Deleted from the National Priorities List	Not Yet Achieved
Most Recent Five-Year Review	Not Yet Achieved
Site Ready for Reuse and Redevelopment	Not Yet Achieved

Not only is groundwater contamination particularly common and difficult to treat at Superfund sites or elsewhere, it can be exceptionally dangerous to humans (Smollin and Lubitow, 2019). Exposure to toxins from contaminated water can occur in several ways: ingestion (drinking the water or consuming food prepared using the water), inhalation (breathing in toxins that volatilized during showering, bathing, or other household use), and dermal exposure (absorbing toxins through skin during showering, bathing, or other use) (Aluwalia, 2015). Often, ingestion exposure is the most significant source of exposure to hazardous substances from a site. In the case of the volatile organic compounds (VOCs) contaminating this site, however, inhalation and dermal exposures can make a significant contribution to the total exposure dose (Aluwalia, 2015). Despite the attempts to limit human exposure, without containment and treatment of the plume, damage to the environment and risk to the area’s residents will only increase as the spread grows.

The demographics of the area's residents raise concerns about environmental racism and injustice. As seen in Figure 4.8, which uses the EPA's EJSCREEN mapping tool to show the environmental justice index for Superfund proximity, the ORGC Superfund Site is located in a very large region that scores in the 95-100th percentile. Areas in the 95-100th percentile contribute the most toward the nationwide disparity in that environmental factor, which is Superfund proximity in this case. This is unsurprising because there are two Superfund sites (the ORGC site and the neighboring U.S. Radium Corp. site) with high hazardous rankings located in an area populated almost entirely by racially marginalized communities. The City of Orange township is approximately 3% White (not Hispanic or Latinx), 70% Black, 2% Asian, and 25% Hispanic or Latinx (Table 4.4) (United States Census Bureau, 2019). This is one of the many cases that illustrates how people of color are more frequently exposed to hazardous waste pollution.

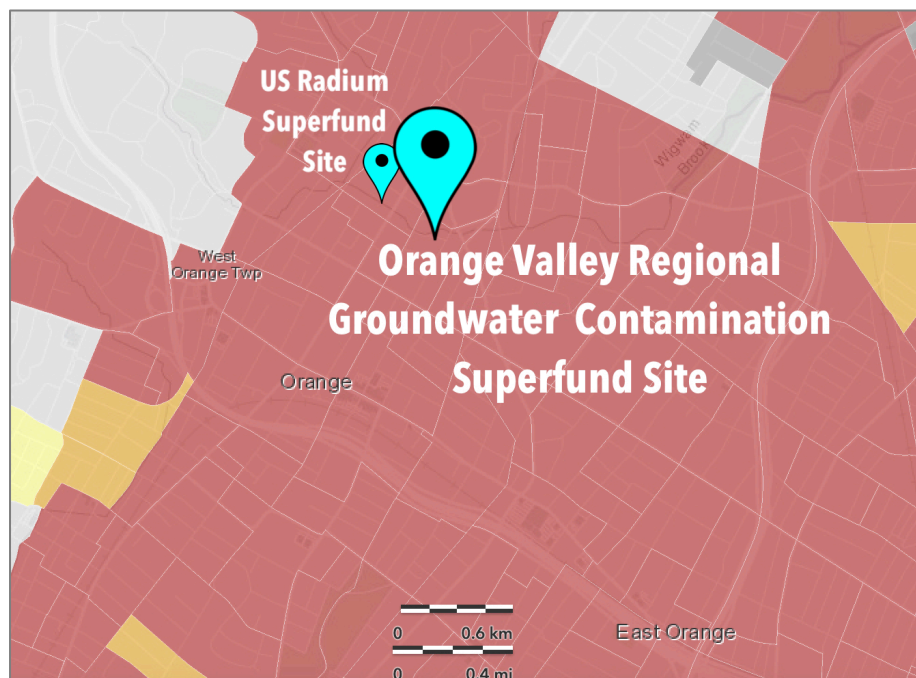


Figure 4.8: Map of Environmental Justice Index (EJ Index) for Superfund proximity at the Orange Valley Regional Groundwater Contamination Superfund Site. *Colors correspond to national percentiles in Figure 4.3 (EPA, 2021A).

CHAPTER 5 - CONCLUSION

The United Nations officially recognized safe drinking water as an internationally binding human right in 2010, stating that everyone is entitled to access to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic use (United Nations, 2018). Drinking water with high levels of contaminants, such as the heavy metals lead, copper, and zinc, violates the international right to both safe and acceptable water. In the United States, the right to “safe” water, which entails that water is free from chemical, biological, and radiological hazards that may be detrimental to human health (United Nations, 2018), can be violated if contaminants on the EPA National Primary Drinking Water Regulations list exceed the maximum contaminant or action level (e.g., if lead is above 15 ppb or copper is above 1300 ppb), as regulated by the EPA’s Safe Drinking Water Act (SDWA). Likewise, contaminants on the Secondary Drinking Water Standards list with levels above the secondary MCL (e.g., a level of copper exceeding 1000 ppb or zinc exceeding 5000 ppb) may be in noncompliance with the right to “acceptable” water, which states that water should be an acceptable color, odor, and taste for each personal or domestic use (United Nations, 2018).

Around the world, about 2.2 billion people don’t have access to safely managed drinking water services (World Health Organization, 2019). In the United States alone, which has among some of the safest drinking water supplies in the world, water systems in violation of the Safe Drinking Water Act served more than 77 million people in 2015 (Fedinick et al., 2019). Although these violations occur all across the country, some populations and communities have borne the majority of the adverse consequences of the failures of these systems (Schaidler et al., 2019). Those most vulnerable to sharing a

disproportionate amount of the disadvantages of inadequate water quality tend to be low-income communities and/or communities of color. Moreover, these communities are often already overburdened with health and environmental threats, making unsafe drinking water particularly devastating (Fedinick et al., 2019).

Threats to drinking water systems can come from anywhere, but anthropogenic sources of pollution can be especially harmful and prevalent. The Superfund program was created to address the worst cases of human-caused environmental contamination (Smollin and Lubitow, 2019). Superfund sites, like most sources of SDWA violations, disproportionately affect historically marginalized communities. Hazardous waste sites are located in low-income areas and communities of color more frequently than in white or wealthier communities, and these sites also tend to include worse contamination (Smollin and Lubitow, 2019). Furthermore, not only are these marginalized communities disproportionately exposed to hazardous pollution, but they can also expect a discriminatorily ineffective and slow response (Lavelle and Coyle, 1992). These Superfund sites tend to result in drinking water violations, and so communities of color and low-income populations are forced to bear the brunt of the negative impacts that poor water quality has on both human health and quality of life (Schneider et al., 2019).

By offering free and accessible water analyses to the public, this project provides some of the resources necessary for individuals to learn what heavy metal contaminants might be in their water, taking matters into their own hands rather than relying on governmental systems to properly monitor and report any issues. As a part of the Union College Water Initiative, this project helps individuals detect harmful contaminants in drinking water that may be in violation of the Safe Drinking Water Act. Of the 307

samples I collected, I found 47 violations of the SDWA that infringe on the UN-established right to safe and acceptable water. Furthermore, this does not include contaminant concentrations exceeding maximum contaminant level goals, because few samples had levels of these contaminants (lead, arsenic, and uranium) that were low enough to not be detected by the ICP-MS instrument. Some of the most egregious violations of drinking water regulations included alarmingly high levels of lead, as high as approximately sixty times the EPA limit, that were found in public elementary schools. While running the water before use can help improve the water quality in many cases of contamination from plumbing systems, using a filter works best to address harmful contaminants. Lack of access to safe and sufficient water has a devastating effect on health and quality of life. Though this project operates on a small scale, by identifying potentially hazardous contamination and alerting those involved so it can be addressed, this study can make a significant impact on those individuals affected.

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